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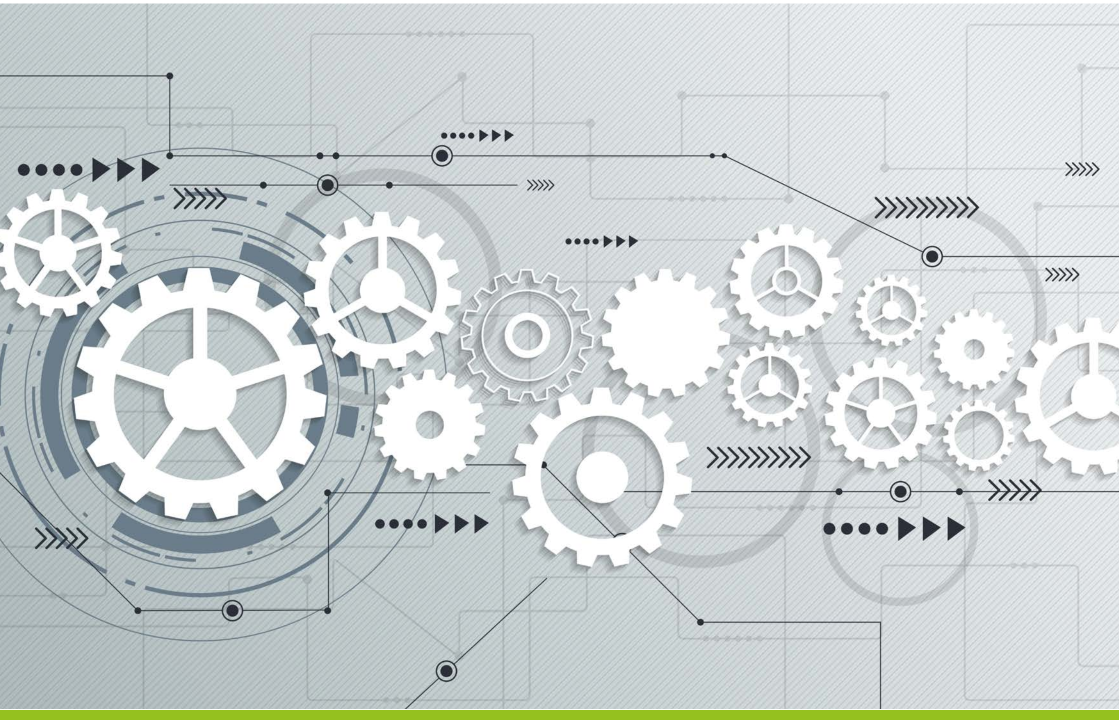
VDI ZRE Publications: Brief Analysis No. 23

Resource Efficiency in the Value Chain



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VDI ZRE Brief Analysis No. 23: Resource efficiency in the value chain

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The brief analyses of VDI ZRE provide an overview of current developments related to resource efficiency in research and industrial practice. They each contain a compilation of relevant research results, new technologies and processes as well as examples of good practice. The brief analyses thus provide a broad audience from business, research and administration with an introduction to selected areas of resource efficiency.

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Resource Efficiency in the Value Chain

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LIST OF ABBREVIATIONS

b2b	Business to business
b2c	Business to consumer
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CAD	Computer aided design
CAM	Computer aided manufacturing
CO2	Carbon dioxide
CTQ	Critical to quality
DBU	German Federal Environmental Foundation
DIN	German Institute for Standardization e.V.
DMAIC	Define-Measure-Analysis-Improve-Control
DoE	Design of Experiments
EMAS	Eco-Management and Audit Scheme
g	gram
GiBWert	Design of innovative modular and value-added structures (project)
IT	Information technology
KIT	Karlsruhe Institute of Technology
kg	kilogram
SMEs	Small and medium-sized businesses
CIP	Continuous improvement process

kWh	Kilowatt hour
l	Litres
LAN	Local area network
ML	Markup language
PET	Polyethylene terephthalate
PDCA	Plan-Do-Check-Act
QFD	Quality function deployment
SIPOC	Supplier - Input (input factors) - Process - Output (results) - Customer (customer)
t	Metric tonne
TRIZ	Theory of inventive problem solving
TU	Technical University
BMWi	Federal Ministry of Economics and Energy
UBA	Federal Environment Agency
VDE	Association of Electrical Engineering Electronics Information Technology e.V.
VDI	Association of German Engineers e.V.
VDI ZRE	VDI Zentrum Ressourceneffizienz GmbH
WLAN	Wireless local area network

1 INTRODUCTION

Resource-efficient production is characterised by the conscious use of materials and energy. If the resource expenditure is thereby reduced, costs can be saved and competitive advantages can be generated. Resource efficiency measures can be implemented at various points in the production process. The potentials are manifold.[1] However, the increasingly complex networked production economy no longer only requires punctual, but also comprehensive resource efficiency measures, those that work across processes as well as operating and business boundaries.

In particular, inter-business resource efficiency measures can achieve a much higher degree of efficiency if businesses coordinate their value chains and cooperate with each other.[2] The integration of suppliers into the business's own processes, for example, promotes product and process quality, streamlines the organisation and thus leads to more efficient cooperation.[3] The integration of the customer enables more customer-specific solutions which, in addition to higher competitiveness, can result in reduced inventories and thus less capital commitment.[4]

Current trends, driven among other things by globalisation, the development of new technologies or product individualisation, are forcing entrepreneurial thinking away from isolated gate-to-gate approaches towards flexible value creation structures. Against the background of the digital transformation, this change is becoming more and more constant. The limits of a conscious handling of materials lie not only within the factory gates: Comprehensive resource efficiency measures between businesses can generate further savings potential and also generate new business ideas, cooperation and competitive advantages.

But also internal links of e.g. business divisions or process stages can lead to an increase in resource efficiency. Cooperation between business divisions helps to optimise processes and can contribute to resource-conserving

1 Cf. industry-specific process chains on https://www.resource-germany.com/tools/process-chains/

2 Cf. Hennicke et al. (2009) in Berg et al. (2014), p. 14 f.

3 Cf. Helmhold and Terry (2016), p. 92.

4 Cf. Mussbach-Winter (2014), slide 65.

economic growth. In addition, the analysis and efficient interlinking of value-added stages in the production process support more comprehensive process control. The interlinking can then result in material and energy savings.

This brief analysis sheds light on resource efficiency potentials that have an effect beyond value creation and process stages and presents measures that can tap these potentials. To this end, the terms value creation, value creation stage and value chain are first classified. The brief analysis shows potentials that can be tapped at the levels of supply chain, business and production process. The resulting resource efficiency measures are either more technical or more strategic in character. These are presented according to the structure and illustrated by examples of good practice and model projects. Before the presented measures are summarized in the context of the development of new value creation structures and challenges such as the transfer of sensitive business data, methods for data and material flow analysis are presented. They are a key to the successful implementation of cross-value-added resource efficiency measures and support the disclosure of internal and external input and output flows.

2 RESOURCE EFFICIENCY POTENTIALS IN THE VALUE CHAIN

2.1 Value added, value-added stage and value chain

The concept of value creation can be used from different perspectives. Value added describes the economic performance of the individual economic sectors[5] from an economic point of view and is the goal of economic activity.[6] From the point of view of business administration, value creation is understood as the contribution of a business to national income.[7] This contribution of value added therefore comprises the results of business-specific productive activities (as well as services) and results from the selling price of a product less intermediate consumption (e.g. purchase of materials, external services).[8]

In this brief analysis, value added is understood as a productive activity that adds a higher monetary value to a good/product. Value creation takes place within a value creation stage and along a value chain.

The productive activities take place in so-called value-added stages. Each stage makes a contribution to increasing the value added. Within a business, value-added stages are, for example, purchasing or production.[9] In a supply chain, for example, they represent the individual suppliers.

In this brief analysis, a value-added stage is understood as a framework in which productive activities take place. The value -added stage is one link in the value chain.

A value chain can be described as the "totality of processes (such as production, delivery, etc.) that lead to value creation"[10]. The "totality of processes"

5 Cf. Weizäcker and Horvath (2018).
6 Cf. Haubach (2013), p. 15.
7 Cf. Weizäcker and Horvath (2018).
8 Cf. Teuscher (2011), p. 16.
9 Cf.Bach et al. (2012), p. 4.
10 Duden (2018).

comprises the sequence of productive activities or value-added stages that are linked to each other by supply relationships. In[11] addition, the value chain in its original sense is an analytical instrument from business administration. The entire, strategically relevant activities of a business to create a product (or service) are presented in a structured way in the value chain.[12]

In this brief analysis, the value chain is understood as the totality of productive activities or as a sequence of value creation stages that are usually linked to each other via supply relationships.

The framework in which a value chain is considered varies. Depending on the desired depth of detail, different observation levels can be focused (Figure 1). The consideration of the value chain can comprise, for example

- the entire life cycle or the entire value chain (cradle-to-grave),
- only one supply chain or several supply chains (supply chain, cradle-to-gate),
- only one business or
- only one or more production processes and the associated infrastructure (gate-to-gate).

[11] Cf. UVK Lucius (2018).
[12] Cf. Günther (2008), p. 172.

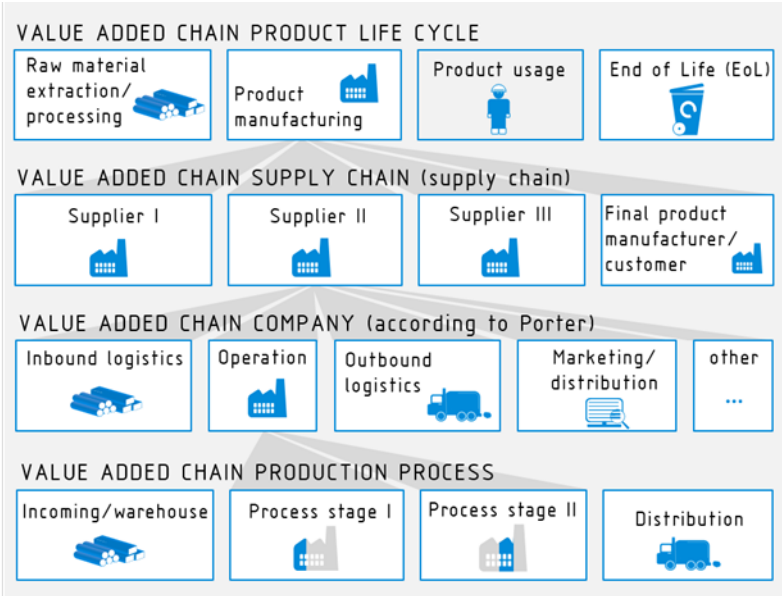

Figure 1: Observation levels in the value chain

The observation levels Supply Chain, Business and Production Process listed here also serve to shed light on the relationships between the individual stages of the value chain (Figure 2, white boxes) and to show resource efficiency potentials as well as concrete measures that can be tapped beyond the stages of the value chain.

Due to the superordinate and complex nature of the product life cycle or the entire value chain, this is not considered further in the following explanations.

2.2 Observation level supply chain

Suppliers, wholesalers, retailers or end customers are part of a supply chain. In practice, this supply chain is often perceived as a network in which several businesses are linked by material flows.[13] It can thus also be described

[13] Cf. Bush and Dangelmaier (2002), p. 4.

as a network of organisational units that provides a product or service through interaction.[14]

In order to optimise the supply chain in a resource-efficient manner, the upstream and downstream stages of the value chain must be analysed and coordinated from the point of view of a business (Figure 2).

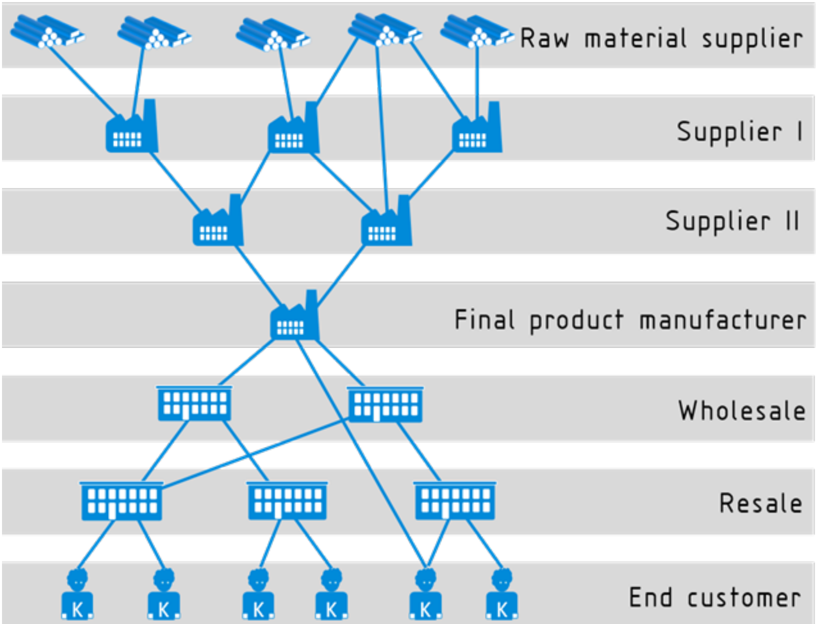

Figure 2: Schematic represenation of the supply chain[15]

By designing these value-added agreements or cooperation's against the background of resource efficiency, synergy effects in the area of resource saving can be exploited and thus the employment and competitiveness of the participating businesses can be improved.[16] The decision for a resource-ori-

[14] Cf. business knowledge (2017a).

[15] Based on Bush and Dangelmaier (2002), p. 4.

[16] Cf. Berg et al. (2014), p. 30.

ented cooperation between the business partners often takes place on a strategic level and can be implemented, for example, via supplier or customer integration.[17]

Resource efficiency measures at strategic level across all stages of the value chain, which have an effect across businesses (Chapter 3.1)

- Integration of suppliers into business processes (Chapter 3.1.1)
- Integration of customers into business processes (Chapter 3.1.2)

Both measures will be explained in more detail in Chapter 3.1 and will be further developed on the basis of practical examples and model projects. The measures are only to be understood as a selection or as non-exhaustive.

2.3 Observation level business

The internal networking of value creation stages can be promoted through resource efficiency measures and at the same time save material and costs. Most of these organisational and institutional measures are implemented at management or strategic level. By successfully integrating resource consumption as a control variable in management approaches, optimisation potentials can be tapped.[18]

According to Porter, there are nine different stages of the value chain in a business.[19] They process different task fields and pursue different objectives. The Porter classification enables a targeted analysis of strengths and weaknesses in a business and, building on this, identifies opportunities and risks for profit evaluation (Figure 3).[20]

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[17] Supply Chain Management includes many tools that can be used to analyse and organize the supply chain and suppliers. Within the scope of this brief analysis, only the supplier and customer integration can be presented in favour of the scope. At this point, reference should also be made to the development of "Sustainable Supply Chain Management", through which the supply chain is ecologically, economically and socially oriented.

[18] Cf. Neugebauer (2014), p. 110.

[19] Cf. Porter (1985), p. 64.

[20] Cf. Günther (2008), p. 172.

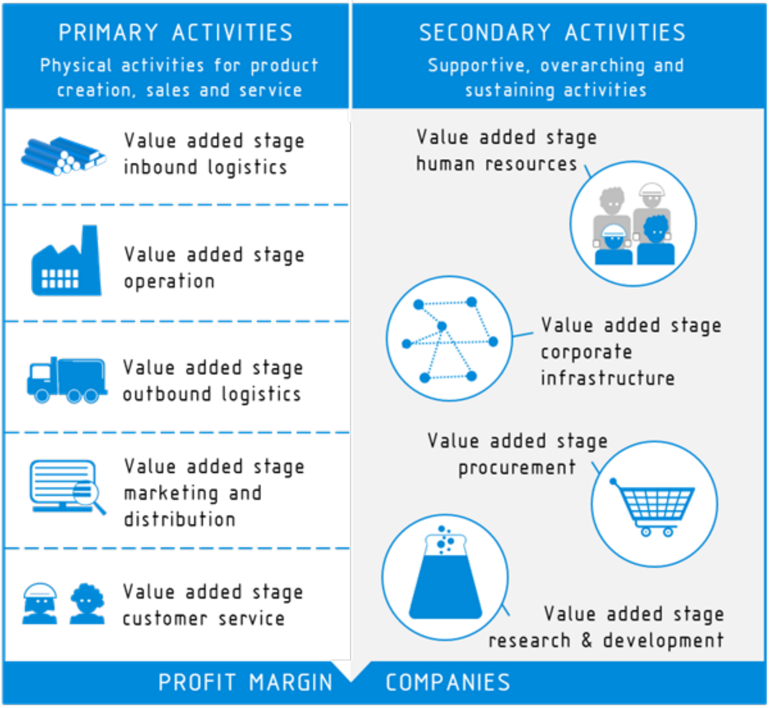

Figure 3: **Value creation stages according to Porter**[21]

At the same time, this overview of the corporate structure helps to determine resource efficiency potentials across value-added levels from the perspective of the business and to derive measures (Figure 3). This requires the identification of the most relevant tasks per value added stage (Table 1). In addition, significant relationships between the levels can already be identified through which resource efficiency potentials can be tapped.

21 Based on Porter (1985), p. 64.

Table 1: Essential tasks of the value chain stages[22]

Value creation stage	Main tasks (e.g.)
Primary Activities	
Inbound logistics	- Incoming goods and stock control - Materials handling - Warehousing - Vehicle scheduling - Return of goods to the supplier
Surgery	- Machining, manufacturing, assembly and packaging of the Product
Outgoing logistics	- Storage - Delivery to the customer
Marketing & Sales	- Publicity - Sales - Offers and pricing
Customer service	- Installation - Maintenance - Maintenance & Repair - Customer trainings
Secondary Activities	
Procurement[23]	Strategic tasks: - Procurement market research - Definition via centralized and/or decentralized procurement - Supplier analysis, evaluation and selection - Creation of procurement portfolios Operational tasks: - Stock control - Demand determination and order quantity planning - Supplier selection
Research & Development	- Product development - Product improvement - Process improvement
Enterprise infrastructure	- Activities related to the entire value chain such as management, accounting, Controlling and quality control
Human resources	- Recruitment - Education and training - Wage payment - Further education/staff training

In principle, networking should take place between all stages of the value chain within the business. Based on the task areas of Table 1, however, an intensive exchange to tap resource efficiency potentials is obvious, especially among the following value creation stages:

- Incoming logistics, outgoing logistics and procurement/purchasing, e.g. with regard to material selection, material control or the conservation of raw materials used in the product and/or process

[22] Cf. Oehlrich (2010), p. 140 et seq.
[23] Cf. Gabler Lexikon (2017).

- Research and development, customer service and operation/production e.g. with regard to quality control and development of product optimisations

Cross-departmental employee and project teams in particular can form a bundled know-how here that makes it possible to understand the working methods, goals and strategies of other value-added stages in the business. These can be integrated into one's own activity processes, so that undesirable developments can be recognised at an early stage and counteracted.[24] But clearly formulated business goals for handling resources or lean management also offer approaches for tapping resource efficiency potentials.

Resource efficiency measures at strategic level that transcend value-added stages and have an interdepartmental effect (Chapter 3.1)

- Inclusion of resource efficiency issues in business strategy (Chapter 3.1.3)
- Use of quality and environmental certifications (e.g. ISO 14001, EMAS, Ökoprofit)[25]
- Use of Lean Management elements (Chapter 3.1.4)
- Cross-value-added level employee and project teams (Chapter 3.1.5)

The measures presented will be explained in more detail in Chapter 3.1 and will be further developed on the basis of practical examples and model projects. The measures are only to be understood as a selection or as non-exhaustive.

2.4 Observation level production process

A process chain is an interlinked sequence of manufacturing stages in a production process.[26] In industrial production, this includes the storage of materials, various production stages with return options for production aids and

[24] Cf. Schmidt et al. (2017).

[25] At this point, reference is made to the VDI ZRE brief analysis "Resource Management", which describes quality and environmental management in detail. The brief analysis can be accessed at www.ressource-deutschland.de/publikationen/kurzanalysen.

[26] Cf. Heinemann et al. (2013), p. 268.

products, and outbound logistics. Figure 4 shows an example of the process chain for an electroplating process.

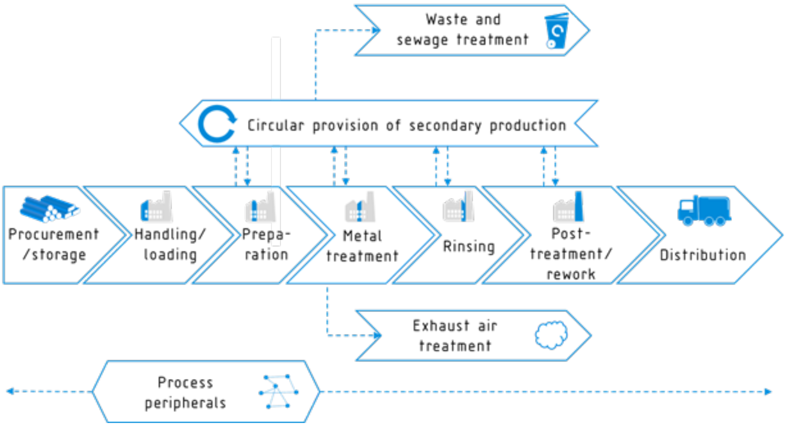

Figure 4: Exemplary process chain of an electroplating process[27]

Recycling, in particular, represents a resource efficiency measure that spans all stages of value creation. For example, acids used in the electroplating process shown can be recovered by adsorption and returned to the process. With this measure up to 60 % depletion rates can be achieved.[28]

Such circulating process flows should already be considered during the planning of process chains by simulation methods. Even in already existing production processes, considerable potential can be tapped by restructuring, e.g. by eliminating or replacing value-added or process stages[29].

Process-engineered resource efficiency measures that have an effect beyond the operational level across process stages include, for example, condition monitoring and predictive maintenance, the joint use of resources in business pools or cascading use. These resource efficiency measures are usually

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27 Based on VDI Resource Efficiency Centre (2017a).

28 Cf. VDI Zentrum Ressourceneffizienz (2017a).

29 On the observation level of a production process (Figure 1), a value-added stage can be equated with a process stage. For easier understanding, the following explanations speak of process stages within the production process observation level.

implemented at the technical level and can contribute to optimised process control in addition to material and energy savings.

Resource efficiency measures across value-added stages at technical level (Chapter 3.2)

- Simulation of continuous process chains (Chapter 3.2.1)
- Restructuring of process stages (Chapter 3.2.2)
- Recycling and recirculation (Chapter 3,2.3)
- Condition Monitoring and Predictive Maintenance (Chapter 3.2.4)
- Shared use of resources (business pools) (Chapter 3.2.5)
- Cascading use (Chapter 3.2.6)

The presented measures are explained in chapter 3.2 and are deepened by examples of good practice and model projects. The measures are only to be understood as a selection or as non-exhaustive.

3 RESOURCE EFFICIENCY MEASURES IN THE VALUE CHAIN

3.1 Resource efficiency measures at strategic level

3.1.1 Integration of suppliers into business processes

One way of integrating upstream suppliers into one's own business processes for the benefit of resource efficiency is supplier integration - an instrument of supplier management (Figure 5).

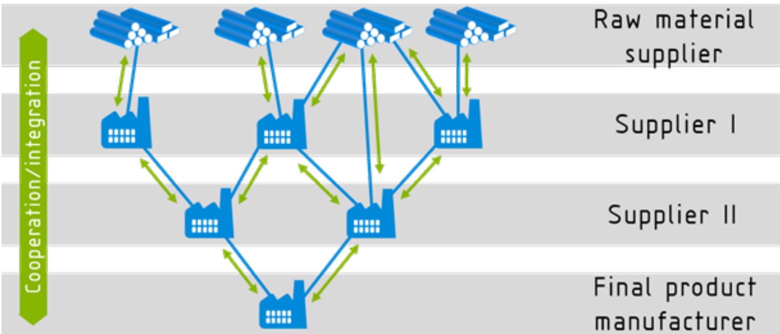

Figure 5: Integration of suppliers

Supplier integration makes use of the competence of external partners within the business. The suppliers are integrated into the business processes by synchronizing processes and systems and thus increasing the efficiency of cooperation.[30] Supplier integration enables you to

- improve product and process quality,
- streamline the organisation,
- realise cost advantages,

[30] Cf. Helmhold and Terry (2016), p. 92.

- improve delivery quality (reliability and delivery time) and
- reduce negative environmental impacts.[31]

In addition to other approaches, there are three strategies according to the 3-phase model for implementing supplier integration. Depending on the intensity of the cooperation, this takes place either in Research & Development, in Engineering/Construction or in Procurement/Production/Logistics (Table 2). Here, for example, the SME as a supplier can provide suggestions for participating in the individual value creation stages of its customer. In this way, processes between the actors can be optimised, resource efficiency potentials can be tapped and at the same time the supplier-customer relationship can be strengthened.

Table 2: Implementation and potential of supplier integration[32]

Research & Development	Engineering/ Construction	Procurement/ Production/Logistics
IMPLEMENTATION		
The supplier is involved in all levels of the product development process - from the idea to production.	The supplier is involved in the problem solving of existing production processes.	Close coordination and synchronization with the supplier regarding information, communication and process flow are implemented.
POTENTIAL		
- Reduction of design and development time - Reducing design and development costs - optimised material usage and material cost reduction - Increase in product and process quality - Improved reliability and durability of parts - better resource utilisation - Use of development know-how	- early involvement in development projects - Knowledge and competitive advantages - greater planning reliability - better planning and use of resources and capacities - coordinated interfaces in the software systems - Use of design know-how	- Reducing procurement costs - Shortening of delivery and throughput times and adherence to agreed delivery dates - greater flexibility in the event of changing requirements - Increase in security of supply - Increase in process quality - greater transparency and faster response times - stable and standardized supply processes - Minimisation of procurement risks - Establishment of a relationship of trust

[31] Cf. Schaltegger et al. (2007), p. 169.

[32] Based on Arnold (2004), p. 37.

The most important prerequisite for successful supplier integration, especially in the area of procurement/production/logistics, is the continuous, IT-based flow of information. For example, changes in planning and delivery bottlenecks can be responded to at an early stage. The supplier in turn receives information through a production preview in order to coordinate capacities and resources for the coming orders.[33] One instrument that supports supplier integration is Lean Management (Chapter 3.1.4).

Practical example 1: Supplier integration

J. Schmalz GmbH, a manufacturer of vacuum technologies, uses an intelligent system to ensure the supply of parts. Via the so-called Kanban system, an element of lean management (Chapter 3.1.4), the supplier is informed by scanning a card that one of the parts containers of a product to be delivered is empty (Figure 6).

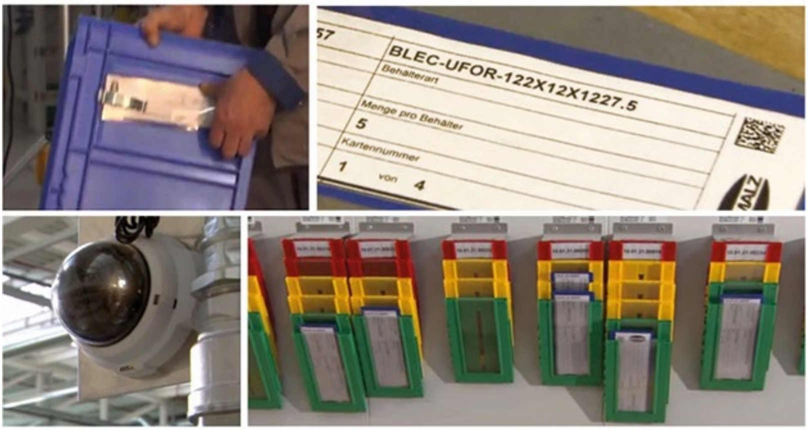

Figure 6: Kanban system for the supply of parts by the external suppliers of the business J. Schmalz GmbH[34]

Using a webcam, the supplier can monitor a special board that stores the scanned cards. Each green-yellow-red row of the board is assigned a part for production (Figure 6). The scanned cards of the empty containers are placed

[33] Cf. Arnold (2004), p. 37.

[34] Cf. VDI Zentrum Ressourceneffizienz (2017b).

in the compartments in ascending order from green to red. If the red compartment is reached, replenishment is necessary. The external partner thus receives information about the stock and the urgency of the delivery. In this way, only those goods arrive at the warehouse of J. Schmalz GmbH that will be needed for production in the near future.[35]

Practical example 2: Supplier integration

The business Krämer GmbH produces wooden rung ladders. By process optimisation an increase of the production quantity could be achieved. At the same time, however, this led to a disproportionate increase in the quantity of scrap: About 30 % of the purchased wood was lost through cutting. The reason for the high reject rate was the quality of the wood delivered. This reached Krämer GmbH via a multi-stage supply chain with an asymmetrical distribution of power. Due to a lack of knowledge about the entire supply chain, the business could not directly influence the suppliers operating at the beginning of the chain (Figure 7).[36]

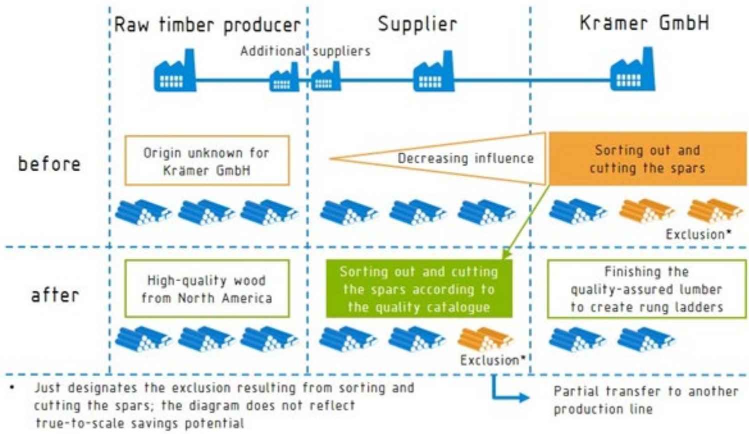

Figure 7: Supplier integration of Schäfer GmbH[37]

[35] Cf. VDI Zentrum Ressourceneffizienz (2017b).
[36] Cf. Schmidt et al. (2017), pp. 86 - 89.
[37] Cf. Schmidt et al. (2017), pp. 86 - 89.

The upstream supplier was therefore included in the woodworking process in order to reduce wood waste. On the one hand, an internal test catalogue on the wood quality to be delivered was drawn up. On the other hand, a cooperation was entered into with a supplier who takes over the wood quality control according to the test catalogue as well as the wood cutting and the cutting out of defects in the wood. For example, the focus of quality assurance was shifted from the end of the supply chain to the middle. The supplier has a stronger negotiating position with the upstream raw timber producers, whereby the quality requirements can be communicated and controlled along the entire supply chain (Figure 7). As a result, Krämer GmbH was able to produce around 32 to 35 tonnes less scrap material. This corresponds to an annual value of 48,000 euros. [38]

3.1.2 Integration of customers in business processes

Businesses are focusing more and more on manufacturing products to customer specifications. The trend is moving away from standard products towards modularised and customised products. Customers must therefore be involved in the development and production process of the products they order - in other words, they must be able to act as an active value-adding partner. [39, 40]

Without integration of the customer, so-called production in stock (made-to-stock) takes place. The production is designed for the anonymous mass market and is based on market research analyses and forecasts. The integration of the customer, however, is possible with the following options (Figure 8): [41]

- Fulfillment of orders (match-to-order): Selection of existing standard products according to customer requirements

[38] Cf. Schmidt et al. (2017), pp. 86 - 89.

[39] Cf. Hofbauhe (2013), p. 1.

[40] Within the framework of customer integration, reference is made to the so-called Living Labs or Sustainable Living Labs. These are centers for the exchange of (product) ideas between customers and businesses, such as the *Fraunhofer-inHaus-Zentrum*.

[41] Cf. Hofbauer (2013), p. 3.

- Bundle of services on order (bundle-to-order): Bundling of existing products into a customer-specific product

- Composition on order (assemble-to-order): Compilation of customer-specific products from standardised and prefabricated parts

- Production on order (made-to-order): production of customer-specific products (including component manufacturing)

- Development on order (development-to-order): customer-specific product development followed by customer-specific production

The further upstream the value chain the customer is integrated into the business, the more flexible the production must be adapted to customer requirements. Development-to-order results in the highest level of production flexibility, made-to-stock to the lowest. In the context of production control, a distinction is made between the push and pull principle of the production organization.

- Push principle (pressing principle): The aim is to achieve maximum capacity utilisation and maximum lot sizes along the value-added stages of the business. Regardless of actual demand, materials, parts and products are 'pushed' through the production chain according to a designated plan. A 100 % push principle corresponds to production in stock ('made-to-stock', Figure 8).[42]

- Pull principle (pulling principle): The pull principle is based on the actual needs of the customer. The required materials, parts and/or products are not manufactured until the order has been received. A one hundred percent pull principle corresponds to development to order ('development-to-order', Figure 8).[43]

[42] Cf. Chair of Materials Handling Material Flow Logistics (fml) (2017a).
[43] Cf. Chair of Materials Handling Material Flow Logistics (fml) (2017b).

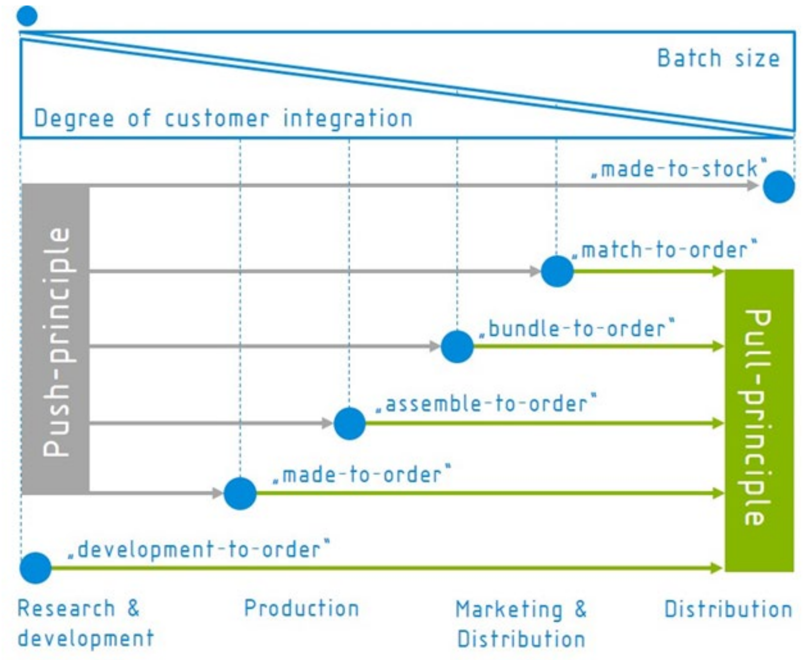

Figure 8: Push, pull principle and degree of custoner integration[44]

The push principle (pressing principle) is characterised by high capacity utilisation and short delivery times. However, the increase in customer-specific solutions and smaller order quantities can lead to decreasing delivery capability, larger inventories and thus higher capital commitment, rising logistics costs, increasing disposal costs and uneven production capacity utilisation.[45]

The pull principle is particularly suitable for customer-specific solutions and small batch sizes. The scope of the pull principle, i.e. order-oriented production, is determined by the entry point of the customer order (made, assemble, bundle-to-order, etc.): The pull principle applies from the entry point of the customer order (Figure 8, blue dot).[46]

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[44] Based on Hofbauer (2013), p. 11 and Wolff (2016).

[45] Cf. Mussbach Winter (2014), slide 65.

[46] Cf. Wolff (2016).

Practical example 3: Customer integration

Wetropa GmbH designs individual foam packaging for customers in the automotive and electrical industries, in medical and measurement technology as well as for craft businesses. In order to produce even the smallest batch sizes, such as individual tool and camera packaging, as efficiently and cost-effectively as possible, the business has developed an app with which the customer can carry out the development process himself (development-to-order). This allows him to adapt the foam insert and the transport case individually to his needs. Advantage of digitization: Since the design data is immediately available online, several smaller orders can be bundled into a single production process without great effort. In addition, no more samples need to be sent to the customer for preview.

Research project 1: Customer integration

The research project GiBWert "Design of innovative modular and value-added structures" aimed at the development of a modular development process especially for machinery and plant manufacturers. Using modular strategies, different product variants can be produced from the smallest possible number of components (assemble-to-order). This is necessary because the number of variants of the machinery to be produced more than doubled within 15 years. Many businesses are already implementing modular strategies intuitively. The GiBWert project therefore developed a superordinate, structured "Guide to modular design".[47] One business that introduced modular systems estimated that there would be cost savings of around 20% in development, procurement and production.[48]

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[47] Cf. Fraunhofer (2015).
[48] Cf. Industrieanzeiger (2012).

3.1.3 Inclusion of resource efficiency issues in business strategy

The business strategy defines the fundamental, long-term behaviour towards the environment. It thus describes the path to achieving the business's goals.[49] Resource efficiency is also being integrated into corporate strategy by small and medium-sized businesses - with an upward trend. While in 2011, according to a survey, 57 % of businesses surveyed included resource efficiency in their corporate strategy, this percentage rose by nine percentage points to 66 % in 2015.[50] This development also shows that a business strategy is never static, but must always be adapted to market and environmental developments. One variant of a flexible business strategy is the strategy cycle (Figure 9).[51]

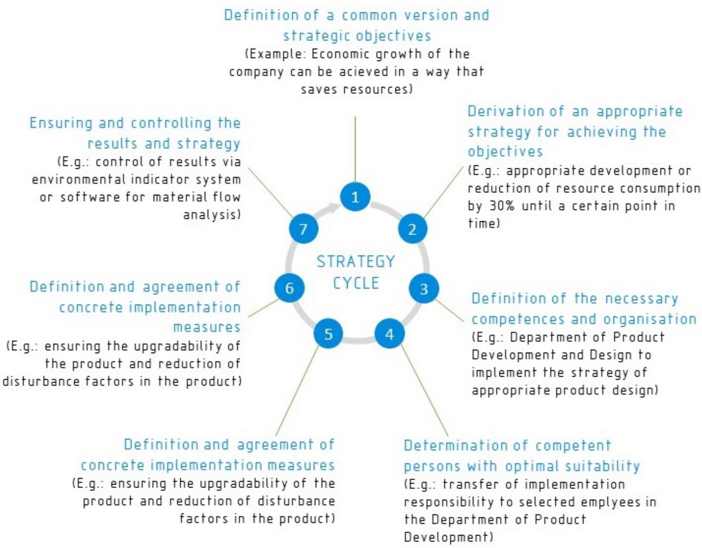

Figure 9: Strategy Cycle[52]

[49] Cf. Gabler Lexikon (2017).

[50] Cf. VDI Zentrum Ressourceneffizienz (2015a), p. 6.

[51] Cf. Radner (2013).

[52] according to Radner (2013) und Günther (2008), p. 14.

The business goals are a state of output quantities of the business that is strived for in the future. They give concrete form to the corporate philosophy and specify the orientation for concrete measures.[53] Here it can already be determined in favour of resource efficiency that the economic growth of the business can be achieved in a resource-conserving manner. The efficient use of resources through defined measures can at the same time contribute to the central business strategy - profit maximization.

The integration of resource efficiency into the business strategy also sends clear signals to potential customers. In a survey conducted in 2015, 60 % of the manufacturing businesses surveyed stated that resource efficiency is a high priority for customers. In 2011 it was still 37 %.[54] It also sends a clear message to employees at all levels of the business who identify with the business's objectives and raises awareness of resource efficiency. Interdisciplinary work between business divisions in particular can significantly promote the corporate objective of resource-conserving economic growth (cf. Section 3.1.5).

3.1.4 Use of Lean Management elements

Lean management means lean production and is understood more as a business philosophy and less as a pure method toolbox. [55] The focus is on the employee whose way of thinking focuses on detecting and eliminating waste in business processes.[56] There are five lean principles that build on each other (Table 3).

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[53] Cf. Günther (2008), p. 12.

[54] Cf. VDI Zentrum Ressourceneffizienz (2015a), p. 12.

[55] Lean management is introduced at the strategic level, while the practical implementation of lean management elements is carried out at the technical level, i.e. in the process. A clear differentiation is not possible at this point.

[56] Cf. Pointner and Steinhoff (2016), p. 14.

Table 3: Five Principles of Lean Management[57]

Principle	Content of the principle
1. Specify customer value	It must be clarified who the actual customer of the product or service is and what precise benefits they expect from the product or service. Product or service aspects that do not contribute to satisfying customer needs are considered wasteful and should be avoided.
2. Identify value stream	The exact activities that are carried out in an organization as a whole in order to manufacture the product must be identified. This means that all processes at the individual stages of the value chain are disclosed and analysed.
3. Creating a Value Flow	A flow principle (e.g. "One-Piece-Flow") must be implemented, a uniform production process without waiting times along all value-added stages of a business. The basic prerequisites are measurability of the process steps, an optimal sequence of the work processes and synchronization of these with each other.
4. Set up pull principle	The processes are to be controlled according to the customer's requirements (demand-oriented production). This determines the times and the quantity or the handling of the production and delivery of his product.
5. Strive for perfection	A continuous improvement process (CIP process) must be implemented. The processes of the business are to be continuously checked for improvement potentials. The CIP process is based on the Plan-Do-Check-Act cycle (PDCA cycle), which is run over and over again without interruption.

Lean management avoids different types of waste by applying the five principles. These are systematized according to the acronym DOWNTIME (Figure 10).

By avoiding waste, resources and associated costs can be minimised along the internal value creation stages. In terms of energy, conservation of at least 20 % can generally be achieved. A study conducted as part of the Lean & Green Efficiency Award 2012 confirmed that an average of 10 % conservation were achieved without investment. The study also showed that the businesses that were successful in this respect expect a savings potential of at least 20 % in resources such as energy, water and waste over the next three to five years. For the participating businesses, this corresponded to a reduction in production costs of more than 0.6 %.[58]

[57] Cf. Pointner and Steinhoff, pp. 18 - 23.
[58] Cf. Hofer and Reichert (2013), pp. 20 - 22.

Figure 10: Types of waste in lean management[59]

Practical example 3: Lean management

In 2016, Rhode & Schwarz Messgerätebau GmbH received the Lean & Green Award for virtually waste-free production at the Memmingen site. In this production plant, a holistic lean management approach is pursued, which includes the entire site in the considerations. The combination of efficient use of resources and waste-free production is achieved by consistently aligning production with value streams and by carrying out product life cycle evaluations. This approach will gradually bring us closer to the target conditions that have been set.[60]

[59] Based on Pointner and Steinhoff (2016), p. 31.
[60] Cf. Rohde & Schwarz GmbH & Co KG (2016).

Practical example 4: Lean management

J. Schmalz GmbH is a manufacturer of vacuum grippers, i.e. products that suck in, lift or hold workpieces. The supply of the components in production is organized in such a way that a surplus in the warehouse and at the workplaces is avoided. Single-piece production (one-piece flow) and the coordinated logistics system, which intelligently controls not only the material flows within production, but also the suppliers with the aid of a Kanban system (Chapter 3.1.1), reduced inventories by almost 50 %. This saves approx. 200 kg of aluminium profiles and 2,600 kg of foam material per year.[61]

3.1.5 Cross-value-added level employee and project teams

An essential prerequisite for increasing resource efficiency in a business is the integration of employees into the optimisation process (Figure 11).

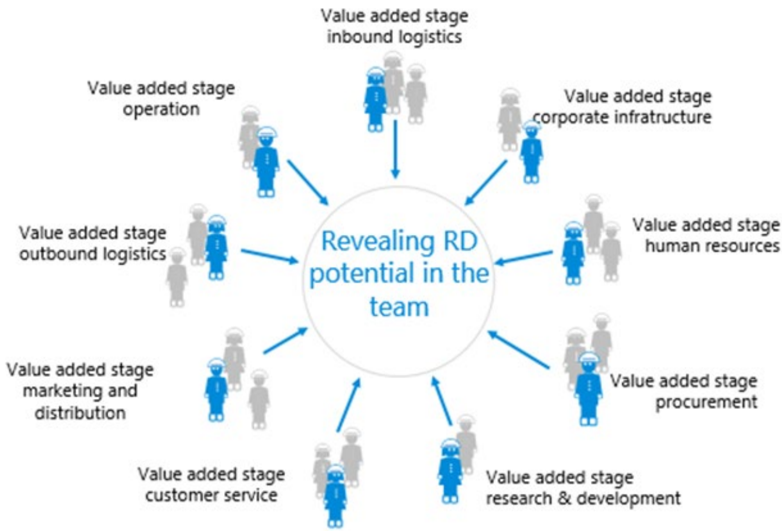

Figure 11: Cross value added level employee and project teams

[61] Cf. VDI Zentrum Ressourceneffizienz (2017b).

Employee competence is also a driving force behind a business's ability to innovate. In bundled form, i.e. in employee and project teams, it contributes to uncovering resource efficiency potentials in the business and jointly deriving solution options.

The goal of cross-value-added employee and project teams is to sensitize and understand the goals and tasks of other areas and to jointly analyse intersections in the business's value-added process. The various perspectives, e.g. from a production point of view, from the point of view of customer service or procurement, promote transparent handling of the entire flow of materials and information.

The challenge of setting up employees with a working time relationship that is often already fully utilised for additional project work is critical. The additional project work to increase resource efficiency is a continuous task and must be mastered parallel to the usual everyday tasks.[62] However, through early coordination within the employee and project teams, e.g. with the aid of simultaneous engineering, the additional areas of responsibility can be efficiently transferred into continuous activities.

Practical example 5: Cross-value-adding steps
employee and project teams

The Laupheimer Kokosweberei GmbH & Co KG manufactures floor mats for the automotive industry as well as for entrance areas. Each year, the business incurs around 220,000 euros in material losses. The production process was critically questioned by a cross-departmental team, particularly from the areas of purchasing, sales, production, quality management and business management, and an actual status was worked out from the various perspectives. As a result, the material losses in the area of the punchers and cutters could be detected as the main source of cause. These and other sources of losses were counteracted in continuous project meetings with elaborate measures. Material losses in the manufacturing process thus fell by approx. 44,000 euros. The intensive coordination between sales, purchasing, and production control improved the planning of special orders and reduced the

[62] **Cf. Schmidt et al. (2017), p. 78.**

quantity of stock piles. In addition to other measures, it was possible to increase the total value added, as the avoidance of rejects made it possible to use working and machinery times more efficiently.[63]

Practical example 6: Cross-value-added level employee and project teams

Festo AG & Co KG produces control and automation technology and planned a factory in Scharnhausen for the manufacture of valves, valve terminals and electronics. The goals of the new planning included intelligent automation and lean, sustainable and environmentally conscious production. The latter was achieved, among other things, by the "Energy and Environment" subproject, which consisted of an interdisciplinary working group with employees from the areas of production, building management, energy and environmental management as well as research. The result was a comprehensive resource efficiency concept for the building and the production process, which forecast conservation of around 78,000 tonnes of CO2 emissions. For example, the compressed air is generated highly efficiently and the electroplating process is redesigned. Minimal quantity lubrication is used in the manufacturing process. A monitoring system continuously monitors the electricity and energy requirements so that any unusual deviations can be reacted to quickly. Resources can therefore be used most efficiently if the design of the building infrastructure and the production processes are coordinated with each other. The formation of the "Energy and Environment" working group was seen as an essential cornerstone for the development of the overarching concept, but also for achieving the objectives. In the future, the energy and environment team will methodically support the production areas and implement further measures for resource-efficient production.[64]

3.2 Resource efficiency measures at technical level

The last chapter looked at resource efficiency measures from a strategic perspective, i.e. how a business can save resources in a supply chain or internally. The following chapter focuses on the technical level. Examples are given of how savings can be achieved in the production process itself. Value

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[63] **Cf. Schmidt et al. (2017), p. 78 – 81.**
[64] **Cf. Schmidt et al. (2017), p. 210 – 213.**

creation takes place through the sequence of process stages that raise a product to a higher value level.

3.2.1 Simulation of continuous process chains

The flow of substances within a business is usually characterised by a large number of process stages. Each process stage contains parameters with which production is controlled. The large number of parameters makes it possible to control the manufacturing process very precisely but makes it inflexible for changes and bears the risk of interactions. The introduction of new components, series or products or even technological advances require changes to processes. In order to be able to foresee the effects of the changes on production processes and to make them as resource-conserving as possible, continuous process chains can be simulated. Thus, complete chains or parts can be analysed with certain evaluation factors, such as machining times or machine availability. The goal of the simulation is to model material flows using a virtual model in such a way that possible effects of changes on the process can be evaluated. A simulation can be used in the planning, implementation and operation of a process chain.[65] The decisive factors in a simulation are the data basis and accuracy. When software systems are used, a distinction is made between different application levels (Figure 12).

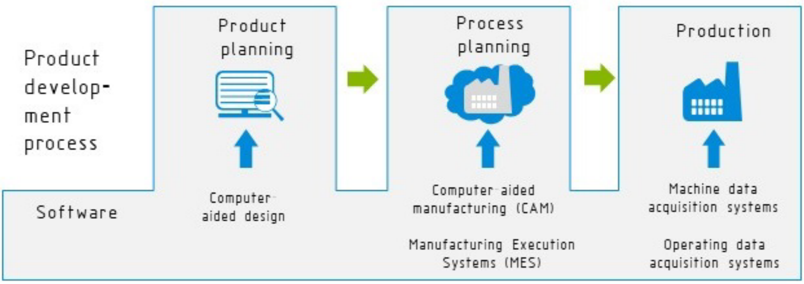

Figure 12: Software system to support the product development process[66]

Software is used at several points along the product development process. In product planning, products are digitally designed using CAD (computer-

[65] Cf. VDI 3633 Sheet 1: 2010-12, p. 7.
[66] Based on VDI Zentrum Ressourceneffizienz (2015).

aided design) software. The CAD model can then easily be used for further process planning. The production steps are planned virtually on this component. CAM (computer-aided manufacturing) software can be used to simulate and optimise machining strategies. In the implementation of real production, an MES (Manufacturing execution system) is used, which helps to control and monitor production in real time. These three systems can pass on their data to the other systems, which use it for further planning and optimisation of the manufacturing processes. It is also possible to return data from production to product planning in order to continuously improve existing products.

Practical example 7: Simulation of continuous process chains

The company Rieber manufactures sheet metal components for kitchens, but also aircraft equipment by means of deep drawing, annealing and welding. Approx. 35 % of the stainless steel used is scrap due to rejects and waste. In order to reduce the use of materials, three methodical steps are carried out: Visualization of the material flows, visualization of the associated information flows and finally the implementation of measurement and control variables to quantify optimisation potentials. To this end, it was purchased a new data acquisition tool for the production. The material flow model is calculated in Excel on the basis of the production data from Rieber's SAP system. This can be used to evaluate production orders, product groups, workstations and work steps. Through the implementation of initial process optimisations resulting from the improved data situation, the business has already been able to save at least 5 % of material, which corresponds to a value of approx. 400,000 euros. However, these only represent the savings in the implementation phase - after successful implementation and evaluation it can be assumed that further savings can be achieved.[67]

3.2.2 Restructuring of existing process stages

An extension, an exchange or an elimination of process stages can optimise an entire production process (Figure 13).

[67] **Cf. Schmidt et al. (2017), p. 146 - 149.**

Figure 13: Extension, exchange and elimination of process stages

The extension of process stages can improve the overall process flow and save resources at the same time. This is done, for example, by recycling residual materials and waste.

When process stages are exchanged, one or more stages are replaced. If new technologies or manufacturing processes are available that produce more resource-efficiently, an investment can quickly pay for itself. Here the process stage is retained, only the type of execution changes. Any incompatibilities that may occur with upstream and downstream process stages must, however, be taken into account.

When eliminating process stages, new technologies are used in other process stages, which means that subsequent stages can be completely dispensed with. To ensure a smooth process, the downstream process stages must be analysed in detail to ensure that the production material meets all the requirements of the downstream stages.

Practical example 8: Extension of process stages

Eduard Merkle GmbH & Co KG operates a quarry in Michelreibershalde. In order to increase the yield and service life of the limestone deposit, the business initiated a process change. The limestone deposit used consists mainly of high-purity lime, which is however contaminated by naturally deposited clay minerals. These minerals hinder the further processing of the lime, as they have a negative influence on the colour, chemical properties and grain size of the lime powder. A pre-screening of the clay/lime mixture can remove the clays, but 80 % of the usable limestone is also filtered out. The lime is also exposed to the weather. Due to the moisture, the clays stick to the lime and separation is made more difficult. For this reason, a special screening machine has been installed which greatly accelerates the screening material. The moist rock can thus be sifted out by overcoming the adhesive force of the water. In addition, a heavy-duty screen was replaced by a roll screen, which further improved the separation of the fractions. This led to a reduction in waste from 20 % to 10 %. An installed drying drum separates the remaining 10 % of the clay/lime mixture. The rotary motion allows the clay to be rubbed off and released from the lime. The implemented measures together achieved conservation of approx. 50,000 kWh of electrical energy, 20,000 l of diesel fuel and 5 t of explosives per year. [68]

Practical example 9: Exchange of process stages

ElringKlinger AG, based in Dettingen/Erms, Germany, increased its resource efficiency by replacing one process step. The business produces metal sealing elements for the automotive industry. Mould sealing rings for exhaust gas turbochargers are manufactured by means of punching and bending processes. In this process, 90 % of the punching waste occurs due to the geometry of the sealing rings. Since the nickel-based alloy used for the sealing rings costs between 50 and 500 Euro/kg, the manufacturing process has been revised to reduce punching waste. Over a period of five years, the business developed a new process to replace the stamping process. In the new process, a narrow metal strip is shortened piece by piece to the desired length, formed into a ring and welded. The ring is then given the desired

[68] Cf. Schmidt et al. (2017), p. 58 - 61.

shape by the new roller burnishing process. In addition, control units have been integrated into the new process, which check the component directly after forming and sort it out if necessary. This reduces the amount of components that are further processed in the following process stages. By replacing the process stage, the business reduced the amount of nickel-based alloys used by approx. 21 t. In addition, further, non-quantifiable conservation results in transport and melting processes.[69]

Research project 2: Elimination of process stages

The DBU-funded project "Environmentally Friendly Process Chains in Cold Forming of Sections by Avoiding Wet Chemically Applied Conversion Layers" describes the new development of single-layer lubricants in cold forming. In this project, it was demonstrated that the use of alternative lubricants makes the energy-intensive and environmentally damaging process stage of zinc phosphate coating unnecessary. In this process stage, lubricant carrier layers of zinc phosphate are combined with reactive soap. This process consumes a lot of water and is characterized by a high use of chemicals. Due to the complexity of the process, the sheets are first treated and then temporarily stored. In addition, the phosphating sludge must be disposed of in a costly manner. As an alternative, lubricants based on molybdenum disulphide, polymer and salt wax were tested. The project showed that the lubricant on molybdenum disulphide can withstand loads in multi-stage processes very well and achieves similar results as zinc phosphate coatings. The use of the new single-layer lubricants means that the process stage of intermediate storage can be dispensed with. The treatment of the sheets is carried out in the cycle of the plant. Furthermore, the disposal of phosphate sludge is not required.[70]

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[69] Cf. Schmidt et al. (2017), p. 130 - 133.

[70] Cf. Ludwig et al. (2016).

3.2.3 Resource recycling and closed loop management

Residual materials, rejects, but also operating materials are produced in various process stages.[71] Internal recycling processes lead the so-called circulation materials in a cycle (Figure 14). On the one hand, material can be saved, but on the other hand, additional energy and resources must be used for the preparation of recyclable materials.[72]

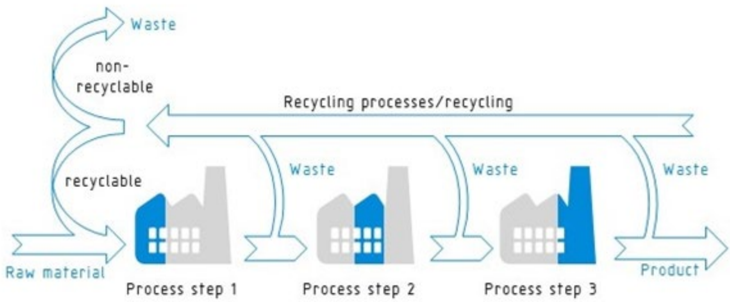

Figure 14: Schematic represenation of the internal recycling

In order to keep the costs for recycling as low as possible, production processes should be optimised and scrap rates reduced. Unavoidable rejects should be sorted as accurately as possible in order to make the return to the production process technically simple and resource-poor. If the business lacks the necessary capacity to carry out internal recycling processes, or if the scrap quantities are so low that an installation is not profitable, it can be recycled externally. In addition, it can be examined whether neighbouring businesses can in turn use the residual materials produced as starting materials for their production.[73]

[71] Cf. Schmidt et al. (2017), p. 36.

[72] Cf. Liesegang and Sterr (2003), p. 266.

[73] This measure is described in more detail in the brief analysis "Resource Efficiency through Zero Emission Industrial Areas". Die Kurzanalyse ist abrufbar unter https://www.ressource-deutschland.de/publikationen/kurzanalysen/

Practical example 10: Resource recycling and closed loop management

The company Rhein Chemie Additives, a subsidiary of the Lanxess Group, manufactures a component for the production of polycarbonates at its Mannheim site. For the production of this component phenol is used as reactant in a batch process. The production process involves a multi-stage equilibrium reaction. Here the phenol is used in excess. More phenol is added than is actually converted. Thus phenol-containing residues remain after the process. Due to the toxicity of the residues, disposal in a sewage treatment plant is not permitted and chemical separation of the residues is hindered by other dissolved substances. So far, disposal has therefore been carried out via cost-intensive hazardous waste incineration.

Since the residues are recyclable, but no process solutions were available on the market, Rhein Chemie Additives modified the existing process infrastructure without installing additional distillation columns. The modified processes make it possible to separate the phenol from the waste water and return it to the process. The closed phenol cycle saves around 150 tonnes of phenol per year. In addition, 150 t of waste water and twelve tankers, which supplied the phenol previously required, are no longer required. This corresponds to approx. 1000 l diesel per year.[74]

Practical example 11: Resource recycling and closed loop management

Brugger GmbH manufactures products with magnetic systems. These include gripper units as well as decoration and organization magnets. To protect the magnets themselves from environmental influences, they are sheathed with a thermoplastic elastomer. This coating is applied in-house by injection moulding. A large part of the plastic sprue is disposed of after the injection moulding process, only a small part is reprocessed by a plastic mill. This process step causes strong dust generation and deteriorates the material quality. For this reason, a regranulator was installed which melts the sprue residues homogeneously and presses them into an extruded form. The plastic strand is then crushed into uniform granules, which can easily be

[74] **Cf. Schmidt et al. (2017), pp. 102 - 105.**

added to the primary material. With this measure the business saves approx. 7 tonnes of plastic per year. This corresponds to around 4,200 euros.[75]

3.2.4 Condition monitoring and predictive maintenance

Condition monitoring is the real-time monitoring of the condition of systems. The data is recorded by sensors during operation, collected centrally and evaluated. This data acquisition allows conclusions to be drawn about the current operating status of the plants, so that the current operation can be optimised (Figure 15).[76]

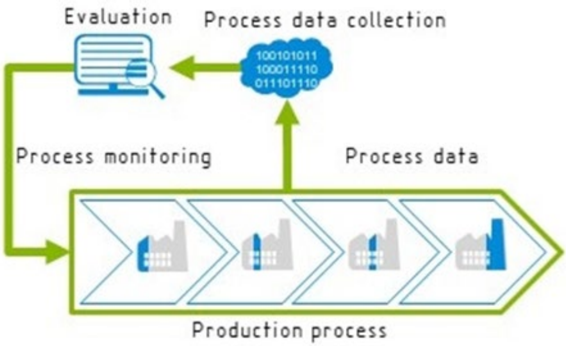

Figure 15: Schematic structure of condition monitoring

Predictive maintenance goes beyond mere monitoring and stands for the predictive maintenance of technical systems through the use of sensors and information technology.[77] By collecting data and evaluating them during operation, the remaining service life of equipment and tools is determined. Maintenance intervals can thus be set very precisely. This avoids unnecessary maintenance due to too early replacement and also minimises downtimes due to defective and worn components. The data acquisition is carried out by sensors at the machinery in real time and collected by a network at a central location. The data evaluation is carried out by suitable algorithms, which

[75] Cf. Schmidt et al. (2017), pp. 122 - 125.
[76] Cf. Shebek (2017), p. 157
[77] Cf. VDI Zentrum Ressourceneffizienz (2015b), p. 25

recognize certain patterns in the data and can thus interpret an error image. The error images are then used to predict downtime. Until now, the data have mostly only been used for the current status measurement of the running process.[78]

A possibility of process improvement also exists in cooperation with machine suppliers with whom production processes are set up. Selective data transfer can contribute to the optimisation of process plants in the long term (Figure 16).[79]

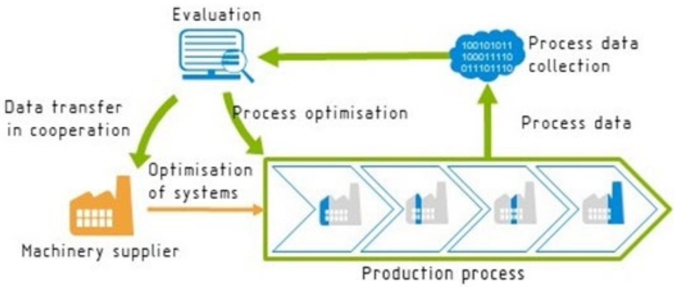

Figure 16: Schematic structure of predictive maintenance

Practical example 12: Condition monitoring and predictive maintenance

Sicos BW GmbH is a spin-off of the TU Stuttgart and the Karlsruhe Institute of Technology (KIT). The business, which is funded by the Baden-Württemberg Ministry of Science, Research and the Arts, provides cost-neutral advice to SMEs on the topics of simulation and big/smart data.[80] A consulting service consisted of data preparation for Hermle AG. In this case, status data of the machinery from twelve months were evaluated. Axis states of machining centers were examined and divided into travel profiles. This would make it possible to identify potential for possible remote maintenance. In a second step, learning methods were used which were then able to use the data to

[78] Cf. Feldmann et al. (2017), p. 3.
[79] Cf. Shebek (2017), p. 158.
[80] Cf. Karlsruhe Institute of Technology (2017).

make supportive predictions. Automatic data evaluations of the machinery states were implemented, with the help of which machine failures could be minimised.[81]

Practical example 13: Condition monitoring and predictive maintenance

An example of the cross-value-added cooperation in condition monitoring, which is based on a product instead of a production process, is the cooperation between CMC GmbH and wind farm operators. Here, turbine data from wind farms are continuously recorded and sent to the business headquarters in Kiel. This is where the data is collected and evaluated. Any errors that occur are identified by the employees and reported to the wind farm operators. The collected data is also used for scheduled maintenance. In this way, it can be determined in advance whether the maintenance can be carried out on site or must take place at the maintenance technician's works. In addition, the components to be replaced can be ordered in advance so that there are no delays during maintenance. The downtimes could be halved by these measures.[82]

3.2.5 Shared use of resources (business pools)

The possibility of sharing resources across several businesses offers great resource efficiency potential. For example, machinery can be optimally utilised through joint use, as unnecessary downtimes on the part of the providing business are avoided. The user side is better able to cushion short-term fluctuations in the order situation through the offer, without having to make a cost-intensive purchase of new machinery.

The sharing of resources is also called "Sharing/Collaborative Economy". The idea here is that in a merger of businesses, none of the businesses provides a complete machine park, but only a part of the necessary machinery owns. For work that cannot be done by the user, a business in this network is then commissioned. This reduces overall costs and optimises machine utilisation.

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[81] Cf. SDSC BW (2017).

[82] Cf. VDI Zentrum Ressourceneffizienz (2017c).

Figure shows the cooperation schematically. Business A partially outsources the production to businesses B, C and D. Inversely, these three partners can have parts of their production carried out in business A [83]

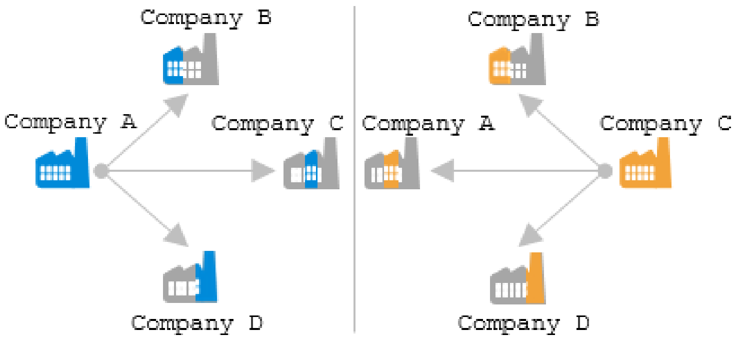

Figure 17: Scheme of a collaboration of several businesses with outsourced production from the point of view of two participating businesses

Practical example 14: Shared use of resources

A master carpenter from Hildesheim is relying on cooperation with other businesses for the production of wooden furniture. Some of the orders can be carried out directly with the customer. However, 60 % to 70 % of orders are in the furniture manufacturing sector. This requires a workshop with appropriate equipment, which the master carpenter does not have. Through cooperation with five other joineries in the area, the master joiner has the necessary machinery at his disposal. For incoming orders for furniture production, free workshop or machinery capacity of the cooperating joineries is provided by means of E-mail or telephone. If a positive feedback is given in one of the joineries, the master joiner can rent a room there. Invoicing is carried out at a fixed hourly rate. This allows the master carpenter to keep his costs low and at the same time has a large selection of different machinery at his disposal.[84] The cooperating joineries benefit from a high machine utilisation as well as rental income.

[83] Cf. Christmann (2016).
[84] Cf. handwerk.com (2018).

3.2.6 Cascading use

Cascading use stands for the use of raw materials and products in successive steps. The goals of cascading use are to increase resource efficiency and reduce waste generation. Raw materials and products are kept in the system for as long as possible so that a high level of added value is maintained. A one-off conversion of a raw material into an end product with subsequent recycling describes a single-stage cascade. If the end products are recycled several times, this is referred to as multi-stage cascading use.[85]

Cascading use is usually used in the field of biomass utilisation (Figure 18). Various types of raw materials have potential for cascading use. These include wood, paper, bio-based plastics and textiles. Roundwood is first processed into solid wood, which can then be pressed into chipboard after regular use[86]. Paper can then be extracted from this and converted into chemical products in the penultimate cascade stage. The last step is the energetic utilisation. In principle, this can be carried out after each stage, which significantly shortens the cascades.

85 Cf. Cosmol et al. (2012), p. 10.
86 Cf. Cosmol et al. (2012), p. 24.

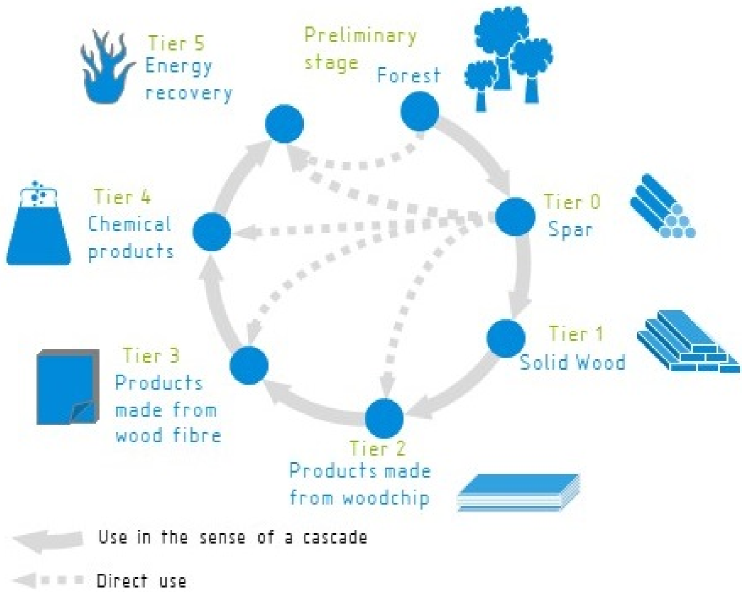

Figure 18: Schematic sequence of biomass cascading use [87]

Practical example 15: Cascading use

In a project funded by the Nova Institute for Political and Ecological Innovation in Hürth, Germany, an attempt is being made to use fermentation residues from biogas plants as wood products. In the model experiment, for example, the inorganic nitrogen components are first removed from the digestate during the process. The purified cooking mass is then used as a raw material for the production of chipboard and fibreboard of medium or high density. The fibreboards are then used as the raw material for the production of laminate flooring. The model test has shown that the process saves up to 386 t CO_2 equivalents per year in the model case. [88]

[87] According to Höglmeier et al. (2015), pp. 335 – 346

[88] Cf. Essel et al. (2015).

4 DATA AND MATERIAL FLOW ANALYSES IN THE VALUE CHAIN

4.1 Linking data flows with integrated engineering

In addition to vertical and horizontal integration[89], end-to-end engineering is one of the three cornerstones of Industry 4.0. For cross-value-added networking of actors and means of production, not only physical networking but also the linking of the associated data and data flows must be guaranteed without loss.[90] Integrated engineering enables this fast and targeted access to the right data at the right time.[91]

The data flow between value added stages can be divided into three classes: the product-related data flow, the production plant-related data flow and the order-related data flow (Table 4).

Table 4: Examples of continuous information flows between value creation stages[92]

Data and information flow		Advantages
Example for the PRODUCT-RELATED FLOW of DATA		
from product development	to the plant construction	- early selection and adaptation of suitable production processes - Safeguarding in product development specified properties - Mapping of production steps on the basis of product (line) data
Example for the PRODUCTION PLANT-RELATED FLOW of DATA		
from plant construction	to the supplier of plant components	- cross-industry compatibility of the plant construction specifications is ensured - facilitated acceptance of system specifications
Example for the ORDER-RELATED FLOW of DATA		
from sales	to production planning (operative) and production	- Checking customer requirements for available production capacities - Implementation of customer wishes without loss of information and without delay - precise capacity planning through information on the order situation

89 In the sense of Industry 4.0, vertical integration describes the networking of means of production at all business levels, while horizontal integration encompasses the networking of all machinery, equipment and employees at a business level with the value chain, i.e. between businesses. (Schebek et al. (2017), p. 19.

90 Cf. Drumm et al. (2016), p. 2.

91 Cf. Process (2016).

92 Cf. Drumm et al. (2016). pp. 5 - 8.

Between the value-added stages of one or more businesses as well as between customers and businesses, data information is transmitted in an optimised manner via continuous engineering. A prerequisite for this are identical file formats in order to guarantee transfer compatibility. AutomationML (Automation Markup Language), for example, is such a file format and was developed as a free standard for storing and exchanging plant planning data.[93]

4.2 Material flow analysis and computer-aided simulation methods

4.2.1 Analysis of material flows according to VDI 2689

The determination of resource efficiency potentials across value-added stages requires an analysis of the material flows along the value chain under consideration (Figure 1). Changes in the production process and location, changes in production processes, high costs and problems with warehousing and material procurement can be detected and analysed via a material flow analysis in favour of resource optimisation. Characteristic values that are examined in a material flow analysis are products, quantities, surface areas/paths, processes/sequences, costs and times.[94]

After defining a target, a material flow analysis is performed in eight steps. As a result, different solutions are proposed, from which the most favourable solution is chosen. This must be implemented and compared with the original objective (Figure 19).

[93] Cf. AutomationML (2018).
[94] Cf. VDI 2689: 2010-05, p. 3.

Figure 19: Flow diagram of a material flow analysis [95]

Methods for analysing material flow and collecting data include the 7W method and the use of material flow matrices. The 7W method uses seven question words (what, where from, where to, why, how often, how much, how long) to describe and catalogue objects in the material flow. Material flow matrices link all operating divisions and the respective material flow intensity with other operating divisions. The data recorded in this way can then be transferred to operating plans in order to obtain a concrete representation of the material flow. VDI 2689 also contains checklists with which important information on material flow planning can be derived from general business data. [96]

4.2.2 Simulation of material flows according to VDI 3633

A computer-aided simulation helps to model and take into account the growing complexity of production and goods traffic as well as the additionally

[95] According to VDI 2689: 2010-05, p. 6.
[96] Cf. VDI 2689: 2010-05, pp. 11 - 12.

increasing requirements on product and process quality. Simulation means modelling a dynamic, technical system in order to draw conclusions about a real system. Thus, solutions for problems can be viewed in simulated models and tested for feasibility before implementation without large investments.[97]

The simulation can be applied along the entire value or supply chain, i.e. within and across businesses. They are used in the planning, implementation and operating phases of processes (Table 5).

Table 5: Fields of application and possible uses of simulation[98]

Fields of application	Possible uses
Planning stage	Securing and optimising processes
Existing plants	Improvement of existing plants by optimizing the application and identification of weak points, investigation of the influence of changing variables on the running process
New planned plants	Proof of the functional concept of the plant, optimisation of the plant dimensioning
Realization phase	Running in of the plant and preparation of the employees
Performance test	Review of the plant performance with systematic increase of the utilisation up to the capacity limit
Variability testing	Testing the system behaviour by changing process parameters and system states during operation, changing requirements during the construction phase of the system
Staff training	Training of employees at the plant and training in case of malfunctions and emergencies
Operating phase	Evaluation of the effects of process variants and incidents on the plant
Variant analysis	Investigation of the operational procedure for modification of products
Emergency investigation	Testing the impact that emergencies or immediate actions have on the ongoing process
Variant check	Analysis of possible changes to product variants for future order processing

The simulation process can be divided into three phases: the preparation phase (points 1 - 3), the action phase (point 4) and the evaluation phase

[97] Cf. VDI 3633 Sheet 1: 2010-12, p. 3.
[98] Cf. VDI 3633 Sheet 1: 2010-12, pp. 6 - 9.

(points 5 - 6). Before the simulation, the actual problem must be clearly formulated in order to derive a suitable task and objective (

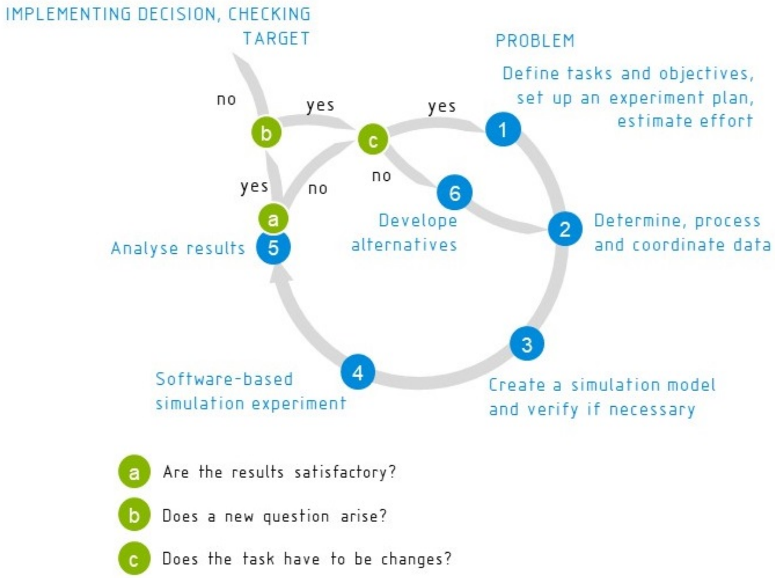

Figure 20: Simulation sequence[99]

Simulation or modelling is used to create a simplified pattern of the system to be mapped. This model is reduced to the necessary process steps. The level of detail of the model contributes significantly to the scope of the simulation, therefore it should be checked exactly which process parameters are necessary. The advantages of simulation lie in targeted process optimisation without interrupting ongoing operations and in the rapid familiarization of employees with new systems.

[99] According to VDI 3633 Blatt 1: 2010-12, p. 19.

5 CURRENT AND FUTURE VALUE CREATION STRUCTURES

5.1 Selected instruments of value networks

The shift away from original supply chains (linear supply chains) towards value-added networks is highly topical.[100] This trend will continue to intensify in the future, driven by globalization, the emergence of new technologies at shorter intervals and product individualisation. Businesses with immobile production conditions will have to adapt to a certain extent to flexible economic structures in the foreseeable future (Figure 21)[101]

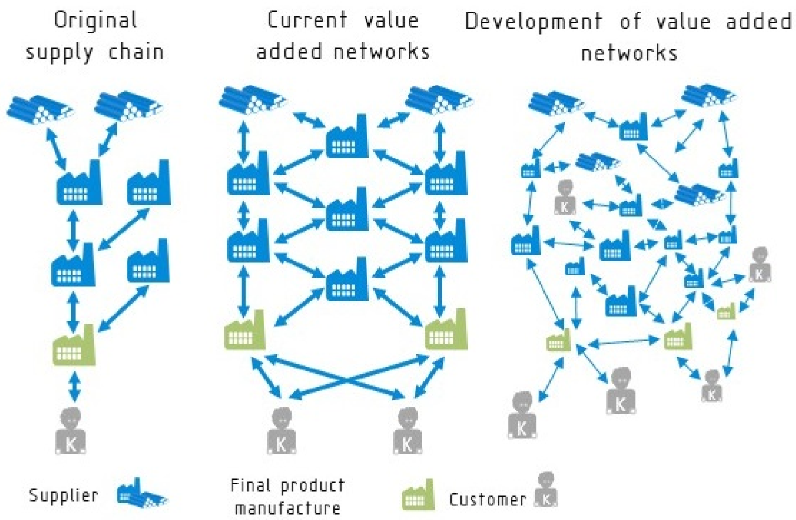

Figure 21: Value added structures of supply chains [102]

Shifts along the value chain and an increasing complexity of value-added structures have been observed in many industries in recent years. The core competences of businesses are becoming more and more specialised, so that the small-scale value-added structures must be used and an intensive

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[100] Cf. Walther (2010), pp. 1 - 4.

[101] see Walther (2010), pp.. 1 – 4.

[102] Cf. Schellmann (2012), p. 9.

exchange between the value-added stages must be accelerated.[103] Value-added networks are defined as "a network of businesses in which services are provided on a cross-business basis with a view to making profit"[104]. The necessary interaction between businesses opens up further resource efficiency potentials, cost savings and competitive advantages, as the examples in Chapter 3 shown. In these examples, instruments are used that enable the linking of value-added stages or force the change to value-added networks. Figure 22 summarises the instruments listed in Chapter 3, but is not exhaustive (middle box).

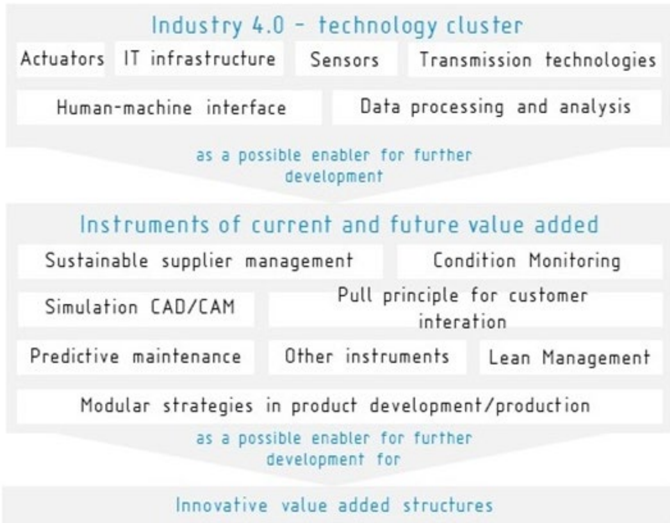

Figure 22: Selection of instruments for future value added networks[105]

In particular, the technology clusters of industry 4.0 are essential enablers for further developing and optimising the instruments of future value-added networks (Figure 22, top box). For example, in predictive maintenance, the process capability (of production processes) is controlled on the basis of real-

103 Cf. Kaiser (2018), p. 60.
104 Schellmann (2012), p. 9.
105 According to Bernardy (2017), Slide 8.

time data. The use of sensors results in faster, more accurate and more comprehensive data sets for the actual state measurement, which can also be used to optimise the system (Chapter 3.2.4).

Industry 4.0 means connecting the digital world of the Internet with the conventional processes and services of the manufacturing industry.[106] The six technology clusters as a basis for the implementation of Industry 4.0 are characterised as follows (Figure 22):[107]

- Actuators: Manipulation of a system under consideration by hardware or software (e.g. by robots)
- Data processing and analysis: Generation of information and knowledge from data (e.g. through evaluation software)
- Sensor technology: Data generation and data acquisition (e.g. by sensors)
- Transmission technologies: Transmission of raw data (e.g. LAN and WLAN networks)
- IT infrastructure: Basic supply for the exchange, storage and transport of information and knowledge (e.g. through clouds)
- Man-machine interface: Interaction and explicit communication between man and machine (e.g. through tablets or smartphones)

These technology clusters of industry 4.0 and, building on this, the instruments for linking value-added stages can guarantee the necessary characteristics of value-added networks in their entirety or in individual applications. These include, but are not limited to flexibility, acceleration, transparency, a decentralised structure of supply chains, individualisation of orders and recycling of materials. At the same time, this is an important starting point for tapping untapped resource efficiency potentials and producing in future in line with a sustainable circular-flow economy.

106 Cf. BMWi (2015), p. 7 in Schebek et al. (2017), p. 18.
107 Cf. Bernardy (2017), slide 8.

5.2 Outlook: Development of digital platforms

Against the background of industry 4.0, digital platforms will become a central component of future value-added structures. They form a new variant for networking businesses and their value-added stages.

An increasing number of markets are now functioning bilaterally: Customer groups are networked through one or more digital platforms.[108] Digital platforms are described as "Internet-based forums for digital interactions and transactions".[109] Among the best known examples in the b2c area are Amazon and Alibaba.

This development is also finding its way into the b2b sector via the digital transformation in the industry. New economic structures for small and medium-sized businesses, among others, will develop here in the future. Especially in production, digital platforms can fundamentally change customer-supplier constellations and at the same time open up new business models (Figure 23).[110]

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108 Cf. Baums (2015), p. 15.

109 Cf. BMWi (2017), p. 21

110 Cf. Engelhardt et al. (2017), p. 9.

Figure 23: Networking through digital platforms

Businesses are recommended to deal with the development of digital platforms, as the interface between internal and external business areas will increasingly be served by these in the future.[111] According to a survey conducted by Bitkom e.V. in 2017, over 50% of the businesses surveyed stated that they did not know the term digital platform. Of the industrial businesses that are familiar with the concept of digital platforms, around two thirds considered the topic to be irrelevant for their own business's future operations. It is predicted that digital platforms will establish themselves in almost every industry. 112 The reason for the constant further development of digital platforms lies in their advantages:[113]

- Digital platforms reduce transaction costs by creating an exchange location between demanders and suppliers.
- Digital platforms create strong network effects.
- They enable a more flexible production (keyword lot size 1).

111 Cf. Engelhardt et al. (2017), p. 10.
112 Cf. Streim and Meinecke (2018).
113 Cf. Baums (2015), p. 17.

- They form the basis for efficient innovation management.

Resource efficiency potentials can be tapped via digital platforms, i.e. new value-added structures between businesses. The opportunities and obstacles are currently still being discussed and researched by experts.

In particular, the protection of sensitive business data is in focus. Data security must be reorganized in the context of the increasing networking by industry 4.0. Technologies that promise secure data handling include the blockchain. Encrypted data blocks are stored one after the other in a parallel database.[114] Another system is, for example, the IND2DUCE technology developed by Fraunhofer IESE and Fraunhofer IOSB, TU Munich and other businesses. This technology is used to define security policies that precisely define access rights to information.[115] These data security systems are particularly important for the development of instruments such as predictive maintenance, condition monitoring (Chapter 3.2.4), lean management (Chapter 3.1.4) or customer and supplier integration (Chapters 3.1.1and 3.1.2).

If these IT-based security methods are established, it will be possible to take advantage of digital platforms and other industry 4.0 tools. At the same time, measures for the efficient use of resources can be addressed, which can additionally optimise costs and thus increase added value.

114 Cf. young and Schmitz (2016).
115 Cf. Jung and Schmitz (2016).

6 CONCLUSION

Resource efficiency measures along the value chain can open up great savings potential. Actors who coordinate their productions and form cooperations can reduce their material and energy consumption, reduce costs and generate additional competitive advantages or even new business ideas.

The brief analysis shows that resource efficiency measures that are implemented across value creation stages can achieve a high degree of efficiency. In supply chains, for example, the integration of suppliers into business processes can promote product and process quality and streamline organisational processes. In addition, special requirements can be communicated and controlled to the supplying cooperation partners. A business thus reduced its own production waste by coordinating with the supplier. The savings amounted to around 48,000 euros per year. [116]

Customer integration is also playing an increasingly important role. Customer-specific configurable products will be increasingly in demand in the future. The production towards batch size 1 and thus the implementation of a flexible, customer-oriented production is to be considered for future business processes. The development of modular systems can be helpful here. This makes it possible to manufacture different product variants from the smallest possible number of components. One business estimated that this resulted in around 20 % cost savings in development, sourcing and production. [117]

Cross-business cooperation is a central component of resource efficiency measures that work across value-added stages. Within a business, such cooperation between business divisions can also point out resource efficiency potentials. If cross-departmental employee and project teams are formed, existing know-how can be bundled and, in particular, interfaces between the divisions can be analysed. An example of a business showed that a cross-departmental employee or project team identified resource efficiency potentials amounting to approx. 44,000 euros in the joint analysis of business processes.

116 Cf. Schmidt et al. (2017), p. 89 - 99.

117 Cf. Industry Scoreboard (2015).

In addition to cooperation, process analysis is an essential prerequisite for comprehensive measures along the value chain. Software for the simulation of continuous process chains supports data acquisition. The measured and evaluated data can be used to analyse and optimise the production process in real time. In one business, process analysis using a new data acquisition tool resulted in savings of approx. 400,000 euros.

In particular elements of digitization, such as predictive maintenance, smart factories or cloud computing, are perpetuating the change towards new value-added structures. This is where resource efficiency potentials lie, which can be tapped through digital interaction between businesses. Developments in Industry 4.0 are rapid, so businesses should follow them continuously and define their own implementation strategies. For example, digital platforms are becoming more and more interesting in the b2b area, as the interface between internal and external business areas can be served by them.[118]

The brief analysis shows that the linking of value creation stages is an important measure to save material and costs. At the same time, there is a general economic shift towards new, more complex value-added structures. Businesses, in particular SMEs as part of the value chain, can use this structural change to profit from further resource efficiency potentials that can be tapped across value-added stages.

[118] Cf. Engelhardt et al. (2017), p. 10.

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Im Auftrag des:
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NATIONALE KLIMASCHUTZ INITIATIVE