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Resource efficiency via production planning and lean production

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Author:

Manuel Weber, VDI Zentrum Ressourceneffizienz GmbH

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This brief analysis was developed on behalf of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection.

The brief analyses of the VDI ZRE provide an overview of current developments in the field of resource efficiency in research and industrial practice. They contain a compilation of relevant research results, new technologies and processes as well as best- practice examples. The brief analyses thus provide an introduction to selected resource efficiency topics for a broad audience with business, research and administration background.

Editorial:

VDI Zentrum Ressourceneffizienz GmbH (VDI ZRE)
Bülowstraße 78
10783 Berlin
Tel. +49 30-27 59 506-0
zre-info@vdi.de
www.ressource-deutschland.de

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LIST OF ABBREVIATIONS

CAD	Computer-Aided Design
CIP	Continuous improvement process
CNC	Computerized Numerical Control
CO_2	Carbon dioxide
ERP	Enterprise-Resource-Planning
IKT	Information and communication technologies
LPS	Lean production systems
MFCA	Material flow cost accounting
MIT	Massachusetts Institute of Technology
OEE	Overall equipment effectiveness
PDCA	Plan-Do-Check-Act
PPS	Production planning and control
RE	Resource efficiency
TPM	Total productive maintenance
TPS	Toyota production system
VDI	Association of German Engineers (Verein Deutscher Ingenieure)
VDI ZRE	VDI Centre for Resource Efficiency GmbH (VDI Zentrum Ressourceneffizienz GmbH)

1 INTRODUCTION

Numerous companies in the manufacturing sector face the challenges of maintaining their competitive edge in the face of global competition and establishing themselves successfully on the market in the long term. In addition, there is the prospect of increasing demand from customers for individual production, which results in an ever-growing number of variants and smaller batch sizes. A fast-moving market environment shortens product life cycles and requires a heightened response to changing demand. Moreover, as the Covid-19 pandemic has also shown, financial uncertainty or unexpected issues problems in the supply chain can arise, to which companies must adapt immediately.

Climate protection and the efficient use of natural resources – such as materials, energy and water – are playing an increasingly important role, both in social discourse and in the context of customer requirements. Companies must respond to this with various measures.

Another aspect is the ongoing development of digitisation, especially within a production environment, which is an increasingly important factor for the future viability of companies. Companies have to face all these challenges and pursue the goal of aligning and organising their own production system in the most effective way possible.

In chapters 2 and 3 the brief analysis provides a basic understanding of production management, as well as production planning and control (PPC) in the context of a production system. It traces how methods and approaches originally developed at Toyota in Japan have spread around the globe, and which can make production systems more productive by implementing principles.

Chapter 4 presents strategies that can serve as guidelines for increasing resource efficiency in the production system. A selection of practical examples illustrates how companies can improve resource efficiency in the production system, reduce costs and, at the same time, reduce the resulting impact on the environment and climate.

Chapter 5 will then present how lean production and lean production systems (LPS) approaches can not only influence productivity in a positive way, but also contribute to reducing the use of natural resources. It also lists the extent to which LPS principles can also support resource efficiency strategies.

In chapter 6 selected methods of Lean Production and LPS are presented. They are classified in terms of LPS principles, as well as the resource efficiency strategy supported in each case.

Recommendations for LPS implementation and procedures for implementing a culture of improvement are presented in chapter 7.

In view of the fact that efficient production can be supported with approaches to digitisation in the production environment, chapter 8 presents how digitisation or Industry 4.0 can support various lean production methods. Selected examples from industry help to bridge the gap through practice.

Finally, chapter 9 offers some insight into the methodical procedure for developing successful strategies with the help of an innovative strategy design approach.

2 MANAGEMENT, PLANNING AND CONTROL OF PRODUCTION

Production is an operational, value-adding process in which input factors are transformed into higher-value output factors.[1] For the production of goods and services, natural resources are relevant, in addition to technically essential economic resources such as personnel, production equipment, capital and knowledge.[2] These are subdivided into raw materials, energy, water, air, land and ecosystem services in accordance with guideline VDI 4800 Sheet 1.[3] Value-creating processes also take place in supply chains and, increasingly, in complex value networks with the specialised core competencies of the companies involved.[4]

Production is organised in a production system and includes both transformation processes and various entities that adopt a steering role.[5] Within the framework of a production system, production management (cf. chapter 2.1) represents the entity that adopts a steering role.

Manufacturing or transformation is the executing entity.[6] Production planning and control (PPC), which is dealt with in chapter 2.2, is part of so-called operational production management (cf. Illustration 1).

1 Cf. Schuh, G. and Schmidt, C. (2014), p. 2.
2 Cf. Weber, M. and Oberender, C. (2015), p. 9.
3 Cf. VDI 4800 Sheet 1:2016-02, p. 14.
4 Cf. Lange, U. and Surdyk, K. (2018), p. 57 – 58.
5 Cf. Schuh, G. and Schmidt, C. (2014), p. 3.
6 Cf. Schuh, G. and Schmidt, C. (2014), p. 5.

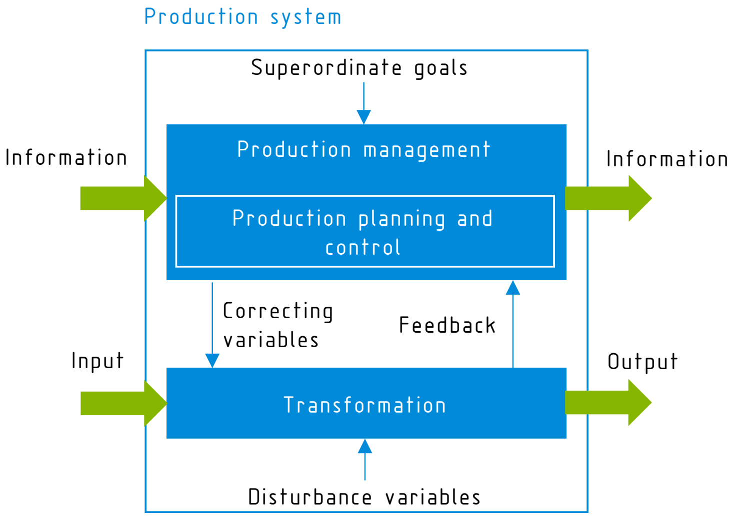

Illustration 1: Interaction of production management and transformation process in the production system[7]

2.1 Production management

In order to be able to classify production management within the overall and complex apparatus of a company with its different interfaces, the St. Gallen Management Model (in its third generation) is used in the following. This is also known as the new St. Gallen Management Model. The model offers a framework for management systems and their issues that is designed for a holistic view.[8]

Illustration 2 visualises the management model and takes into account the elements found in the environment of a company, for example, stakeholders, environmental spheres and interaction issues. It also lists processes, moments of order and modes of development as internal elements of the company.

7 Cf. Schuh, G. and Schmidt, C. (2014), p. 5.
8 Cf. Offenhammer, A. (2015), p. 131.

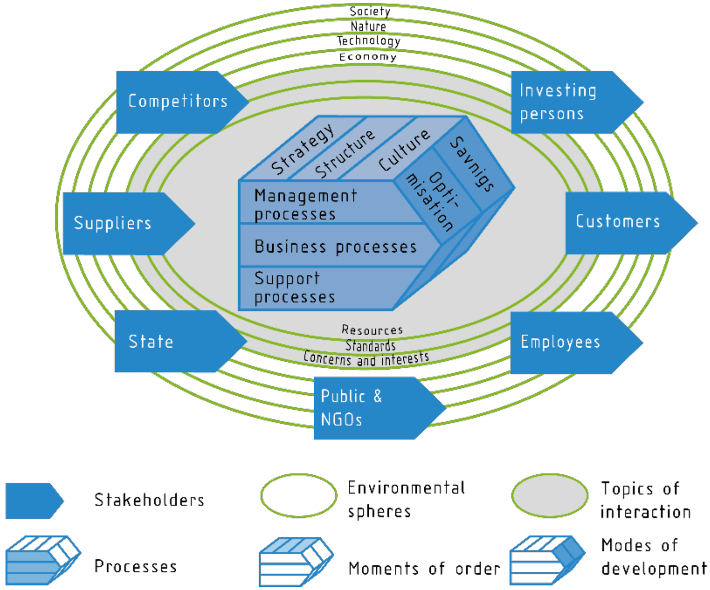

Illustration 2: St. Gallen Management Model 3rd Generation[9]

Within the framework of management processes, a distinction can be made between normative, strategic and operational management processes. When applied to production management, this can be differentiated into normative, strategic and operational production management.[10]

In normative production management, superordinate enterprise targets, as well as guiding principles and the company's prevailing culture, are defined. Overriding goals can include, for example, the need to ensure the continued existence of the company by maximising profits, or to achieve market leadership in a technology area.[11] Another overarching goal within the framework of normative production management can also include increasing resource efficiency and its importance for the future development of the company.

[9] Cf. Rüegg-Stürm, J. (2002), p. 22.
[10] Cf. Schuh, G. and Schmidt, C. (2014), p. 6.
[11] Cf. Schuh, G. and Schmidt, C. (2014), p. 5.

The strategic production management has the task of observing the production system's environment and initiating adjustments based on changing framework conditions, in accordance with the goals and principles of normative production management. In addition to the strategic alignment, e. g. by designing organisational and process structures, or initiating strategic programmes for the conceptualisation of enterprise processes and performance systems, it is the task of strategic production management to create an awareness of quality, costs and time.[12] The formation of those tasks is based, for example, on the principles of value orientation (classic shareholder value approach), a consideration of sustainability in corporate development, or adaptability in a dynamic and turbulently changing environment.[13] One measure aimed at increasing resource efficiency when taken at the level of strategic production management can, for example, be the introduction of lean management by the company's technical management.

The enterprise targets defined at both normative and strategic levels are translated into production-related and measurable targets within operational production management.

Typical goals that result from the requirements dictated by the market are delivery reliability, delivery time and delivery capability. Operational objectives include the efficient use of production equipment, e.g. by maximising the rate of utilisation or minimising work in progress, as well as the associated costs. In the context of operational production management, market and operational goals, in particular, can conflict with each other.[14] If, for example, the introduction of lean management is decided in strategic production management, production management and master craftsmen in operational production management control the implementation of individual methods, taking into account the targets at hand.

The task of operational production management is to position the production system in the most effective way possible, in order to meet the required targets. The individual operating point of a production system lies in the area

[12] Cf. Schuh, G. and Schmidt, C. (2014), p. 12.
[13] Cf. Schuh, G. and Schmidt, C. (2014), p. 15.
[14] Cf. Schuh, G. and Schmidt, C. (2014), p. 20 – 21.

of conflict between the target variables of maximum operating performance/utilisation, maximum adherence to schedules, minimum process and total costs, and minimum lead time.[15] Operational production management essentially comprises five core processes:

(1) Production programme planning

(2) Order management

(3) Production requirements planning

(4) In-house production planning and control

(5) External procurement planning and control

These are also reflected in the tasks of the production planning and control – or PPC (see chapter 2.2).[16]

Designing the core processes of production management depends on the company-specific manufacturing types. A distinction is made between the following four categories: order, blanket order, variant and make-to-stock production. Four feature groups can be differentiated for characterisation purposes: Initiation of order fulfilment activities, execution of products, execution of scheduling activities and execution of the actual manufacturing process.[17]

The feature groups can, in turn, be categorised based on twelve individual features:[18]

(1) Type of contract solution

(2) Product spectrum

(3) Product structure

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[15] Cf. Schuh, G. and Schmidt, C. (2014), p. 21.
[16] Cf. Schuh, G. and Schmidt, C. (2014), p. 8 – 9.
[17] Cf. Schuh, G. and Schmidt, C. (2014), p. 22.
[18] Cf. Schuh, G. and Schmidt, C. (2014), p. 23 – 33.

(4) Determination of the product or component requirements

(5) Triggering of dependent requirements

(6) Procurement type

(7) Stockpiling

(8) Production type

(9) Workflow type for parts production

(10) Workflow type for assembly

(11) Production structure

(12) Change influences of clientele during production

An essential aspect of production management is the administration of data. The following types of data can be distinguished:[19]

(1) Master and transaction data

(2) Inventory and change data

(3) Application and control data

With regard to the dimension of usage, different data sets result for the areas of product, production, personnel, clientele and supplier company.[20] The records are managed in number systems, categorised according to subject, person and order number systems.[21]

[19] Cf. Schuh, G. and Schmidt, C. (2014), p. 44.
[20] Cf. Schuh, G. and Schmidt, C. (2014), p. 45.
[21] Cf. Schuh, G. and Schmidt, C. (2014), p. 50.

2.2 Production planning and control

PPC is a sub-discipline of operational production management.[22] The term production planning and control had become widespread by the early 1980s. It represented an overarching concept that addressed both materials and time management within the manufacturing industry. In his work entitled "Produktionsplanung und -steuerung (PPS): ein Handbuch für die Betriebspraxis"[23] (Production Planning and Control (PPC): A Manual for Operational Practice) the occupational scientist, Rolf Hackstein, focused on the entire production area and those areas indirectly involved (e.g. design). Over time, the term PPC has been expanded to include other operational areas and now includes sales, purchasing, shipping and commissioning in addition to manufacturing, assembly and design.[24]

PPC can be differentiated into core tasks, cross-sectional tasks and network tasks (cf. Illustration 3). In addition to internal company tasks, which can be found in the core and cross-sectional tasks, the value network plays an increasing role for producing enterprises. These tasks are mapped in the network tasks. This includes network configuration, sales planning and requirements planning. The management of data affects all three task areas, as they all use the corresponding data. The cross-sectional tasks include order management, inventory management and controlling.[25]

[22] Cf. Siepermann, C. (2018).
[23] Cf. Hackstein, R. (1984).
[24] Cf. Schuh, G. and Schmidt, C. (2014), p. 9.
[25] Cf. Schuh, G. and Stich, V. (2012), p. 29 – 30.

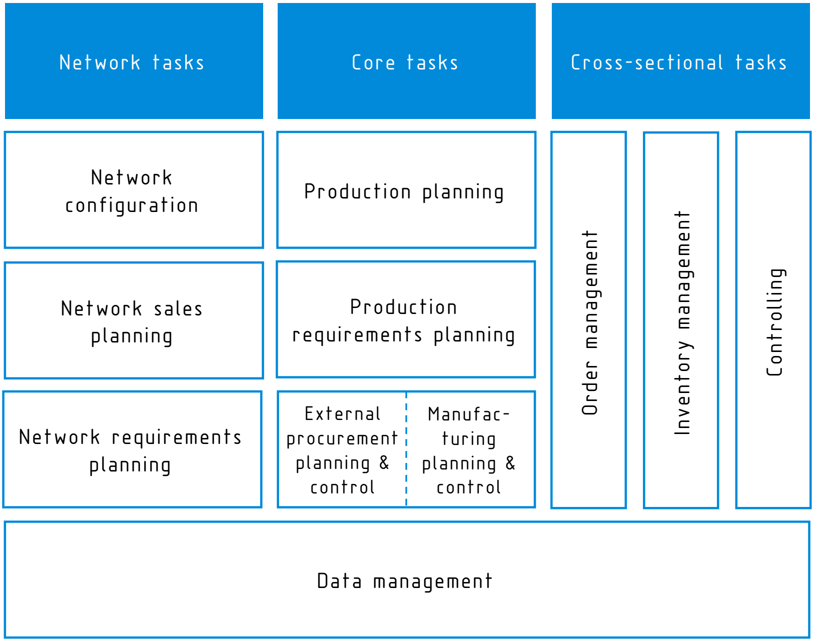

Illustration 3: Task view of the Aachen PPS model[26]

Order management includes order planning tasks, as well as controlling and monitoring activities relating thereto. Producing enterprises often display weaknesses in the continuous flow of order-related information. Insufficient implementation of cross-process order management can be the cause of this.[27] In the following, the core tasks of PPC, production programme planning, production requirements planning, external procurement planning and control, as well as in-house production planning and control, are discussed in more detail.

Production programme planning

In production programme planning, a programme is defined for all products to be manufactured in a time-scheduled planning period, in order to obtain a production plan and an outline procurement plan. Production programme

[26] Cf. Schuh, G. and Stich, V. (2012), p. 30.
[27] Cf. Schuh, G. and Stich, V. (2012), p. 60.

planning consists of sales planning, primary requirements planning and rough resource planning. Based on market requirements and the orders – both anticipated and existing – through sales statistics and trends, a sales plan is drawn up. This forms the basis for primary requirements planning. The term “primary requirements” denotes the demand for products (saleable products) depending on the order situation. The net primary requirement is determined by subtracting inventory from the gross primary requirement. The net primary requirement then flows into the rough resource planning. With the help of a coverage calculation, a comparison is made between resource requirement and supply.[28] The requirements for products, parts or components are roughly planned according to type and quantity, as well as with regard to the production date or period and set in relation to the available resources. The resources taken into account are materials, operating and auxiliary resources, as well as personnel. Once it has been ascertained as to whether the net primary requirement can be realised with the available resources, a long-term production programme can then be defined within the framework of rough resource planning.[29]

Production requirements planning

A procurement programme is derived from the production programme. The production plan, which is the result of the production programme, serves as the information basis for procurement planning. This, in turn, has to ensure the feasibility of the production programme and is made up of dependent requirements determination, lead time scheduling and capacity planning. The dependent requirements describe the demand for parts (individual parts, components) for the production of the saleable product. Dependent requirements are determined in accordance with the calculation of primary requirements. By subtracting inventory from the gross dependent requirements, net dependent requirements can be determined.[30] In lead time scheduling, both different production orders and – in particular, internal – procurement orders are set in a time context. This results in key dates with regard to capacities or capacity groups. For the time being, this scheduling is carried out

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[28] Cf. Schuh, G. and Stich, V. (2012), p. 39.
[29] Cf. Schuh, G. and Schmidt, C. (2014), p. 68.
[30] Cf. Schuh, G. and Stich, V. (2012), p. 44 – 45.

under the assumption that capacities are available in unlimited quantities.[31] The final step is capacity planning. This involves a comparison of capacity requirements and available capacity. In contrast to lead time scheduling, capacity planning takes into account the actual capacity load that results from the processing of different orders competing for capacity.[32]

In-house production planning and control

Batch sizing is implemented on the basis of the in-house production programme. This pursues the goal of determining the optimal batch sizes (from an economic standpoint) for production, finding a compromise between high inventories and inflexibility with higher batch sizes, as well as significant set-up times and costs for small batches. The subsequent final operation scheduling determines the lead times for the individual production batches from the required production operations, as well as the processing and transition times. With the help of sequence planning, the target-specific optimal allocation of operations to machines is ensured, taking into account restrictions and capacities. The availability of capacities is ensured through detailed resource planning.[33]

External procurement planning and control

In addition to the in-house production programme, the production requirements planning also results in the external procurement programme, which serves as the information basis for external procurement planning and control. Delivery dates, procurement quantities and provision requirements for materials and components are determined therein. External procurement planning and control can have a significant influence on the economic success of a company with a low in-house production depth.[34]

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[31] Cf. Schuh, G. and Schmidt, C. (2014), p. 156.
[32] Cf. Schuh, G. and Schmidt, C. (2014), p. 158.
[33] Cf. Schuh, G. and Stich, V. (2012), p. 50 – 51.
[34] Cf. Schuh, G. and Stich, V. (2012), p. 57 – 58.

Table 1: Influence of PPC tasks on resource efficiency

Task category	Tasks	Influence on resource efficiency	Example
Network tasks	Network configuration	Medium	Network selection, taking into account resource efficiency aspects
	Network sales planning	Medium	Resource efficiency through demand-oriented sales planning
	Network requirements planning	Medium	Resource efficiency through the identification and distribution of requirements in the network
Core tasks	Production programme planning	High	Consideration of resource efficiency in the production programme
	Production requirements planning	High	Resource efficiency through demand-driven requirements planning
	External procurement planning and control	Medium	Resource efficiency through demand-oriented material planning
	In-house production planning and control	High	Work process planning, taking resource efficiency into account
Cross-sectional tasks	Order management	High	Resource efficiency through transparent and consistent information flow
	Inventory management	High	Avoiding resource waste through efficient warehousing
	Controlling	Medium	Provision of information on the resource efficiency of the production system
Overarching tasks	Data management	Medium	Recording and data management with regard to resource efficiency

Table 1 provides an overview of how great the influence of individual task areas of PPC is on resource efficiency, and reveals exemplary approaches in the respective areas.

For a detailed elaboration and implementation of PPC, the reference views of the Aachen PPC model can lend support. The preceding presentation of the tasks provides the basic task view. In addition, the Aachen PPC model consists of three further reference views: the process architecture view, the process view and the function view. The individual process steps for the process architecture and process view can be derived from the task view. The process architecture view enables the interfaces of tasks at a network and enterprise level. It describes the distribution and coordination of processes and process elements at network level. In the process reference view, the areas of the task reference view are brought into a logical sequence from a temporal perspective, and the order processing is detailed in terms of content. In the function reference view, functions of the PPC are mapped that are derived from the other three reference views. The requirements description for an IT system, for example, for an enterprise resource planning (ERP) system, is also derived from the functional reference view.

3 LEAN APPROACHES AND LEAN PRODUCTION SYSTEMS

The idea of lean production is derived from the Toyota Production System (TPS). Chapter 3.1 provides some insight into the system's development. Chapter 3.2 deals with the basics of Lean production systems and presents their principles. Chapter 3.3 defines the concept of lean management and refers to lean approach developments in other operational environment areas.

3.1 Toyota Production System and Lean Production

Key aspects of the TPS go back to Sakichi Toyoda and his son, Kiichiro Toyoda, founder of Toyota Motor Corporation. Sakichi Toyoda developed an automated loom in 1924 that stopped itself when problems arose. The aim was to avoid waste caused by faulty products and the associated, additional activities. Kiichiro Toyoda continued to pursue the idea of waste-free value addition in cooperation between people and machines.

In 1938, he established the flow principle at Toyota, derived from the way a conveyor chain works in textile production, and is thus considered the inventor of the "just in time" concept. From this, Taiichi Ohno, as production manager – with strong support from Eiji Toyoda (Toyota's director or general manager) – developed and established the TPS from the second half of the 1940s.[35] The aim was to save the Japanese car industry, which had been very depressed after the Second World War, to learn from the weaknesses of the then leading car manufacturers in the USA and to catch up with them with improved, individual production.[36]

A central idea of the TPS is to consistently avoid waste.[37] Waste is understood as obstacles that have a negative influence on the work processes in the company. These include wasteful activities (Japanese: muda), overwork (Japanese: muri) and irregularities (Japanese: mura).[38]

[35] Cf. Toyota Motor Corporation (2020).
[36] Cf. Dahm, M. H. and Brückner, A. D. (2017), p. 3 – 4.
[37] Cf. Wettengl, p. (2011).
[38] Cf. Kanbanize (2020).

TPS is based on two main methodological pillars, Just in time (cf. chapter 6.5.1) and Jidoka or "Autonomation" (cf. chapter 6.2). As a result of the realisation of just in time and the resulting continuous production flow, as well as autonomisation, the tasks of the employees also changed. For example, they were now responsible for several machines at the same time, which required a broader qualification of the employees. In addition, it was their task to identify and solve any problems that arose themselves on site and to constantly and successively improve their own processes.[39]

TPS is often depicted as a house (cf. Illustration 4). In addition to the Just in time and Jidoka (autonomation) pillars, the employees represent the third pillar. Avoidance of waste and continuous improvement form the foundation. The roof of the house is characterised by a strong orientation towards the clientele and is composed of the overriding objectives of short lead times, low costs and high quality. Another objective is the prevention of adverse health effects, which includes both occupational safety and environmental impacts.[40]

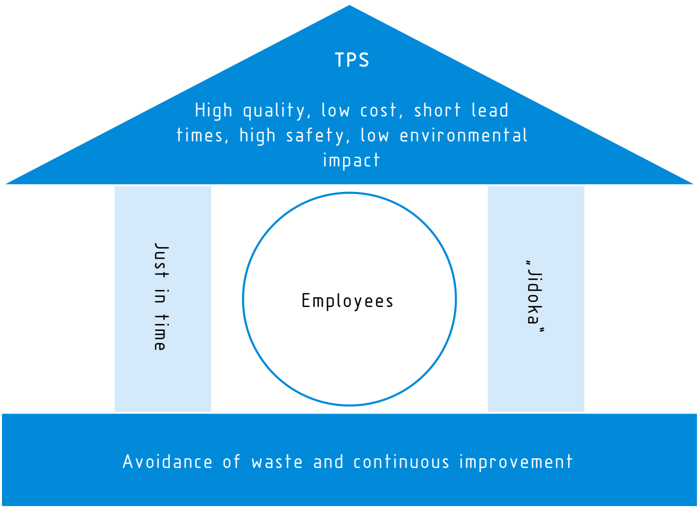

Illustration 4: Essential elements of the Toyota Production System[41]

[39] Cf. Dombrowski, U. and Mielke, T. (2015), p. 18.

[40] Cf. Toyota Material Handling (2010), p. 14 – 15.

[41] According to: cf. Dombrowski, U. and Mielke, T. (2015), p. 17.

Scientists at the Massachusetts Institute of Technology (MIT) became aware of the TPS and its methods, and published their study results on the special features of the TPS in 1990 in the book "The Machine That Changed The World: The Story of Lean Production – Toyota's Secret Weapon in the Global Car Wars That is Revolutionizing World Industry"[42]. The German-language publication was entitled "Die zweite Revolution in der Automobilindustrie"[43].[44]

The results of the study quickly spread, and numerous industrial companies tried to adopt the TPS. The companies primarily implemented individual methods that showed promise, with which corresponding successes could also be achieved.

However, methods were often just copied and there was no awareness of how the path to solutions worked. In some cases, the objectives of lean methods were not understood, or were even misunderstood, and applied in the course of rationalisation measures. This inevitably led to mistrust among employees, which prevented the development of a long-term culture of improvement in the companies.

It has been shown that the success of the TPS is not based on the application of individual methods, but on a coordinated overall system – with a focus on the benefits for the clientele. From this realisation (and based on lean production methods), the concept of LPS developed.[45]

Another key recipe for success of the TPS is that the company's objectives are seen as a vision, and the employees continuously strive for improvement towards the vision of zero defects (high quality), 100 % added value (low costs) and one-piece flow (short lead times).

Another target vision is that neither employees nor customers suffer health impairments from the products. One way to methodically anchor this

[42] Cf. Womack, J. P.; Jones, D. T. and Roos, D. (1990).
[43] Cf. Womack, J. P.; Jones, D. T. and Roos, D. (1992).
[44] Cf. Bertagnolli, F. (2018), p. 203 – 204.
[45] Cf. Dombrowski, U. and Mielke, T. (2015), p. 18 – 19.

continuous improvement in the company and the achievement of goals is the Toyota KATA (cf. chapter 7.2).

3.2 Lean production systems

Lean production systems (LPS) essentially build on the elements of the TPS and lean production, and allow these to be integrated into the company-specific characteristics of a production system.[46] The guideline VDI 2870 Sheet 1 "Lean production systems – Basic principles, introduction, and review" defines a lean production system (LPS) as a "methodical system of rules for comprehensive and continuous designing of enterprise processes"[47].

Even if the specific design is individual for each company, LPS are structured in a comparable way. The guideline VDI 2870 Sheet 1 shows a uniform framework with the help of which principles (as well as the application of specific methods and tools for their implementation) can be derived. In this way, the methods, as well as the implementation of the principles, can be linked to the company's goals and processes and integrated in the long term.[48]

Illustration 5 shows the basic structure of a LPS. Sub-targets are derived from higher-level enterprise targets, which, in turn, are linked to the enterprise processes concerned. Depending on the chosen principle, there are methods and tools that can be applied during implementation. The guideline VDI 2870 Sheet 2 presents a selection of methods and tools and supports the selection of appropriate methods and tools for the individual principles.

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[46] Cf. Dombrowski, U. and Mielke, T. (2015), p. 19.

[47] VDI 2870 Sheet 1:2012-07, p. 5.

[48] Cf. Dombrowski, U. and Mielke, T. (2015), p. 26 – 27.

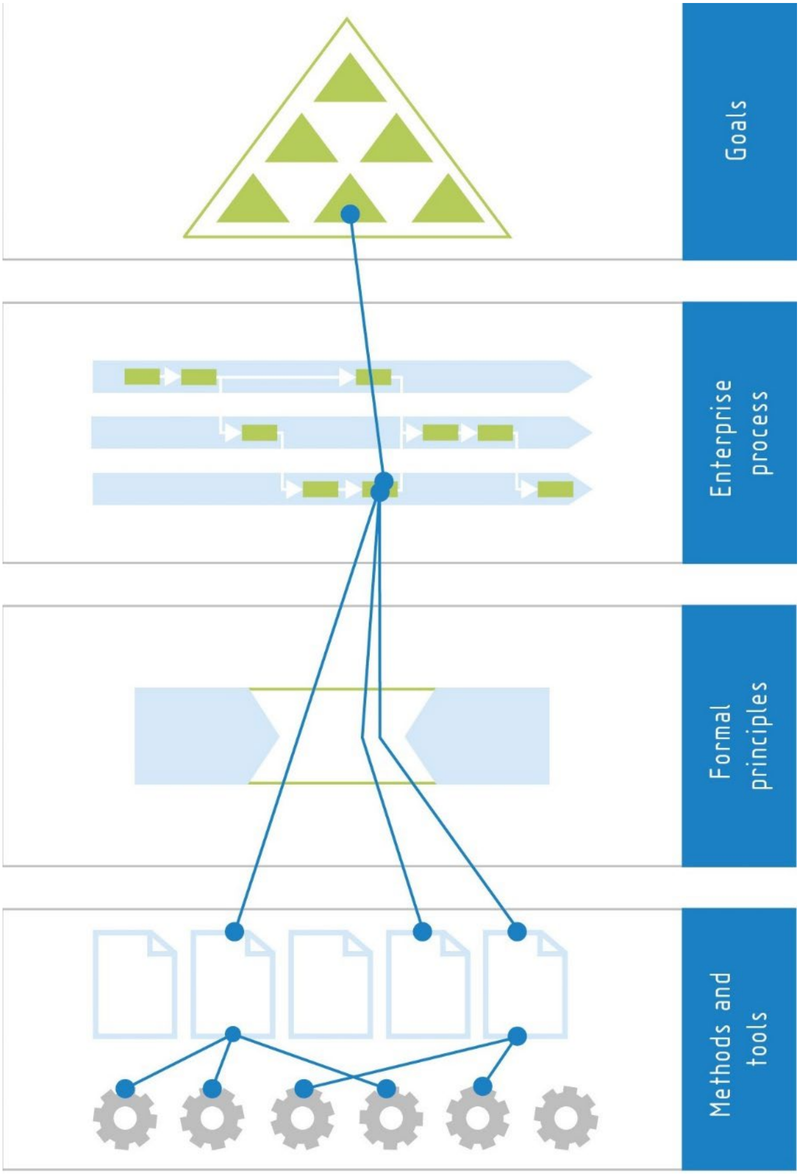

Illustration 5: Basic structure of a lean production system (LPS)[49]

The derived sub-targets are specified for individual corporate divisions. These are, in turn, specified for implementation in individual enterprise processes relevant to the achievement of objectives. Suitable principles for the implementation of the sub-targets are selected and implemented with the help of appropriate methods and tools.[50]

The comprehensive anchoring and holistic consideration of different principles and methods creates the basis for a successful LPS. The aim is for this to be understood and implemented by all employees at the different levels of the company.[51]

The guideline addresses the following eight principles:[52]

(1) **Standardisation:** Standardisation, especially of repetitive processes and manufacturing steps, allows them to be improved and designed in the most effective way possible. Based on the defined standard, the target and current status of the processes are compared and evaluated in terms of quality or lead times.[53]

(2) **Principle of zero defects:** A central principle is the zero defects principle – the realisation of production without any rejects and rework. However, as errors cannot be completely avoided in reality, they should be seen as an opportunity to understand weak points in the processes and to derive improvements from them.[54]

(3) **Flow principle:** With the help of the flow principle, the continuous flow of materials and information is realised along the value chain within the company.[55]

(4) **Pull principle:** By designing a pull principle, customer-oriented production is made possible. The demand for a product on the part of the

[49] VDI 2870 Sheet 1:2012-07, p. 10. (Reproduced with permission of the VDI e.V.)
[50] Cf. VDI 2870 Sheet 1:2012-07, p. 10.
[51] Cf. VDI 2870 Sheet 1:2012-07, p. 2.
[52] Cf. VDI 2870 Sheet 1:2012-07, p. 13.
[53] Cf. Dombrowski, U. and Mielke, T. (2015), p. 67.
[54] Cf. Dombrowski, U. and Mielke, T. (2015), p. 80.
[55] Cf. Dombrowski, U. and Mielke, T. (2015), p. 96.

customer leads to an impulse for production or demand in the respective preceding process stage.[56]

(5) **Continuous improvement process:** An essential aspect of LPS is the constant striving for perfection, which is reflected in the principle of the continuous improvement process.[57]

(6) **Employee orientation and management by objectives:** The principle addresses the change in employee behaviour towards a learning organisation whose employees advance the principle of continuous improvement.[58]

(7) **Avoidance of waste:** The principle of waste avoidance pursues the goal of increasing value addition by cutting out unnecessary, non-value-adding activities (waste).[59]

(8) **Visual management:** By using visual management in the context of LPS, targets, processes, performance or problems in the company can be presented transparently. On the one hand, deviations in the process are recorded and appropriate measures are taken. On the other hand, the employees' identification with their tasks and the environment is improved.[60]

3.3 Lean Management

The term "Lean Management" stands for "the totality of thinking principles, methods and procedures for the efficient design of the entire value chain of industrial goods"[61]. Originating from the principles of lean production, lean management can be seen as an overarching approach that transfers the

[56] Cf. Dombrowski, U. and Mielke, T. (2015), p. 110.
[57] Cf. Dombrowski, U. and Mielke, T. (2015), p. 50.
[58] Cf. Dombrowski, U. and Mielke, T. (2015), p. 129.
[59] Cf. Dombrowski, U. and Mielke, T. (2015), p. 32.
[60] Cf. Dombrowski, U. and Mielke, T. (2015), p. 150.
[61] Pfeiffer, W. (1991), p. 2.

principles of thinking to indirect areas.[62] Even if business areas aside from production are not excluded in LPS, this is where the focus lies.[63]

Separate approaches and terms have developed for the implementation of the lean idea or the principles of LPS in other disciplines. For example, in administrative areas, use of the term “Lean Administration” is commonplace; in development, professionals speak of “Lean Development”, or in approaches at leadership and management level, people talk of “Lean Leadership”.[64]

This brief analysis is essentially limited to the production environment. Even though indirect areas certainly offer great potential for improvement, production and production-related areas – such as logistics and warehouse management – are particularly responsible for the efficient use of natural resources.

[62] Cf. Krauß, M. (2019).
[63] Cf. VDI 2870 Sheet 1:2012-07, p. 4.
[64] Cf. Dombrowski, U. and Mielke, T. (2015), p. 189.

4 RESOURCE EFFICIENCY IN THE PRODUCTION SYSTEM

In a business context, the term resource is often used more broadly and can include financial, physical, human, organisational and technological resources.[65] In the following, only natural resources are considered under the terms 'resources' and 'resource efficiency'. For operational practice, the efficient use of raw materials, energy and water is of primary importance. Chapter 4.1 lists various strategies for increasing resource efficiency in the production system. Practical examples, which are presented in chapter 4.2, illustrate this in an exemplary manner and show how both, resource consumption and costs could be reduced through various production management measures.

4.1 Strategies for resource efficiency

In order to improve resource efficiency in entrepreneurial activity, there are a variety of approaches and measures that can affect the manufacturing processes, on the one hand, and the product offered, on the other. The guideline VDI 4800 Sheet 1 "Resource Efficiency – Methodological principles and strategies" provides an overview of various product- and process-related strategies and measures for increasing resource efficiency in companies. In the following, selected resource efficiency strategies are presented that can be pursued as strategic guidelines within the framework of a production system. These are related to the LPS principles in chapter 5.

Manufacturing process optimisation

In order to reduce the amount of resources required while maintaining process output and product quality, a variety of options can be used to optimise manufacturing processes. In particular, the optimisation of process parameters contributes to significant savings with low implementation costs.[66]

Reduction of planned scrap

Reducing scrap can be achieved by reducing material waste during process start-up and by reducing the percentage loss that occurs. This can be

[65] Cf. Schreyögg, G. (1993), p. 112.
[66] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019b).

implemented by making adjustments to the manufacturing process, or to the product itself. Higher material utilisation in the production process leads to a reduction in material requirements and waste.[67]

Minimisation of planned loss

Another strategy for better material utilisation is to reduce planned loss. Measures are taken to reduce material loss that occurs for technical reasons during the change in mould (e. g. residual material during punching). As with reducing scrap, this strategy can be implemented through adjustments to the manufacturing process or product and help to reduce material requirements and waste generation.[68]

Minimisation of machining volume

The strategy of minimising the machining volume not only reduces the amount of raw material used, but the lower machining volume also reduces tool wear and shortens the occupancy time of the operating resources. Depending on the application, not only material savings but also energy savings – due to shorter machining times – can be realised.[69]

Reduce storage losses

Reducing inventory losses helps to avoid unnecessary material and energy expenditures that result from the disposal of unused products, components and raw and auxiliary materials. Reasons for stock losses can be overproduction, incorrect planning, unnecessarily high safety stocks or inadequate warehouse management.[70]

Reduction of energy consumption

The strategy of reducing energy consumption aims to reduce the input of electrical energy and energy sources in the company without negatively

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[67] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019j).
[68] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019k).
[69] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019g).
[70] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019l).

affecting quality and process output. By reducing fossil fuels, in particular, climate-damaging greenhouse gas emissions can also be reduced.[71]

Recirculation of raw materials, consumables and supplies

Through the internal and external recirculation of raw materials, auxiliary materials and operating supplies, resources can be saved that are required for the extraction of raw materials and the original production of the production input. In addition, waste streams can be reduced, for example, through the reprocessing of operating supplies or the reuse of material losses and rejects.[72]

Recirculation of products and components

In addition to the recirculation of raw materials, consumables and supplies, one strategy for increasing resource efficiency can be the recirculation of components or products. By reprocessing and reusing components or products, it is possible to reduce the amount of material and energy required to manufacture them from the corresponding raw materials.[73]

Substitution of auxiliary materials and operating supplies

Auxiliary materials and operating supplies, some of which are used in large quantities, offer great potential for increasing resource efficiency. Substitution can contribute to reducing the consumption of auxiliary materials and operating supplies in production or reduce disposal quantities and the associated costs. It is important to consider the entire life cycle of operating supplies, in order to ensure a holistic improvement in resource efficiency.[74]

Cascading use of auxiliary materials and operating supplies

Another way to extend the useful life of auxiliary materials and operating supplies is cascade usage. In this case, the auxiliary materials and operating supplies are reused after their initial use in an area of application with lower

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[71] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019i).
[72] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019e).
[73] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019d).
[74] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019f).

technical and qualitative requirements. Material and energy are saved that would be needed for the other applications. In addition, the volume of waste and the costs for disposal are reduced.[75]

Planning resource-efficient manufacturing processes

In the sequence design of manufacturing processes, various sources of potential for increasing resource efficiency can arise by taking resource efficiency aspects into account as early as the planning stage. Resource consumption is often determined on a long-term basis, especially when purchasing and dimensioning new facilities. Resource consumption can also be positively influenced at an operational level through appropriate planning.[76]

Efficient operational organisation

Efficient operational organisation can reduce the use of resources within a company. Approaches can be manifold and concern, for example, work-related organisational structures or communication structures and processes. If, for example, work processes, production targets or quality specifications are clearly defined and communicated, faulty batches and thus material and energy losses can be reduced.[77]

Employee qualification/ employee potential

Coming up with ideas to improve resource efficiency should not only be encouraged, but their implementation should also be supported and successes rewarded.[78]

4.2 Practical examples for increasing resource efficiency in the production system

The following are examples of companies that have identified resource waste in their production systems and have been able to save both resources and costs by implementing improvement measures.

[75] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019c).
[76] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019h).
[77] Cf. VDI Zentrum Ressourceneffizienz GmbH (2019a).
[78] Cf. VDI 4800 Sheet 1:2016-02, p. 52.

Reduction of material losses through cross-departmental employee competence

For a manufacturer of car mats and floor mats for entrance areas, production process-related material losses amounting to approx. EUR 220,000 per year represented a significant cost item. In the course of a material flow analysis (see chapter 6.6.2), a cross-departmental team identified the largest material losses amounting to EUR 200,000 in the punching and cutting processes. The implementation of the project team's optimisation ideas was accompanied by an external company with expertise in the field of resource efficiency. Due to the optimisation of punching and cutting processes, the material loss was reduced by 17 %, which corresponds to 18 t of wastage worth EUR 40,000 annually. In addition to the material costs, these measures also save five-digit costs due to lost added value, because the avoidance of rejects means that working and machine times can be used in a value-adding manner.[79]

Reduction of the use of resources in maintenance

At a manufacturer of fastening systems, a new maintenance process for cold forging equipment was developed during a cross-departmental improvement process. This new process can be done more quickly and, at the same time, reduces oil consumption. The oil change, which is required four times a year as part of the maintenance of the forging machines was very labour- and time-intensive due to its respective design. Cleaning the machines also caused high costs due to the large oil consumption and the long downtimes during cleaning.

A conversion – and thus a possible reduction in the number of previous oil pans/collection tanks in the machines – reduced the oil requirement by half. In addition, the cleaning intervals were able to be reduced to once a year. With a specially purchased centrifuge, the oil can be cleaned and reused. By purchasing a mobile oil trolley and installing hoses with quick couplings, the oil change was able to be carried out much faster than before. Reducing oil demand through oil purification and reuse saves resources and reduces the

[79] Cf. Schmidt, M.; Spieth, H.; Bauer, J. and Haubach, C. (2017), p. 78 – 81.

procurement costs for new oil, as well as the disposal costs for used oil. Since the time required for an oil change is now only 15 minutes, the downtime of the machines due to oil pan cleaning has been reduced from ten hours to one . Overall, the cost reduction compared to the previous year is about 23 %.[80]

Increasing resource efficiency through holistic production control

At a manufacturer of stainless steel containers, around 35 % of offcuts and rejects occur in production due to the large and varying product variety. Since the material costs in the company amount to 50% of total costs, the potential for significant monetary savings can be assumed. In order to be able to allocate the material and energy flows to the products and processes that cause them, the data was recorded on a source-related basis and entered into a material flow model. After visualising the material flows and the associated information flows, measurement and control variables were implemented to quantify potential savings. In order to implement this, investments were made in a new data collection tool in production. Already through the partial implementation of the production control model and the holistic view of the production processes, savings of 5% in the use of materials in production were achieved, which corresponds to a stainless steel quantity worth EUR 400,000. In addition, the implementation of a concept for waste heat utilisation in an annealing furnace saved 600 MWh of electricity and 10,000 m^3 of natural gas annually.[81]

Reduction of the use of resources through automated process control

The surface treatment of tractor bodies at a manufacturer of agricultural machinery requires a complex technical process in which the metal bodies undergo several steps in the dipping process. In order to prevent the active baths – consisting of different liquids such as acids, solvents and lacquers – from mixing, a cleaning step is carried out in a rinsing bath after each active bath. The previous process involved continuously adding fresh water at a constant rate based on maximum plant utilisation, in order to maintain cleaning quality. It was found that far more water than necessary was being used

[80] Cf. Schmidt, M.; Spieth, H.; Bauer, J. and Haubach, C. (2017), p. 134 – 136.
[81] Cf. Schmidt, M.; Spieth, H.; Bauer, J. and Haubach, C. (2017), p. 146 – 149.

due to a missing control loop. In order to reduce water consumption, a fully automatic control loop was designed in cooperation with the company supplying the chemicals, which enables real-time water analysis and demand calculation. With the help of a conductivity sensor, the degree of contamination is now automatically determined and only the amount of fresh water required to ensure the cleaning performance is added. Water consumption was reduced by 30 % through the introduction of sensor-based water dosing. As the wastewater is already completely treated using vacuum distillation technology and a large part of it is returned to pre-treatment, the reduction in water consumption also reduced the treatment costs (costs for electrical energy and waste disposal) by approx. 30 %. The investment costs were thus amortised in the first year of operation.[82]

Increasing resource efficiency through optimised production and logistics processes

With lean and resource-efficient processes, a company that manufactures mechatronic drive solutions consolidated its future competitiveness. For this purpose, comprehensive, cross-site material flow and value stream analyses (cf. chapter 6.4.4) were conducted. Based on the evaluation and results of the analyses, the entire production and logistics processes were defined in the factories according to sequence, type and electronic Kanban control loops integrated in the ERP system were introduced according to the pull principle (cf. chapter 6.5.2). All production processes were changed in the direction of one piece flow (cf. chapter 6.4.4) and the logistics processes were optimised accordingly. The core element of the new logistics concept is a parts supply point (“supermarket”) for small load carriers and container towers, which has been integrated into the logistics centre. If the stock in this “supermarket” falls below a minimum level, the material stock is automatically replenished with parts from the “department stores”. Its inventory is independently regulated by the supplier company, with the inventory information being transmitted via an internet-based platform. By introducing lean production

[82] Cf. Schmidt, M.; Spieth, H.; Bauer, J. and Haubach, C. (2017), p. 218 – 221.

and logistics systems, inventories were reduced despite increased turnover, and resource efficiency was increased.[83]

Reduction of the use of resources through process optimisation and standardisation

At a company that manufactures components for the semiconductor industry (heat sinks and housings), a lean production team was established to examine the design of tools on eccentric presses with regard to the potential for optimisation. One resulting improvement measure was the standardisation of the tool format, in order to implement a uniform set-up process and machining without set-up parts. This enabled both, time saving in the set-up process and resource saving through reduced set-up and production waste.

Due to the optimisation of tools and the adaptation of the machine parameters of a punching and nibbling machine, it was possible, among other things, to minimise the residual grid between the punched parts. As a result of this waste avoidance, the effective material utilisation of the metal panels and thus the material efficiency was increased by up to 60 %. Thanks to the implemented measures, the annual material consumption of aluminium and steel profiles was able to be reduced by more than 14 t. The total monetary savings amount to around EUR 123,000.[84]

[83] Cf. Reichert, D.; Cito, C. and Barjasic, I. (2018), p. 118 – 123.
[84] Cf. Effizienz-Agentur NRW (2017).

5 LEAN PRODUCTION SYSTEMS AND RESOURCE EFFICIENCY

As noted in chapter 2.1, in the context of classical production management or production planning and control (PPC), the reduction of resource input is only one of the target variables relevant to the lean production system. Already by systematically designing a production management approach or a PPC, weak points can be uncovered and subsequently, resources can be used more efficiently (cf. chapter 2).

With the help of the LPS principles and resource efficiency strategies, improvement measures can be applied to these weak points, in particular. Production systems usually focus on lead time, quality and costs.[85] In lean production and in LPS, the employees themselves and the focus on the customers also play an essential role. Increasing resource efficiency primarily pursues the goal of reducing negative environmental impacts and achieving cost savings in the process.[86]

However, the objective of increasing quality can also have a complementary effect on increasing resource efficiency, e. g. by improving the quality of the process, less waste is produced. But the approach of consistently avoiding waste can also have a positive effect on the efficient use of natural resources. An explicit look at resource efficiency can also reveal additional sources of potential for improvement that would not have emerged with the classic lean approaches.[87]

As presented in chapter 3, an essential aspect of Lean Production and LPS is the improvement of production processes, which are realised through different principles and methods. Several of the design strategies listed in chapter 3.2 can support the implementation of resource efficiency strategies (see chapter 4).

The following tables present the LPS principles (cf. chapter 3.2) that can contribute to increasing resource efficiency and list resource efficiency

[85] Cf. VDI 2870 Sheet 1:2012-07, p. 11.
[86] Cf. Bertagnolli, F. (2018), p. 299.
[87] Cf. Reichert, D.; Cito, C. and Barjasic, I. (2018), p. 36.

strategies that are supported by them. Furthermore, methods of LPS are listed that can be applied for the implementation of the principles, as well as resource efficiency strategies.

The listed methods are subsequently described in more detail in chapter 6. In particular, the principle of avoiding waste addresses the improvement of resource efficiency in production. Therefore, most process-related resource efficiency strategies are supported by it.

Table 2: Principles and sources of resource efficiency potential

Principle standardisation	
RE potential	Standardisation aims to standardise processes and reduce resource waste due to improper handling.
Supporting strategies	▪ Efficient operational organisation ▪ Manufacturing process optimisation
Supporting methods	▪ 5 S ▪ Process standardisation

Principle – Zero defects principle	
RE potential	Wasting of resources due to faulty part production, or necessary rework is reduced.
Supporting strategies	▪ Efficient operational organisation ▪ Manufacturing process optimisation ▪ Reduction of energy consumption ▪ Reduction of planned scrap and rework ▪ Minimisation of planned loss
Supporting methods	▪ Autonomation ▪ Ishikawa diagram ▪ Poka Yoke ▪ Six Sigma ▪ Statistical process control ▪ Worker self-check

Principle – Visual management	
RE potential	Any resource waste (e.g. due to process errors) can be visualised and immediately eliminated.
Supporting strategies	▪ Efficient operational organisation ▪ Manufacturing process optimisation ▪ Reduction of energy consumption ▪ Reduction of planned scrap and rework ▪ Minimisation of planned loss
Supporting methods	▪ Andon ▪ Shopfloor management

Principle – Continuous improvement process	
RE potential	Processes can be continuously improved and adapted in terms of resource consumption.
Supporting strategies	▪ Efficient operational organisation ▪ Planning resource-efficient manufacturing processes
Supporting methods	▪ Idea management ▪ PDCA

Table 3: Principles and sources of resource efficiency potential (continued)

Principle – Employee orientation and management by objectives	
RE potential	Conscious behaviour on the part of employees can reduce waste and continuously improve resource efficiency.
Supporting strategies	▪ Qualification of the employees ▪ Employee potential
Supporting method	▪ Target management
Principle – Flow principle	
RE potential	The material flow is coordinated with production. Stocks and inventories before the individual process steps can be reduced.
Supporting strategies	▪ Planning resource-efficient manufacturing processes ▪ Reduce storage losses
Supporting methods	▪ Value stream planning ▪ One piece flow
Principle – Pull principle	
RE potential	The resource requirements are matched to production. Transport routes and stocks can be reduced.
Supporting strategies	▪ Reduce storage losses ▪ Efficient operational organisation ▪ manufacturing process optimisation ▪ Reduction of energy consumption
Supporting methods	▪ Just in time ▪ Kanban ▪ Levelling
Principle – Avoidance of waste	
RE potential	Any resource waste that occurs is systematically identified and avoided.
Supporting strategies	▪ Planning resource-efficient manufacturing processes ▪ Manufacturing process optimisation ▪ Reduction of planned scrap and rework ▪ Minimisation of planned loss ▪ Minimisation of machining volume ▪ Reduce storage losses ▪ Reduction of energy consumption ▪ Recirculation of products and components ▪ Recirculation of raw materials, consumables and supplies ▪ Substitution of auxiliary materials and operating supplies ▪ Cascade usage of auxiliary and operating supplies ▪ Efficient operational organisation
Supporting methods	▪ Total productive maintenance ▪ Waste analysis ▪ Material flow analysis ▪ Material flow cost accounting

6 METHODS TO INCREASE RESOURCE EFFICIENCY

In the following, selected methods are presented in outline form that are used in the realisation of the principles of LPS and, at the same time, support the implementation of specific resource efficiency strategies. Table 2 (see page 40) and Table 3 (see page PAGEREF _Ref83312999 \h 43) show the sources of resource efficiency potential associated with the respective principle, and the resource efficiency strategies and methods that are supported, at a glance.

6.1 Principle standardisation

Processes are standardised through the principle of standardisation. This can reduce wastage of resources caused, for example, by improper handling. In Table 4, the methods presented below and the resource efficiency strategies they support are listed.

Table 4: Methods for the principle of standardisation

Method	Supported RE strategy
5S	▪ Efficient operational organisation ▪ Manufacturing process optimisation
Process standardisation	

6.1.1 5S method

The method supports keeping the workplace systematically clean and tidy in five steps. The designation 5S is derived from the Japanese terms for the individual steps.

(1) Seiri (sort): Unnecessary objects in the workplace (e. g. heavily worn or duplicate tools) are sorted and removed.

(2) Seiton (set in order): A basic order of the required items is established, classified according to frequency of use if necessary, and arranged accordingly.

(3) Seiso (sweep clean): The workplace, machines and tools are cleaned, and the performance is documented according to defined cleaning cycles.

(4) Seiketsu (standardize): In order to ensure the continuous implementation of these first three steps, the basic order is to be documented and maintained as a standard.

(5) Shitsuke (sustain): In addition to the self-discipline needed to maintain order, approaches for improvement should also be considered and brought in.[88]

6.1.2 Process standardisation

By standardising process flows and working methods, deviations can be identified more effectively and reduced. Standardised processes can be evaluated more adequately in terms of their added value, and interfaces can be presented more appropriately. Standards should not be seen as rigid, but should be regularly adapted in the spirit of continuous improvement.

A systematic approach in four steps is recommended:

(1) Analyse processes

(2) lay down standards for the processes

(3) Document and communicate standards

(4) carry out process audits regularly[89]

6.2 Principle – Zero defects principle

The zero defects principle reduces resource consumption by lowering the production of defective parts or the rework required due to insufficient quality. Table 5 shows the methods presented below and the resource efficiency strategies they support.

[88] Cf. VDI 2870 Sheet 2:2013-02, p. 9.
[89] Cf. VDI 2870 Sheet 2:2013-02, p. 13.

Table 5: Methods for the principle – Zero defect principle

Method	Supported RE strategy
Autonomation	▪ Efficient operational organisation ▪ Manufacturing process optimisation ▪ Reduction of energy consumption ▪ Reduction of planned scrap and rework ▪ Minimisation of planned loss
Poka Yoke	
Worker self-check	
Ishikawa diagram	
Statistical process control	
Six Sigma	

6.2.1 Autonomation

Autonomation or the Japanese term Jidoka stands for autonomous automation. Machines are operated without direct supervision by the employees. In the event of a malfunction, the machine rectifies the fault independently. Employees are notified and called in to rectify the problem.

The autonomous reaction to errors as they occur avoids the passing on of faulty products. Autonomation can be implemented at lower cost, and can be an intermediate step towards full automation.[90]

6.2.2 Poka Yoke

Table 6: Classification of the Poka Yoke method

Method	Poka Yoke
Principle	Principle of zero defects
Supported RE strategies	▪ Efficient operational organisation ▪ Manufacturing process optimisation ▪ Reduction of energy consumption ▪ Reduction of planned scrap and rework ▪ Minimisation of planned loss

The method aims to avoid (Japanese: yoke) random errors (Japanese: poka) and tries to make procedures or approaches to technical implementation as

[90] Cf. VDI 2870 Sheet 2:2013-02, p. 26.

error-resistant as possible, with preferably low-cost solutions that can be implemented at short notice.

Approaches to implementing Poka Yoke can be, for example:

(1) Implementation of a form fit for exact positioning through the use of identically shaped tongue-and-groove connections

(2) Use of clearly visible differences in size or shape, if there is a risk of confusion

(3) Support of assignments through colour coding (e. g. of containers or hoses)[91]

6.2.3 Worker self-check

Quality control is carried out by operational employees themselves in accordance with the specified inspection instructions. This not only promotes the employees' sense of responsibility, but also reduces the passing on of faulty parts to the subsequent processing steps. This helps to improve process quality and reduce waste.[92]

6.2.4 Ishikawa diagram

With the help of an Ishikawa diagram, the causes or influencing variables of individual problems or error causes can be systematically analysed and graphically displayed, especially in teamwork.

The following procedure can be used to create the diagram:

(1) Name the problem

(2) Establish the basic cause classes (e. g. material, human, machine, method, environment)

(3) Collect possible causes

[91] Cf. VDI 2870 Sheet 2:2013-02, p. 33.
[92] Cf. VDI 2870 Sheet 2:2013-02, p. 42.

(4) Assess and classify the causes (examine the cause-effect relationship with sub-causes)

(5) Evaluation of the correlations and derivation of measures[93]

6.2.5 Statistical process control

With the help of statistical process control, quality-relevant parameters in production can be continuously monitored from a statistical standpoint, and adjustments or countermeasures can be initiated if necessary. This helps to avoid rejects due to faulty products.

Quality control charts can be used to implement statistical process control. Measured values and counts are graphically displayed and evaluated, making it easy to recognise when the defined tolerance ranges are exceeded (or not reached), and to intervene accordingly. [94]

6.2.6 Six Sigma

The Six Sigma method, which is applied within the framework of quality management, is used for process improvement with analytical and statistical procedures. Based on customer requirements (internal and external), product or process requirements are defined, standardised and thus the zero defects principle is pursued. The aim is to achieve an error rate of no more than 3.4 errors per million error possibilities, and thus to reduce the scatter on (or in) the process.

The procedure is carried out in five steps, the so-called DMAIC cycle:

(1) **Define:** The desired target state or project goals, as well as the problem and causes of errors, are defined.

(2) **Measure:** Concrete errors are defined and the effects measured.

(3) **Analyse:** The measured data is statistically analysed and core causes of the errors are determined.

[93] Cf. VDI 2870 Sheet 2:2013-02, p. 28.
[94] Cf. VDI 2870 Sheet 2:2013-02, p. 40.

(4) **Improve:** Process improvements are selected, planned and implemented.

(5) **Control:** After implementation, a performance review is carried out based on the goals set at the start, and control mechanisms are defined to ensure quality on a permanent basis.[95]

6.3 Principle – Visual management

The visual management principle aims to visualise any waste of resources that occurs (e.g. due to process errors) and to initiate countermeasures immediately. In REF _Ref82428510 \h Table 7, the corresponding methods and the resource efficiency strategies they support are listed.

Table 7: Methods for the principle – Visual management

Method	Supported RE strategies
Andon	▪ Efficient operational organisation ▪ Manufacturing process optimisation ▪ Reduction of energy consumption ▪ Reduction of planned scrap and rework ▪ Minimisation of planned loss
Shopfloor management	

6.3.1 Andon

The Andon (Japanese for lantern) method provides support in the production area by visualising different statuses or operating faults. In the process, simple operating states such as “malfunction” or “no malfunction”, as well as various key figures or states, can be illustrated via an Andon board by means of an actual-target value comparison. The visualisation allows operating faults to be detected immediately. Measures can then be taken to rectify the fault and production can be stopped, if necessary. This reduces the production of missing parts.[96]

6.3.2 Shopfloor management

The goal of shop floor management is for managers to regularly go into production and involve operational employees in problem-solving activities and goal achievement. The knowledge and experience of employees who know

[95] Cf. VDI 2870 Sheet 2:2013-02, p. 37.
[96] Cf. VDI 2870 Sheet 2:2013-02, p. 44.

about the workplace situation in detail are crucial for successful problem solving. The manager takes on the role of a coach who supports and guides the employees in developing solutions.

Given that the implementation of shop floor management requires new leadership behaviour, there is no general procedure. This depends on the respective company situation. In principle, coaching competencies have to be taught, standards and uniform documents have to be developed, and added-value-oriented and short-cycle communication processes have to be implemented, which can be supported by appropriate visualisation.[97]

6.4 Principle – Continuous improvement process

By taking resource efficiency into account in the Continious improvement process principle, processes are continuously improved in terms of resource consumption. Table 8 shows the supported resource efficiency strategies and methods, which are explained below.

Table 8: Methods for the principle – Continious improvement process

Method	Supported RE strategies
Idea management	▪ Efficient operational organisation ▪ Planning resource-efficient manufacturing processes
Shopfloor management	

6.4.1 Idea management

Idea management can support the continuous improvement process throughout the company. Improvement ideas and processes can be rendered transparent, for example, through intranet-based software solutions, which improves the involvement of operational staff, in particular. Due to the systematic generation and management of improvement ideas, the wasting of resources can be reduced in a targeted manner.[98]

[97] Cf. VDI 2870 Sheet 2:2013-02, p. 47.
[98] Cf. VDI 2870 Sheet 2:2013-02, p. 59.

6.4.2 PDCA

The PDCA cycle is a method to support the continuous improvement process and serves as a sleek procedure for going through an iterative problem-solving process.

There are four phases:

(1) **Plan:** After the problem has been identified, the implementation is planned in this phase. This includes analysing the causes, finding solutions and creating an action plan.

(2) **Do:** The activities defined in the action plan are implemented and interim results are collected as appropriate.

(3) **Check:** On the basis of the defined goals and indicators, the results achieved are monitored and any deviations are recorded.

(4) **Act:** In this phase, the results achieved are processed and visualised and the entire improvement process is reflected upon. If further process improvement is required, the PDCA cycle is run again.[99]

6.4.3 Target management

The method of target management is also referred to by the Japanese term "Hoshin Kanri" and represents a transparent goal setting and agreement process, which is broken down for each level in the company – from management to employees.

This can be done in the following steps:

(1) A limited number of objectives are derived from the corporate strategy.

(2) For the respective management or process level, the objectives are broken down into partial targets.

[99] Cf. VDI 2870 Sheet 2:2013-02, p. 61.

(3) The responsible managers and employees coordinate with regard to the partial tangents and the achievement of targets.

(4) The achievement of objectives is continuously monitored in a transparent manner for all participants, and appropriate measures are derived in the event of deviations.

(5) Regular feedback loops can be used to improve target achievement processes and make adjustments to targets as needed.[100]

6.4.4 Value stream planning

The value stream planning method, also known as value stream design[101], enables a standardised approach to a current-target analysis (value stream analysis) and design of the target value stream (value stream design), taking into account appropriate guidelines. In addition to material and information flows, inventories, lead times and capacity utilisation can be analysed and subsequently optimised.[102]

The procedure is done in four steps:

(1) **Select a product family**: Only one product family is selected, in order to reduce complexity.

(2) **Identify the current status:** The material and information flows are recorded and presented.

(3) **Develop a target status:** Based on the requirements of the clientele, the target state is designed according to guidelines.

(4) **Implement/derive actions:** Measures are prepared, implemented and controlled on the basis of an implementation plan.[103]

[100] Cf. VDI 2870 Sheet 2:2013-02, p. 66.
[101] Cf. Rother, M. and Shook, J. (2015).
[102] Cf. VDI 2870 Sheet 2:2013-02, p. 76.
[103] Cf. Rießelmann, J. (2011), p. 2.

6.4.5 One piece flow

The one-piece flow method involves the implementation of flow production with batch size 1. The fact that finished parts are passed on directly to the next processing station improves defect detection and allows immediate intervention in the event of occurring faults. This reduces production errors and rejects. Further advantages include the reduction of lead times and stocks, as well as the possibility of individual production.

For the implementation, the

(1) existing stocks between the production steps are gradually reduced and

(2) the manufacturing processes are successively adjusted and stabilised (e. g. by eliminating disruptions and adapting internal transport systems).

The procedure is repeated until the one-piece flow is fully implemented.[104]

6.5 Principle – Pull principle

Resource requirements can be matched to production within the framework of the pull principle. This not only reduces transport distances and inventories, but also improves manufacturing processes in terms of material and energy consumption. Methods applicable to the pull principle are listed in Table 9 and are specified below.

Table 9: Methods for the principle – Pull principle

Method	Supported RE strategies
Levelling	▪ Reduce storage losses ▪ Efficient operational organisation ▪ Manufacturing process optimisation ▪ Reduction of energy consumtion
Just in time	
Kanban	

6.5.1 Levelling

In levelling (Japanese: heijunka), irregular orders are converted into a uniform production programme with smaller batch sizes. This reduces fluctuations in capacity utilisation and lead times. With the help of continuous

[104] Cf. VDI 2870 Sheet 2:2013-02, p. 71.

production in smaller batches, it is possible to respond with greater flexibility to customer demand. The wasting of resources due to occurring overload in production is reduced. In addition, stocks of finished products can be minimised. However, the higher number of set-up processes can have a negative impact on resource consumption.

After production orders (e. g. one week) have been divided into equal daily quantities, a processing sequence is determined so that the entire production programme is produced in a fixed order per day. In a further effort to smooth the process, for example, daily productions can be divided into shifts, with the result that the production programme repeats itself with even smaller batch sizes.[105]

6.5.2 Kanban

Kanban supports demand-oriented production control (pull principle), which is made up of individual self-controlling control loops. These control loops are composed of a part-generating and part-consuming area. In the case of a parts withdrawal by the consuming area, the parts producing area or the supplying company is informed about the withdrawal or the parts requirement via cards (Japanese: Kanban) or information carriers. Efficient logistics processes and demand-driven production can reduce the waste of resources.

The following procedure can be used for implementation:

(1) Determine the production area and check the prerequisites for the introduction of kanban control

(2) Planning of the Kanban control loops, which can be verified by simulations, depending on their complexity

(3) Set up order planning according to the pull principle, i.e. ideally, the planning orders are automatically transferred by the Kanban control system from the last process step to the respective proceeding work area.

[105] Cf. VDI 2870 Sheet 2:2013-02, p. 92.

(4) Training of the employees on the handling and the effect of the Kanban system on the work processes

(5) Commissioning of the Kanban system

(6) Carrying out start-up optimisation, which is coordinated between production control, operational employees and logistics planning; documentation and analysis of lead times and inventory levels for improvement approaches

(7) After a successful start-up phase, the stock level can be further reduced.[106]

6.5.3 Just in time

By introducing the just in time concept, logistics processes can be synchronised between supplying companies (internal and external) and the customer. Material and components are delivered in the required quantity and quality at the right time to the corresponding production or assembly site. In order to avoid possible disruptions in the supply chain, supplying companies in close proximity are an advantage. Just in time is particularly suitable for high-value materials and components, as warehousing can be reduced and potential defects and handling errors can be avoided.

For the introduction of just in time logistics processes, the following procedure can be followed:

(1) Analysis of possible parts

(2) Evaluation of the supplying companies with regard to suitability (possible criteria: quality, costs, time)

(3) Conducting negotiations and agreements with the parties involved in the process

[106] Cf. VDI 2870 Sheet 2:2013-02, p. 85.

(4) Definition of the process (e. g. call-off system, coordination between customers and supplying companies, supporting IT systems).

(5) Conversion of a supplying company as a pilot project

(6) Intensive monitoring of the changeover

(7) Expansion of just in time processes[107]

6.6 Principle – Avoidance of waste

The principle of avoiding waste explicitly focuses on systematically identifying and avoiding any waste of resources that occurs in the production system. Table 10 shows the methods presented below and the resource efficiency strategies they support.

Table 10: Methods for the principle – Avoidance of waste

<table>
<tr><th>Method</th><th>Supported RE strategies</th></tr>
<tr><td>Waste analysis</td><td rowspan="4">▪ Planning resource-efficient manufacturing processes
▪ Manufacturing process optimisation
▪ Reduction of planned scrap and rework
▪ Minimisation of planned loss
▪ Minimisation of machining volume
▪ Reduce storage losses
▪ Reduction of energy consumption
▪ Recirculation of products and components
▪ Recirculation of raw materials, consumables and supplies
▪ Substitution of auxiliary materials and operating supplies
▪ Cascade usage of auxiliary and operating supplies
▪ Efficient operational organisation</td></tr>
<tr><td>Material flow analysis</td></tr>
<tr><td>Material flow cost accounting</td></tr>
<tr><td>Total productive maintenance</td></tr>
</table>

6.6.1 Waste analysis

The waste analysis method can be used to identify value-adding and non-value-adding processes and then reduce waste. The method can be carried out as follows:

(1) A selection (and delimitation) of the work areas to be considered, as well as an analysis of the areas or processes with regard to the seven types

[107] Cf. VDI 2870 Sheet 2:2013-02, p. 84.

of waste – overproduction, inventories, transport, waiting times, rejects, movement and unnecessary processing steps – takes place.

(2) The types of waste that occur are evaluated on the basis of criteria such as resource consumption, costs or time.

(3) According to the assessment, the implementation of further methods or measures is planned, in order to avoid or reduce the waste.

(4) Following the renewed prioritisation of approaches, the order of implementation is determined, and action plans are drawn up.[108]

6.6.2 Material flow analysis

With the method of material flow analysis, the use of materials and energy in the individual production steps can be localised and the sources of waste, waste heat and emissions in the company can be identified.

The procedure is divided into the following seven steps:

(1) Define the objective and parameters to be analysed, in order to prioritise areas and derive the level of detail for data collection.

(2) Delimitation of the analysis area according to the selected process flows

(3) Delimitation of the analysis period, e. g. of an analysis year, individual production months or product batches

(4) Recording and naming of the relevant production steps and assignment to display elements

(5) Design of a flow diagram with qualitative material flows, in which input and output flows are qualitatively represented in the respective steps, and an overall view of the material flows in the company is achieved

(6) Quantitative recording of the input and output flows for the production steps shown in mass units

[108] Cf. VDI 2870 Sheet 2:2013-02, p. 108.

(7) Evaluation of the material flow analysis with regard to conspicuous waste flows and material losses, as well as the identification of sources of potential for increasing resource efficiency[109]

6.6.3 Material flow cost accounting

The material flow cost accounting (MFCA) method according to DIN EN ISO 14051 can be used to record material, energy and waste flows in the company depending on the process, similar to the material flow analysis. Furthermore, the method enables a fundamentally different approach to the evaluation of process losses.

In contrast to conventional cost accounting, MFCA distinguishes between costs allocated to the product and costs incurred through material losses. The processes of the production system being considered are represented in so-called quantity points. The material input and output flows at the quantity points are then distributed and monetised.

In the MFCA, costs are differentiated at the level of the quantity centres according to energy, waste management and so-called system costs. Due to the distribution of costs according to output in terms of product and material losses for each quantity point, the scrap losses incurred in a production step also include the corresponding expenses of previous steps. The method can be used to identify potential for increasing resource efficiency as early as the data collection stage. When implemented in the company, MFCA can lead to the continuous improvement of production with regard to occurring material losses.[110]

6.6.4 Total productive maintenance

Total productive maintenance (TPM) aims to continuously maintain production equipment and tools. In this context, the persons operating the machines are responsible for the standardised and routine maintenance and servicing measures themselves. The method is often presented as a pillar model with four to eight pillars.[111] Five essential pillars are the continuous improvement

[109] Cf. Fresner, J.; Bürki, T. and Sittel, H. H. (2009), p. 70 – 76.
[110] Cf. Weber, M. and Oberender, C. (2016), p. 14 – 19.
[111] Cf. Q-Consulting (2020).

of machines and plant, autonomous maintenance carried out by employees within the scope of their own responsibility, the implementation of planned maintenance, education and training measures, and the implementation of maintenance prevention measures. On the one hand, TPM can achieve higher plant availability and, on the other hand, reduce waste of resources through less scrap. An important key figure to illustrate machine- and process-dependent losses is the Overall equipment effectiveness (OEE).[112]

The introduction of TPM can be done in seven steps:

(1) Cleaning of the equipment

(2) Eliminating the causes of the contamination

(3) Defining standards for cleaning, inspection and plant maintenance

(4) Training of employees on inspection and maintenance standards

(5) Integrating maintenance implementation into production

(6) Implementing an independent organisation of the workplaces

(7) Setting up autonomous teams[113]

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[112] Cf. May, C. and Koch, A. (2008), p. 245.
[113] Cf. VDI 2870 Sheet 2:2013-02, p. 105.

7 IMPLEMENTING LEAN PRODUCTION SYSTEMS

In the following, the procedure for the step-by-step implementation of lean production systems, as well as recommendations for the implementation of an improvement culture with the help of Continuous Improvement (CIP) and the so-called "Kata" are presented.

7.1 Phases of implementation

The definition of tasks and the derivation of processes (see also chapter 2.2) are essential for the implementation or reorganisation towards lean or lean production systems.

Even if the goal is the comprehensive adaptation of the production system, it can make sense to start with one method and establish further principles with corresponding methods step by step in the company.[114] Given that the implementation of individual measures may only lead to moderate success, optimisation should be tackled throughout the entire company.[115] A structured approach is recommended, e.g. according to the guideline VDI 2870.

The introduction takes place in the four phases of conceptualisation, piloting/implementation, rollout/transition and operation (cf. Illustration 6).[116]

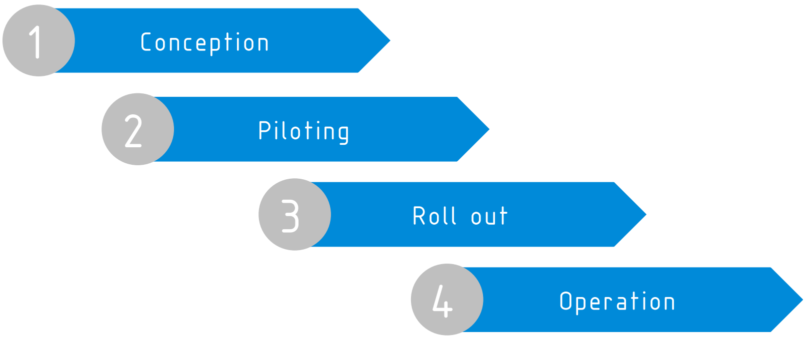

Illustration 6: Phases for the introduction of lean production systems[117]

[114] Cf. Bertagnolli, F. (2018), p. 208.
[115] Cf. Bauernhansl, T.; Hompel, M. ten and Vogel-Heuser, B. (2014), p. 87.
[116] Cf. Dombrowski, U. and Mielke, T. (2015), p. 174.
[117] Cf. Dombrowski, U. and Mielke, T. (2015), p. 174.

(1) **Conceptualisation:** After the decision at a strategic company level to introduce a lean production system (LPS), all relevant stakeholders (e. g. important supplying companies or the works council) should be involved. An analysis of the current situation and the definition of the target state form the basis for the content of the LPS. The scope and structure are determined, and the principles are defined. In addition, appropriate methods and tools are selected. In addition to an introduction strategy, the organisational structure with tasks, competencies and responsibilities – as well as change management measures planned for the introduction process – must be developed.[118] Change management is understood as the regular adjustment of corporate strategy and structures due to changing framework conditions.[119]

(2) Piloting/Implementation: In the pilot phase or implementation, respectively, selected methods are applied in individual areas of the company, change management measures are introduced and necessary organisational changes are implemented. In addition, appropriate qualification concepts are to be developed and training measures are to be carried out. Communication and feedback systems are to be implemented and existing remuneration and employee development systems are to be adapted in line with the objectives of the LPS. A positive attitude among employees is crucial for a successful pilot. Reservations and resistance can be reduced, for example, through the transparent and regular communication of progress, as well as training and practical learning sessions.[120]

(3) **Rollout/Transition:** As part of the rollout or transition, defined goals and the choice of methods used are reviewed and the rollout is implemented throughout the company. The organisational structure adapted for the introduction is fixed in the organisation. This phase also aims to establish the implemented changes in individual departments to such an extent that the systems can develop independently in the operational

[118] Cf. Dombrowski, U. and Mielke, T. (2015), p. 175.
[119] Cf. Gabler Wirtschaftslexikon (2018).
[120] Cf. Dombrowski, U. and Mielke, T. (2015), p. 175 – 176.

phase. Support can be given to employees, for example, through external persons or business simulations.[121]

(4) **Operation:** The full-scale rollout is followed by the operational phase. The methods and tools introduced are known to the employees and are applied consistently. Measures are continuously implemented to improve procedures and production processes.[122]

In order to familiarise employees with the topic of resource efficiency and lean production, for example, a business simulation for lean production was developed as part of the “RE:Plan” project funded by the national climate protection initiative.[123]

7.2 Achieving a culture of improvement with CIP and KATA

The role of the employee is crucial for the long-term success of a LPS. Their experience and implementation in daily work strike the necessary balance between standardisation and applied flexibility.[124]

In particular, realising the idea of Kaizen or continuous improvement (CIP) leads to the further development of the company. The origin of kaizen is by no means in the production sector but is part of Japanese culture. The term Zen (Japanese for good/better) can be traced back to the Buddhist practice of life, the pursuit of one’s own perfection. In connection with the term Kai (Japanese for change), Kaizen stands for the constant striving for change for the better.[125]

But how can this way of life or attitude towards improvement be transferred into operational practice?

[121] Cf. Dombrowski, U. and Mielke, T. (2015), p. 176.
[122] Cf. Dombrowski, U. and Mielke, T. (2015), p. 176.
[123] Cf. Hochschule Pforzheim, Institut für Industrial Ecology (2019).
[124] Cf. IG Metall (2008), p. 17.
[125] Cf. Zollondz, H.-D.; Ketting, M. and Pfandtner, R. (2016), p. 555.

So-called Kaizen or CIP workshops are often held in which improvement approaches are developed. However, ideas and employee motivation for improvement should also emerge away from these workshops.

Researcher Mike Rother has derived the so-called Kata from his studies of the Toyota Production System (TPS). The method can be used to make continuous improvement a habit for employees in the company. The term “kata” is derived from Japanese martial arts and stands for an exercise routine through which sequences of movements are learned and internalised through the repetition of fixed sequences.[126]

The Toyota kata is divided into two sections, the improvement kata and the coaching kata.

The improvement kata supports employees in continuously improving production processes, while the coaching kata supports managers in empowering employees to apply the improvement kata and to develop solutions systematically and independently.[127]

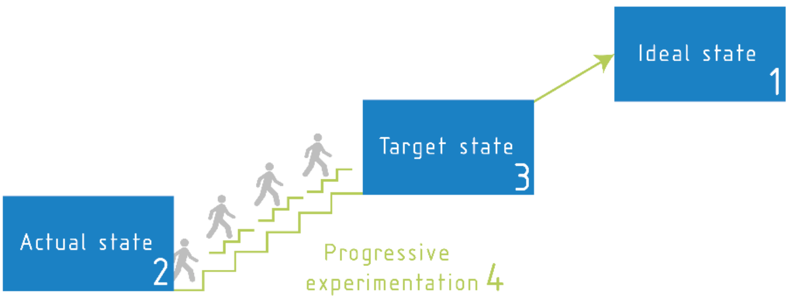

Illustration 7: The four stages of the improvement kata[128]

The improvement kata proceeds in the following four stages and helps to pursue a goal systematically, scientifically and creatively (cf. Illustration 7):

[126] Cf. REFA AG (2020).
[127] Cf. Rother, M. (2015), p. 16.
[128] Cf. Rother, M. (2015), p. 17.

(1) Definition of a vision or an ideal state, which is pursued as the overarching goal

(2) Capture the current as-is state, in order to determine how the processes are running

(3) Determine the next target state to aim for on the way to achieving the challenge.

(4) Daily experimentation, in order to achieve the path from the ACTUAL state to the next target state step by step; the PDCA method can be used for the step-by-step approach

Often, the next target state and the way to get there are beyond the current knowledge limit of employees. Therefore, step-by-step experimentation is crucial to expand knowledge and successively move towards the target state.[129]

The ideal state can be seen as a sort of vision that sets the overall direction. At Toyota, this vision is a production system with zero defects, 100% value addition, a complete one-piece flow and no adverse health effects on employees or customers from the products.

The coaching kata contains exercise routines that managers in the company (coaching persons) use to teach the improvement kata. A coaching consists of the repetitive steps:

(1) **See:** The aim is to understand learners' thinking through observation, questioning and listening.

(2) **Compare:** The coach compares his/her observations with the desired pattern of the improvement kata.

(3) **Instruct:** If necessary, the coach will instruct the learner on the necessary adjustments and guide him/her accordingly.[130]

[129] Cf. Rother, M. (2015), p. 17 – 26.
[130] Cf. Rother, M. (2015), p. 249.

The coaching kata follows a system of five questions:

(1) What is the target condition?

(2) What is the actual condition now?

(3) What obstacles do you think are preventing you from reaching the target condition? Which one are you addressing now?

(4) What is your next step? (next experiment) What do you expect?

(5) When can we go and see what we have learned from taking that step?

After the question regarding the current state (second question), it is advisable to reflect together on the preceding measures and steps using the following questions:

(1) What did you plan as your last step?

(2) What did you expect?

(3) What actually happened?

(4) What did you learn?[131]

The training is conducted in coaching cycles with the aim of guiding the learner in the application of the improvement kata in the work process and supporting them with feedback.[132] So-called 2nd coach feedback sessions are also provided for the coach, which are intended to support the process of reflection on problems in one's own coaching and to optimise it.[133]

[131] Cf. Rother, M. (2015), p. 262.
[132] Cf. Rother, M. (2015), p. 273.
[133] Cf. Rother, M. (2015), p. 298 – 300.

8 INTEGRATION OF DIGITISATION APPROACHES IN PRODUCTION SYSTEMS

With approaches to digitisation in production, process flows can be monitored, controlled and thus made more efficient. The following section presents how digitisation and Industry 4.0 support various lean production methods. In addition, selected practical examples from industry illustrate potential implementation.

8.1 Supporting the principles and lean approaches through digitisation

Scientists at the Technical University of Braunschweig have conducted a detailed literature analysis on the interactions between Industry 4.0 and LPS as part of their research. One of the results: Modern information and communication technologies (ICT) can make LPS more powerful.[134] In addition, two-thirds of the publications see lean approaches as the basis for digitisation or Industry 4.0.[135]

Essential principles of Lean Production are zero-defect production and the complete avoidance of waste. Especially for the optimisation of these principles, digitisation solutions can be integrated into established methods.[136]

Even if lean approaches are usually seen as the basis for Industry 4.0 or processes can still be improved through them, opposing aspects can also be cited. While Lean approaches focus on the holistic consideration of people, technology and organisation, the main driver of Industry 4.0 is technology. There is also a contradiction between the two approaches in their basic philosophy. The Lean approach is based on self-reliant problem solving, respectful interaction and active development of employees. Industry 4.0, on the other hand, focuses on technological feasibility and optimisation, which in the best case scenario is carried out by the system itself.

Industry 4.0 can complement lean approaches, in particular, through the possible exchange of information between any process steps, if necessary, in

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[134] Cf. Dombrowski, U.; Richter, T. and Krenkel, P. (2017), p. 1063.
[135] Cf. Matt, D. T. (2018), p. 53.
[136] Cf. Verbund Deutscher Maschinen- und Anlagenbau e.V. (2018), p. 10.

real time. This not only allows processes to be controlled dynamically and depending on the situation, but also supports continuous improvement in the company through data-based forecasts or self-optimising systems.[137]

Digitisation and Industry 4.0 offer opportunities in terms of the optimised implementation of individual principles and lean methods. This also allows the potential for increasing resource efficiency to be further improved.

Supporting process standardisation through digitisation

Customer-focused production can be burdensome and error-prone in terms of creating standard operating procedures. Digitisation makes it easier to modularise specifications. These can be made available to employees digitally on a product-specific basis. Even if the implementation of digital work instructions initially means increased effort, this is reduced in the processing of the individual orders. In addition, digital worker assistance systems can prevent errors due to outdated documents. The use of digital assistance systems, such as pick-by-vision, can also avoid incorrect actions and thus the waste of resources.[138]

Supporting visual management through digitisation

Digitisation of visual management enables the immediate provision of information on the process at the workplace or on mobile devices. In addition to a simple target/actual comparison, information can be collected and visualised for trend analyses or for forecasting deviations. If problems occur in the process, it is possible to react immediately or take preventive action. This avoids major production errors or machine breakdowns and counteracts a waste of resources. In addition to the possibility for employees to immediately receive visualised process information, managers can also react more quickly in an emergency on the basis of the data and, if necessary, provide personnel or financial resources. In order to support daily shop floor management and continuous improvement, digital data can be displayed,

[137] Cf. Verbund Deutscher Maschinen- und Anlagenbau e.V. (2018), p. 9.
[138] Cf. Verbund Deutscher Maschinen- und Anlagenbau e.V. (2018), p. 12 – 13.

analysed and correlations between occurring deviations and process parameters can be traced.[139]

Supporting levelling through digitisation

Digital data collection and networking can create digital images of a company's current workload. This makes it easier to coordinate the work of sales, adaptation development and work preparation. More realistic deadlines can be promised to customers and rescheduling in development and work preparation can be avoided. Errors and wastage of resources due to short-term rescheduling or occurring overload in production can thus be reduced. For simple individual products, there is the possibility to enter free appointments through digital product configurators and digitally recorded capacity utilisation, which can be booked by clients themselves. Through digital networking and the recording of capacity utilisation, possible bottlenecks in specific production sections can be detected and avoided at an early stage.[140]

Support of flow and pull principle through digitisation

Digitisation can help to improve the flow of information, especially in the case of waiting times due to a lack of information. Logistics processes can be rendered more flexible through digitisation, and inventories can be dynamically adjusted according to demand and delivery availability. For example, "milkrun systems" can be dynamically adapted and inventories can be reduced through the use of electronic Kanban systems (eKanban). In addition to reducing storage space, the risk of wasted resources due to stock loss can also be minimised.

By using digital product keys, it is possible for products to be identified at the various workstations and automatically configured according to the work instruction. By letting the product control the process, the flow principle in the production system can be optimised. Digital networking along the value

[139] Cf. Verbund Deutscher Maschinen- und Anlagenbau e.V. (2018), p. 14.
[140] Cf. Verbund Deutscher Maschinen- und Anlagenbau e.V. (2018), p. 15.

chain also allows bottlenecks to be identified at an early stage, and appropriate measures to be taken.[141]

Supporting autonomy through digitisation

Where appropriate, software-based solutions can be used more flexibly than hardware solutions, in order to avoid mishandling. The digital networking of company divisions can avoid problems in the flow of information, e. g. in the error-prone transfer of data to other systems. By implementing component identification, faulty productions can be better traced and limited. Due to the networking of process data, it becomes possible to train systems. Scrap and rework can be reduced by identifying problems in advance. In addition, residual idle times, e.g. for tools, can be determined, and thus the best possible use of operating resources can be ensured.[142]

Supporting the continuous improvement process through digitisation

Tracking and presenting the progress of the implementation process of improvement measures can be promoted, for example, through software-based action plans. In-house knowledge management can be improved through digitisation. In this way, problems that have occurred and their successful solution can be digitally documented in databases. Employees can access this information in case of recurrence or similar problems. In the event of deviations in the process and defects occurring, the corresponding process data can be analysed and used as a basis for finding the cause and developing improvement measures.[143]

8.2 Practical examples

In the following, practical examples are presented in which the implementation of lean methods was supported by digitisation approaches, and resource efficiency in the company was improved.

[141] Cf. Verbund Deutscher Maschinen- und Anlagenbau e.V. (2018), p. 16 – 17.
[142] Cf. Verbund Deutscher Maschinen- und Anlagenbau e.V. (2018), p. 17 – 18.
[143] Cf. Verbund Deutscher Maschinen- und Anlagenbau e.V. (2018), p. 19.

Reduction of resource waste through digitisation for process standardisation

In the production of individual components for a chemical pump company, the manual transfer of design data into the Computerised Numerical Control (CNC) programme of the machine tool led to frequent errors, which were only detected during final assembly. In addition to rejects, this often resulted in assembly line stoppages.

Through the development and introduction of new software, design and production were able to be linked in a digital process and automated derivation of the CNC programme from the individual configuration data was made possible. As a result, faulty CNC programming was able to be completely eliminated. In addition to saving a considerable amount of time by eliminating the manual creation of CNC programmes, this led to a reduction in scrap and assembly line downtime. The example shows how the principle of standardisation can be successfully applied to individual components through digitisation in manufacturing, thereby saving resources.[144]

Reduction of waste through digital information processing in the TPM system

Despite an established TPM system, waste was occurring in the maintenance processes of a company that manufactures valves, valve terminals and electronics. In order to eliminate faults, the employees had to walk long distances. Obtaining information was cumbersome and finding the spare parts was time-consuming. This led to delays and longer downtimes due to maintenance.

In a cooperation project between IT and maintenance, an app for tablets was developed that allows maintenance staff to call up and search repair instructions, spare parts lists and stocks of spare parts on site. If necessary, the procurement of spare parts can be carried out by the customer. When extrapolated to one year, the mobile solution can save about 3500 man-hours and machine-hours. By recording all information on the location and type of malfunction, as well as messages on the time and status of the

[144] Cf. Verbund Deutscher Maschinen- und Anlagenbau e.V. (2018), p. 32.

implementation, the system also facilitates the recording and evaluation of maintenance key figures. This facilitates the work of the maintenance staff. Reasons for failures can be analysed more easily, and planned maintenance can be optimised depending on the situation.[145]

Resource-efficient production through digitised one-piece flow

A manufacturer of automation, handling and clamping technology converted its production line to single-part production (one-piece flow) with the aim of making processes faster and more demand-oriented for customers, reducing inventory and minimising rejects. One example of this is the single-part production line of individually configurable large-area grippers, which is directly controlled by customer orders. Before the changeover, the basic configuration of the gripper was produced in a standardised way and then stored. This led to high inventories, long storage and delivery times, and wasted materials during customisation.

Since the switch to single-part production, customers can configure the grippers according to their requirements in more than one million variants directly when placing their order. Each product variant receives a digital product key containing the production specifications. The drawings of the required foam parts are also automatically transferred as computer-aided design (CAD) files to the cutting machine, which cuts the specific shape. This individualised production was linked to an intelligent Kanban system. By rendering production and storage flexible, it was possible to almost completely eliminate stock. Despite customised production in small batch sizes, it was not only possible to reduce material efficiency and process costs, but also to shorten delivery times.[146] The savings amount to 2.6 t per year for foam, which corresponds to a saving of 15 t CO_2 equivalents per year. Per year, 233 kg of aluminium are also saved, which corresponds to 7 t CO_2 equivalents per year.[147]

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[145] Cf. Verbund Deutscher Maschinen- und Anlagenbau e.V. (2018), p. 34.

[146] Cf. Schebek, L.; Kannengießer, J.; Campitelli, A.; Fischer, J.; Abele, E.; Bauerdick, C.; Anderl, R.; Haag, S.; Sauer, A. and Mandel, J. (2017), p. 231.

[147] Cf. VDI Zentrum Ressourceneffizienz GmbH (2017).

9 DEVELOPMENT OF A CORPORATE STRATEGY

Companies should aim to consider their lean approaches, digitisation strategy and resource efficiency improvement strategy together, and incorporate them into the design of the production system (cf. Illustration 8). Lean approaches, digitisation and increasing resource efficiency should also be embedded in the company's corporate strategy.

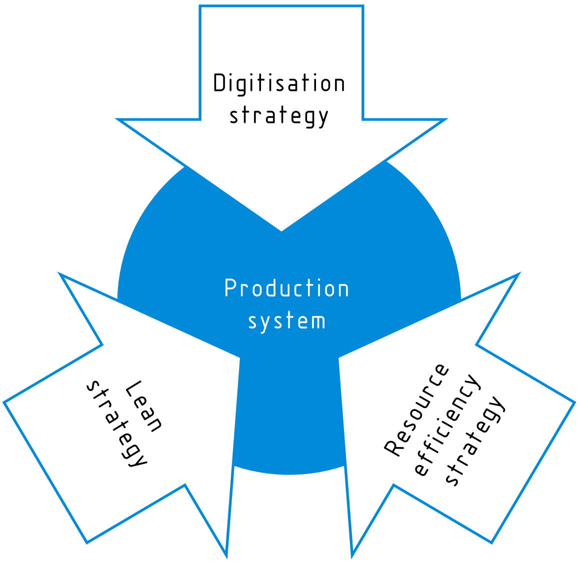

Illustration 8: Merging lean, digitisation and resource efficiency strategy in the production system

In order to be successful in global competition in the long term, a holistic corporate strategy is required that comprehensively incorporates the needs of clients and, at the same time, takes into account digitisation approaches for the company's own business model.[148]

Due to the rapidly changing environment, it is no longer sufficient to decide on a corporate strategy once and stick to it without change. Rather, strategies

[148] Cf. Walter, p. (2019), p. 8.

need to be regularly reviewed and adapted.[149] One way to meet these requirements is to apply agile working methods, in which the changing framework conditions are taken into account from the outset and thus changes can be reacted to more flexibly.

One method for strategy development is the so-called strategy design, the basic idea of which is based on the design thinking approach. Strategy development is seen as a holistic creative act. A strategy is understood as an innovation that develops from an iterative, rapid and holistic interaction of analysis (knowledge-based), idea generation (creative) and implementation. A key principle here is collaboration in an interdisciplinary team that is as free of hierarchy as possible.[150]

Analysis

Starting points for strategy development can be existing skills in the company, good practice from the company's own sector, but also from other sectors, developments and trends in the company's environment, as well as the professional worlds inhabited current and potential customers.[151]

Brainstorming

Brainstorming should take place in interdisciplinary teams within the framework of strategy workshops. An essential part of this is a joint immersion into the lives of current and potential clients. The use of creativity techniques can support the development of ideas. Promising solutions should already be specified and elaborated further, in order to evaluate a first "strategy prototype" as early as in the workshop stage.[152]

Implementation

The further development of a strategy takes place in workshop-like formats with the aim of transferring the idea or the first strategy prototypes to company divisions and improving them iteratively. By involving employees in

[149] Cf. Walter, p. (2019), p. 17.
[150] Cf. Walter, p. (2019), p. 16 - 18.
[151] Cf. Walter, p. (2019), p. 18 - 19.
[152] Cf. Walter, p. (2019), p. 20 – 21.

the strategy's further development, strategy development and implementation are brought together, resulting in a continuous change in the way employees think and act, which is the basis for the future success of the company.[153]

[153] Cf. Walter, p. (2019), p. 22 – 23.

10 CONCLUSION

In order to remain successful as a company in the long term and in the face of global competition, an efficient production system is indispensable. The transformation to efficient production systems that are individualised for the clients and optimised through digitisation approaches offers an opportunity to meet (and master) future challenges. Resource efficiency should be taken into account in the design of the production system – not only to contribute to environmental and climate protection, but also to make a positive contribution to production development and corporate success.

With the help of LPS principles, not only can lean approaches be realised in the company, but resource efficiency can also be improved at the same time. Various methods presented in the brief analysis support implementation in practice. In particular, the consistent avoidance of waste aims to improve resource efficiency and brings together the objectives of a lean and resource-efficient production system.

The digitisation of industrial production not only contributes to increasing resource efficiency. As previous examples have shown, the implemented digitisation measures also support lean methods and approaches. In the course of digitisation, however, the core of the Lean idea – the employees – must not be forgotten. Sole reliance on technology not only reduces the success achieved through lean approaches, resource efficiency strategy and digitisation, but can also result in wrong decisions or measures when system problems occur. The goal should, therefore, be for employees to understand the interrelationships of digitalised processes and to see them as a sources of technical support, in order to continue to embrace a continuous improvement culture.

The methods and examples presented show that, in an ever faster changing market environment, one's own corporate strategy must be regularly reviewed, adapted and supplemented. Innovative methods aimed at strategy discovery – such as strategy design – can help to develop new business fields, products and production methods.

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VDI Zentrum Ressourceneffizienz GmbH (VDI ZRE)
Bülowstraße 78
10783 Berlin
Tel. +49 30-2759506-0

zre-info@vdi.de
www.ressource-deutschland.de