industrielogistik

Master Thesis

Management of variant variety in the context of Industry 4.0

submitted to the

University of Leoben

at the

Chair of Industrial Logistics

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Leoben, 23.01.2019

Affidavit

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume.

Aiping Zhang

Leoben, 23.01.2019

Acknowledgement

This thesis gives me the opportunity to thank the people who contribute to the success of this work.

Special mention goes to my advisor Univ.-Prof. Dr. Helmut Zsifkovits for the professional and constructive manner in which he guided and supported me during this thesis.

I also would like to thank my mum and dad for almost unbelievable support. They are the most important people in my world and I dedicate this thesis to them. Finally thank to my husband Liangliang Shang, for his kind patience, encouragement, and support through it all.

Kurzfassung

In den letzten Jahren fordern Kunden zunehmend Produkte, die individuell auf ihre Bedürfnisse zugeschnitten sind und wollen diese auch in kürzester Zeit erhalten. Dadurch ist die Produktvielfalt in vielen Unternehmen kontinuierlich gestiegen.

Industrie 4.0 heißt die vierte Technologiegeneration in der Fertigungsgeschichte, die einer Technologiewende zugeschrieben wird. Industrie 4.0 ermöglicht eine schnellere Reaktion auf Kundenbedürfnisse als es derzeit möglich ist. Es verbessert die Flexibilität, Geschwindigkeit und Produktivität der Produktionsprozesse. Dies ermöglicht eine neue Ebene von kundenindividueller Massenproduktion, da mehr Industrielle Produzenten in Industrie 4.0 Technologien investieren, um ihr Angebot zu verbessern und anzupassen.

Diese Arbeit befasst sich mit dem Management von Vielfalt mittels Industrie 4.0, um herauszufinden, ob es möglich ist, dass Industrie 4.0 die Möglichkeit bietet die Vielfalt zu erhöhen, und ob es Einschränkungen bei Industrie 4.0 für die Variantenvielfalt gibt.

Zu Beginn der Arbeit werden die allgemeinen Ursachen einer steigenden Variantenvielfalt beschrieben. Diese zeigen, dass die Zunahme der Produktvarianten zusätzliche Kundenanforderungen unterstützt und neue Kunden erschließt. Im Gegensatz zu den Vorteilen ergibt sich aus dieser Variantenvielfalt ein Kosteneffekt. Diese Masterarbeit zeigt viele Methoden und Strategien für das Variantenmanagement und verschiedene Technologien in Industrie 4.0 auf. In den letzten beiden Kapiteln dieser Arbeit werden die Vorteile und Einschränkungen von Industrie 4.0 für die Variantenvielfalt erläutert.

Abstract

In recent years, customers increasingly demand products that are individually customized to their needs and in addition they want to have it in shortest time. Therefore, the variety of products has risen continuously in many companies.

Industry 4.0 is the name of the fourth technology generation in manufacturing history, which is attributed to a technology revolution. Industry 4.0 allows a faster response to customers' needs compared with the possibilities today. It will improve the speed, flexibility and productivity of the production processes. This will enable a new level of mass customization as more industrial producers invest in Industry 4.0 technologies to improve and customize their products.

This thesis is concerned with the management of variety in the context of Industry 4.0, in order to find out if it is possible that Industry 4.0 offers the opportunity to increase variant variety and whether there are restrictions to increase the variant variety within Industry 4.0.

At the beginning of the thesis the general causes for a rising variant variety are described. These shows, that the increase of the product variants supports additional customers' requirements and leads to new customers. In contrast to these benefits, a cost effect results from the variant variety. This thesis also shows many methods and strategies of variant management and various technologies in Industry 4.0. In the last two chapters of this thesis the benefits and restrictions of Industry 4.0 for variant variety are presented.

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1 Introduction

1.1 Initial situation

Nowadays customers are unwilling to purchase products that do not fully meet their needs. For instance, various customers are aware that they could request fridge that accord with the style and color of their kitchen, and therefore are unwilling to receive a "standard" refrigerator in white.[1] An essential competitive factor for companies that enable them to exist in the marketplace is variant variety.[2]

An important way of fascinating customers is to offer a variety of attributes in products, but it tends to increase the cost of complexity and management.[3] The growth of product variants allows developing new client base and market segments, but is also related with increased costs, which are not easy to estimate using traditional calculation methods.[4]

Industry 4.0 is a collective name of value chain organization technologies and concepts. It will realize new modus of customization based on the concepts of technologies such as big data analysis, Radio Frequency Identification (RFID), additive manufacturing, cyber-physical system and the Internet of Things. Direct input from customer into the design will allow companies to produce individualized products with lower costs and shorter cycle-time than the products that correlated with mass production and standardization.[5]

This thesis is concerned with the relationship between variant variety and Industry 4.0. It focuses on if it is possible that Industry 4.0 offer the opportunity to increase variant variety and whether there are restrictions of increasing variant variety in Industry 4.0.

This raises the following research questions:

- How does variant variety and Industry 4.0 behave?
    - What are the main reasons or what are the primary drivers of increasing variant variety?
    - Does Industry 4.0 offer the opportunity to increase variety?
    - Are there restrictions of increasing variant variety in Industry 4.0?

[1]Cf. Forza, Salvador (2007), p.6
[2]Cf. Eurisch (2003), p.3
[3]Cf. Pil, Holweg (2004), p.394
[4]Cf. Eurisch (2003), p.1
[5]Cf. Wang, Ma, Yang, Wang (2017),p.2

1.2 Structure of the thesis

Chapter 1 introduces the topic variant variety in the context of Industry 4.0. The initial situation and the objective of the thesis are explained. Chapter 2 defines the terms variant and variant variety, the external and internal causes of the increasing Variant variety and the effects of increasing variety in a company. Variant management and its approaches is the subject of the third chapter. In the following detailed explanation of the numerous methods and strategies of variant management. The conceptual framework of Industry 4.0 and its important technologies are the subject of the fourth chapter. The fifth chapter represents the main chapter of this thesis. It contains the benefits of Industry 4.0 for variant variety. In the sixth chapter, restrictions of Industry 4.0 for variant variety are discussed. The last chapter concludes the thesis.

2 The concepts for variant variety

In order to dominate the increasing variety of product variants, it is necessary to know and understand the reasons and effects. Before describing the thesis in further detail, product variant should first be defined.

A product variant deals with the discrete product that is provided to the customers. Product variants are a series of end products that have at least one different characteristic value and are part of a variant family.[6]

Fisher et al. suggest that the definition of product variety is in two dimensions: "The breadth of products that a firm offers at a given time and the rate at which the firm replaces existing products with new products".[7]

Martin et al. define two types of variety: [8]

- Spatial variety: spatial variety represents the variety that a company supplies the marketplace at a certain time point.
- Generational variety: generational variety indicates variety span future generations of products.

Product variety is defined as the sum number of products, product variants, or functions that a producer offers to its customer. The designers have to concentrates on the major features on the basis of the customer demands.[9]

Lindemann et al. demonstrate that variant variety can refer to:[10]

- Product variants that the customer can see from the outside (for example the changes in size, performance, materials, or the external designs).
- Part and Assembly variants which are internal, in diverse shapes or assembly and manufacturing approaches.

Lingnau defines the following categorization on the basis of its characteristics shown in figure 1:[11]

- Technical

[6]Cf. Roy, Evans, Low, Williams (2011), p.1939-1950
[7]Fisher, Ramdas, Ulrich (1999), p.297
[8]Cf. Martin, Ishii (1996), p.18-22
[9]Cf. Kamrani, Azimi, Al-Ahmari (2013), p.114
[10]Cf. Ehrlenspiel,Kiewert, Lindemann (2007),p.265
[11]Cf. Lingnau (1994), p.26

- geometry variants
  - ✓ Shape variants (variation in shape)
  - ✓ Dimension variants (different size)
- Material variants (different materials for the identical parts), exceptional case is surface variants (variation in surface, e.g., texture and color)
- Technology variants (changes in processing and processes types within production)

- Structural
  - Different components can compose multi-part variants (structural variants). There are two alternatives, product components (must variants) and additional components (can variants).

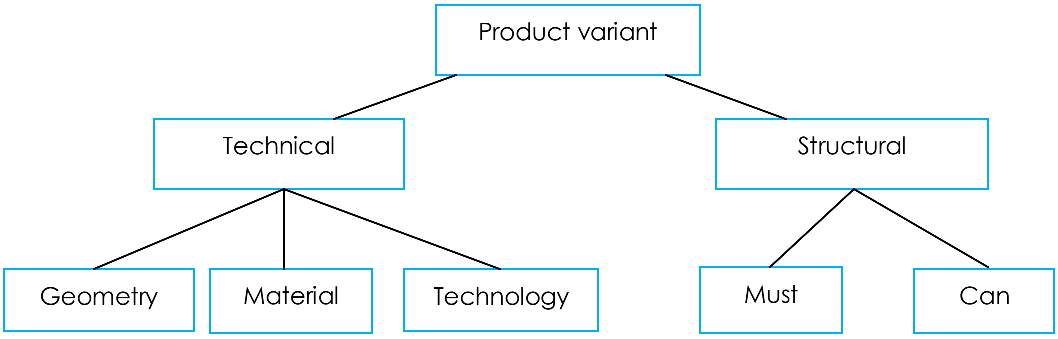

Figure 1: Structure and characteristics of product variants.[12]

The causes of the variant variety can be divided into two categories: internal and external causes, as seen in figure 2. The origin of internal causes is situated in their own company. It means that these causes can be influenced by the company. It is able to avoid the causes of variety by itself or to restrict their influences in terms of variant variety. The external causes are situated outside the sphere of influence of the company. The companies have to accept them and fit them to the best of their ability. A part of the company environment is formed by these causes for the company.[13] Individual causes mentioned above will be discussed in the following sector.

[12]Cf. Eurisch (2003), p.6
[13]Cf. Kestel (1995), p.18

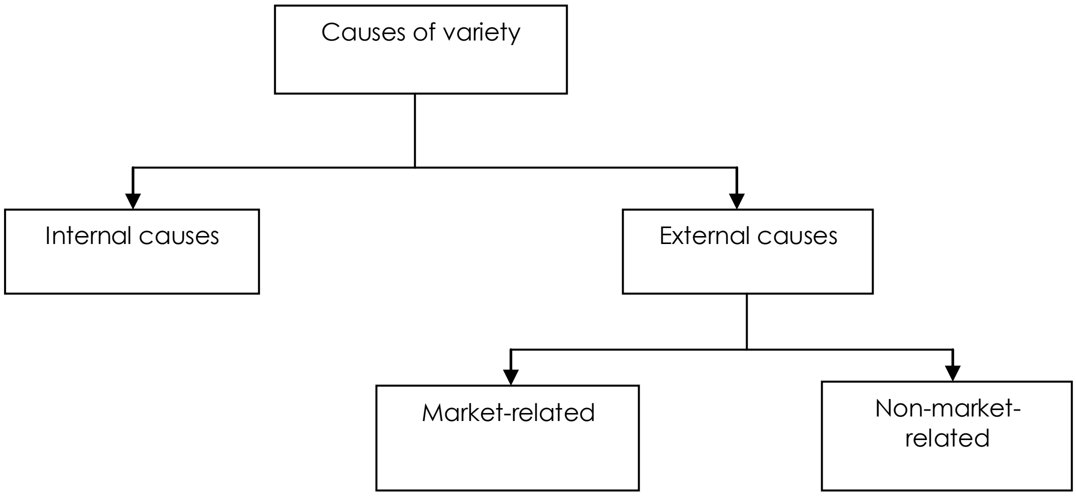

Figure 2: Differentiation of the causes of variant variety.[14]

2.1 External causes of the growth of variants

The external causes can be divided again into two categories: market-related and non-market-related causes. The market-related causes are constrained by the laws of the market, that is to say they are constrained by the fluctuations of the market and they are normally not easy to forecast. Non-market causes have to face this rapid change. These causes are more predictable and therefore are able to be better considered in long-term business decisions.[15]

Market-related causes

The origins of the market-related causes are outside the sphere of influence of the company.[16] Figure 3 shows the main market-related causes of variety.

The common shift from supplier to buyer market and the saturation phenomena of various markets has intensified company's trend towards individual products and issue solutions.[17]

Only those companies that constantly and accurately satisfy the customers' requirements are able to exist in the global competition. The accelerated customer orientation, however, can result in an explosion of variants and considerable economic issues of the company.[18]

[14]Adapted from Kestel (1995), p.19
[15]Cf. Kestel (1995), p.19
[16]Cf. Kestel (1995), p.23
[17]Cf. Eurisch (2003), p.3
[18]Cf. Eurisch (2003), p.3

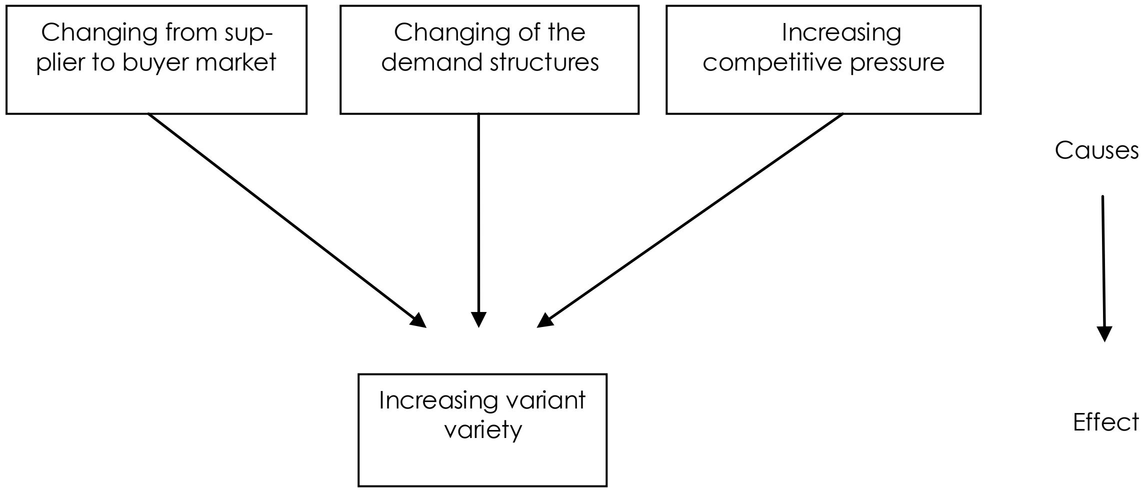

Figure 3: Market-related causes of variety.[19]

Non-market-related causes

Figure 4 shows the major non-market-related causes of variety. As already mentioned, the non-market causes are not constrained by the market laws. That is to say, they are not like market factors, which can be changed fast and unpredictable.[20]

Shortened product life cycle, technological development and lost technology superiority in the global market are additional drivers for the increase in new product variants.[21]

New materials and production processes are brought by the technological change or development all the time. Then the products are usually provided both with preserved and the latest materials. This leads to further variants, and consequently increases the existing variety.[22]

Internationally active companies additionally need to consider country-specific differentiations such as standards, polices, language or culture and thus the scope of their variants is extended again.[23]

[19]Adapted from Kestel (1995), p.23
[20]Cf. Kestel (1995), p.25
[21]Cf. Eurisch (2003), p.4
[22]Cf. Kestel (1995), p.25
[23]Cf. Eurisch (2003), p.4

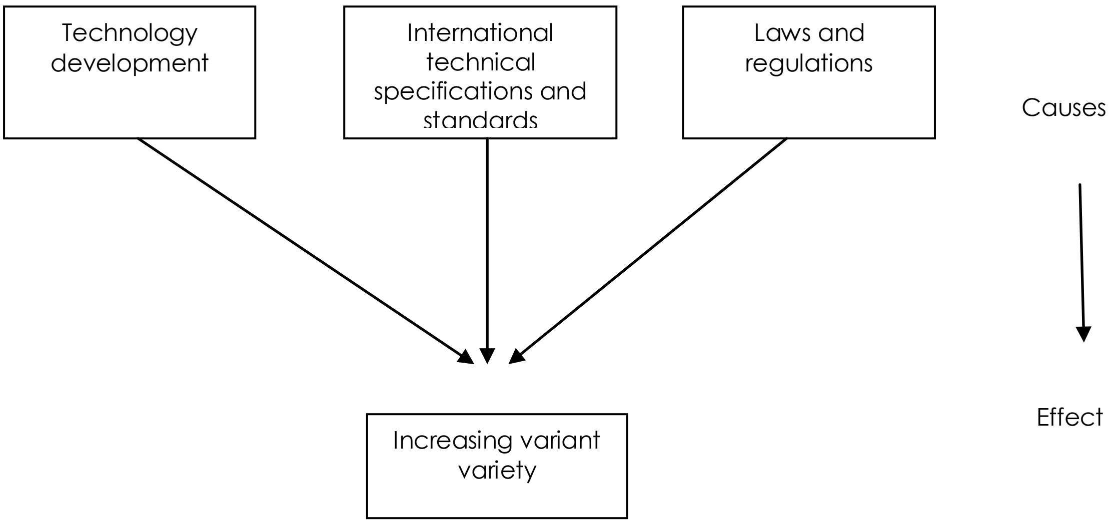

Figure 4: Non-market-related causes of variety.[24]

2.2 Internal causes of the growth of variants

As already described, the internal causes of company are affected by the company. Figure 5 shows the internal causes of variety. The strategy of the company, which is decided by the leadership, can result in a growth of the variant variety. [25]

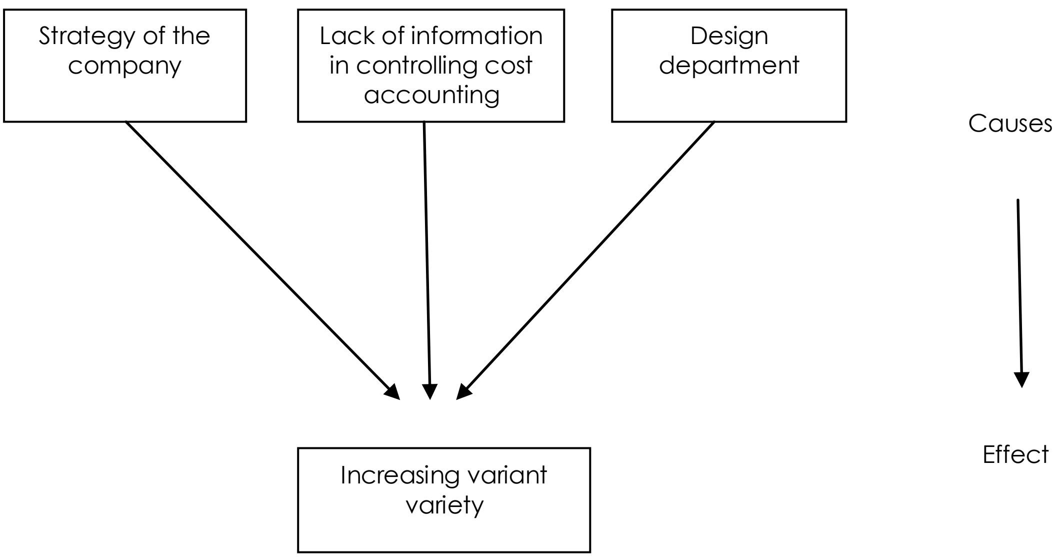

Figure 5: Internal causes of variety.[26]

Variants are usually estimated incorrectly because of incorrect calculation systems. Exotics are categorized as a positive factor and therefore cause a variant explosion.[27]

[24]Adapted from Kestel (1995), p.26
[25]Cf. Pfohl (1972), p.47
[26]Adapted from Kestel (1995), p.20

Internal causes of variant variety are concentrated in many companies in the design section. They develop and construct multiple variants, which then cause procurement, production and sales problems. The reasons why designers are always developing new variants are mainly due to the following factors: lack of information in construction and human motivation.[28]

Increasing variant variety has positive as well as negative impact on the company's success. This will be introduced in the next chapter.

2.3 The effect of increasing variant variety

Today companies have to face changed environmental factors such as the change from supplier to buyer market, the increasing heterogeneity of customer requirements, the international competitiveness and the modern products are becoming ever more complex. This together with the historical development programs result in an increase in the variant variety, which can both have a positive and a negative influence on the success of the company.[29]

2.3.1 The vicious circles of increasing variant variety

As the increase in number of products and parts is also associated with the relevant increase in the variety of suppliers, customers and orders, the level of complexity of all departments and groups increases, which lead to an increasing costs of the organization. The company falls in the worst case into a vicious cycle stemming, which caused by the increase of variant variety and competitive weaknesses. These means the following events as shown in figure 6:[30]

- The starting point is a fairly uncomplicated product plan, which is mainly composed of standard products. Stagnating sales set in.
- The company's reaction is usually to expand the product plan with niche products and particular variants. They hope to increase the sales by increasing variant variety.

[27]Cf. Eurisch (2003), p.4
[28]Cf. Kestel (1995), p.21
[29]Cf. Eurisch (2003), p.1
[30]Cf. Ehrlenspiel,Kiewert, Lindemann (2007),p.273

- The consequence is additional product variety and complexity and market coverage is not significant increased. More specifically, the cost increases disproportionately at the same time the increase of revenues is at a much lower rate.
- This increases the unit costs of the entire product group without additional profits and the competitiveness of the company has declined.
- In this case, the problem is that conventional cost accounting systems usually miss to overlook the actual costs (overhead costs), which are too costly for standard products and too little for "exotic" ones.
- The lack of transparency of cause and effect result in the treatment of the symptoms, not the causes. Numerous companies try to balance this by generating further variants. This cycle continues.

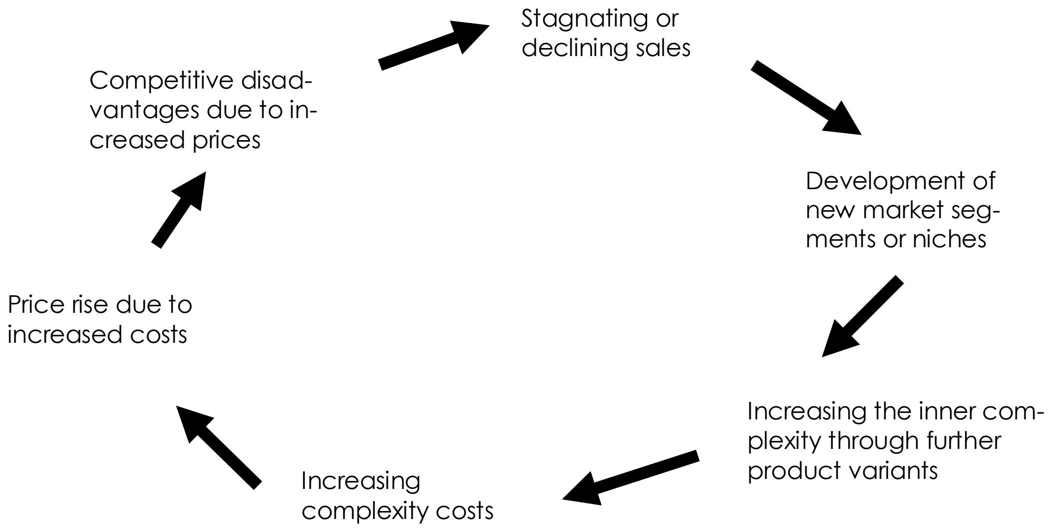

Figure 6: Vicious circles.[31]

In numerous companies the exact reverse situation is evolving than what was originally expected. Therefore, the variant variety represents a significant problem.[32]

Because the vicious circles can be threatening to the existence for many companies, a detailed analysis of the effect of an increasing variant variety is needed.

[31] Adapted from Franke (2002), p.3
[32] Cf. Ehrlenspiel,Kiewert, Lindemann (2007),p.273

2.3.2 The benefits / efforts of variant variety

Product proliferation attracts new customers and allows customers to find the products that exactly meet their needs. The advanced options provided to the customers can increase sales and retain and enlarge the customer base.[33]

If a company can establish a customized but large product portfolio, it is able to become a specialized niche supplier and gain competitive edge in the marketplace.[34] The benefits are categorized as follow:

- Competitive advantage: providing specialized variant variety can decrease competitive pressures and prevent competitiveness of price.[35]
- Obtain new market share: A wider range of product line can significantly increase market share. This has been confirmed in consumer and industrial markets.[36]
- Increase profits and revenues: Increase sales revenues using a broad and more attractive option provided to the customers.[37]
- Increased capacity utilization: The reduced demand means that the equipment intended for certain product is underutilized. If the factory is flexible and can produce diverse models together, it can absorb demand fluctuations. [38]
- Maintain customer base: A wide range of product portfolio can better satisfy distinct customer favors, which result in bigger sales volume and acceptance of higher product prices.[39]

After analyzing the influence of product variety in the automotive industry Schleich et al. summarize the negative effects as follow: With the increase of product variety and due to the decreased economies of scale, enterprises will also experience a decreased performance in many activities that can negatively affect component prices, lead time, and inventory levels of components. If the lot sizes remain the same, direct manufacturing costs, lead time, manufacturing overheads, and inventory levels within the company's internal operations might increase, this in turn will result in

[33]Cf. Child, Sanders, Wisniowski (1991), p.52-68
[34]Cf. Boutellier, Schuh, Seghezzi (1997), p.41-66
[35]Cf. Lancaster (1990), p.189-206
[36]Cf. Kekre, Srinivasan (1990), p.1216-1232
[37]Cf. Child, Sanders, Wisniowski (1991), p.52-68
[38]Cf. Fisher, Jain, McDuffie (1995), p.116-154
[39]Cf. Kahn, Morales (2001), p.63-77

longer supply lead times, and therefore lead to higher inventory and backorder levels.[40]

The benefit for the customers or the company is always related to the costs incurred. Only a best selected product variety can ensure a long-term business success and a high level of customer satisfaction.[41]

2.3.3 Cost-/revenue effect of the variant variety

As already described in the previous section, variants have a cost or revenue effect. The optimization of the variant variety must therefore lead to the result, so that the costs and revenues are in optimal relationship to each other. With regard to the cost trend with increasing variant variety, the following theory can be formulated: with a doubling of the variant variety the unit costs increase around 20-30% as shown in figure 7. This theory is due to the fact that with an increase of variant variety, the total costs increase disproportionately, because in the areas of research and development more costs and higher costs for the coordination of the production process are consumed. On the other hand, the utilization of the production system and the number of pieces per order decrease.[42]

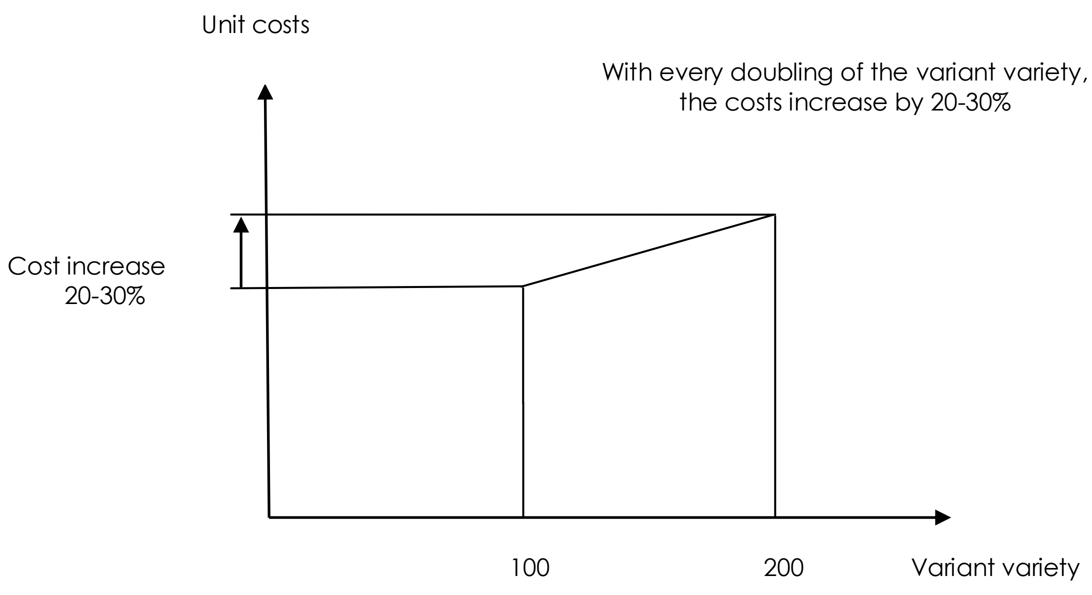

Figure 7: Reverse experience curve for variant doubling.[43]

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[40]Cf. Schleich, Schaffer, Scavarda (2007), p.1
[41]Cf. Schmid (2009), p.30
[42]Cf. Corsten, Reiss (2008),p. 463
[43]Adapted from Bayer (2010), p.46

Product variety induced complexity costs can be divided into two types. The first type is in proportion to the level of variety. Every time a new product variant is introduced to the product plan, it is incurred, for example because of the consumption of marketing efforts and the resources of research and development. The second type of complexity costs that the company incurs is not caused by adding a single variant but by introducing many variants. These costs are fixed costs and show a sudden increase.[44]

On the other hand, the revenues' curve has a logarithmic shape. It means that with the adoption of an additional product variant the average revenues every single variant decrease. There are two reasons for this phenomenon. First, with every new variant, the number of new customers available to the salesman declines. Second, it is possible that cannibalization effect in the range of products occurs. For example, some customers who used to settle for standard products switch to the lately adopted variant. As a result, an increase in the sales quantity because of a new variant leads to a decrease in sales quantity of standard product. In extreme cases, this can result in stagnant or even lower revenues.[45]

Rathnow provides a visual image of the company's needs to balance revenues (profits and revenues) and costs in order to determine the optimal variety,[46] as shown in figure 8.

There is a certain point on the x-axis, after this point the influence of cost for product variety will be more important than revenue effects, and the profit starts to decrease. In order to adopt this concept, companies are constrained to constantly identify the optimal variety that makes the maximal profit. However, the figure of the cost and revenue curves is quite simplified and is used just for theoretic purposes due to the reasons as follows:[47]

- Costs and revenues depend not only on the level of product variety offered but also on many other factors.
- The availability of full and precise cost and revenues estimates when determine the optimal variety is often not the case.
- The idea of optimal variety supposes that the portfolio is naturally static and does

[44]Cf. Abdelkafi (2008), p.123
[45]Cf. Abdelkafi (2008), p.123
[46]Cf. Rathnow (1993), p.44
[47]Cf. Abdelkafi (2008), p.123

not take into account the dynamics of portfolio changes as time goes on.

- The optimal variety model considers only the number of variants rather than the type of variant.

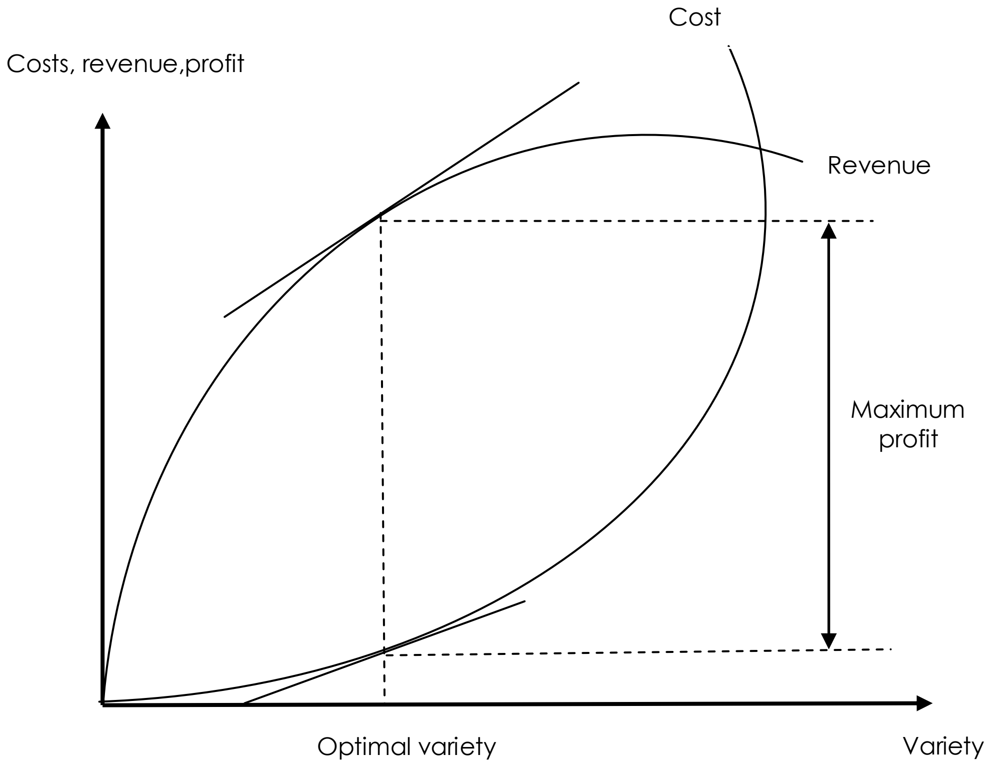

Figure 8: Balance of revenues and costs to define optimal variety.[48]

2.3.4 Complexity effect of variant variety

In order to enable a further unite procedure, the term complexity should first of all be defined.

Today one of the biggest challenges that the industries are facing is the increasing problem of manufacturing complexity because of the product variety that they have to provide to their customers. From an organizational perspective, complexity is the degree of interaction between the segments of organizations that can lead to unforeseeable behaviors. It is essential to identify and understated the causes of these complexities and to reduce risks and difficulties related with these systems. High level of complexities results in more variable lead time, unpredictable system performance and establishes a pressured and difficult working space for operators. [49]

[48]Adapted from Rathnow (1993), p.44
[49]Cf. Kamrani, Azimi, Al-Ahmari (2013), p.124

There are also other forms of complexity such as product complexity, operational complexity and process complexity. Product complexity is attributed to design, material, and special standard of the parts. Operational complexity is on the basis of process, product and the production logistics. Process complexity is attributed to quantitative needs and work conditions that needs process decisions such as equipment types, tools and instrumentations.[50]

Wilson et al. find out when a company introduces a new variant to a product line or introduce new choices to a service, the visible costs of complexity are:[51]

- Variable costs increase because more personnel are needed to manage new products and services, more productive time is required, and the inventory increases due to IT applications or more material goods become more complex to support further options.
- The increased complexity leads to a step-change increase in the cost of brand management and marketing support. Therefore new fixed costs are needed.
- Product complexity leaves the so-called process complexity behind—new management processes and production processes required to offer increased variety—which conversely leads to increased complexity of organization, because functions become flexible to deal with new levels of changes.

And the more hidden costs of complexity are:[52]

- The complexity reduces the capacity of the production and delivery lines and increases waste and production problems.
- New functions just evolve to solve complexity, expeditors are sent to track orders.
- The worst thing is, sometimes complexity creates “a fog”. There is currently no standard process: Every order is considered unique, economies of scale are destroyed and costs continue to rise.

In addition to cost-effectiveness, increasing complexity in all areas of the company leads to further negative consequences:[53]

- Decreased quality: In terms of quality, a high number of variants can lead to considerable quality losses. Basically, an additional variant represents a deviation

[50]Cf. Kamrani, Azimi, Al-Ahmari (2013), p.125
[51]Cf. Wilson, Perumal (2009), p.12
[52]Cf. Wilson, Perumal (2009), p.12
[53]Cf. Giessmann (2010), p.40; Rohrhofer (2009), p.41-42

of the standard process and thus is considered a potential source of error. In production, increased set-up processes, different instructions regarding the order quantities and unsafe processes increase the probability of errors. In order to deal with the error issue, additional testing is necessary. Also in the field of procurement, more intensive and costly incoming inspections are required. With regard to the delivery quality, the number of product variants increases the likelihood of error and incorrect deliveries.

- Reduced flexibility: The more complex the internal structures are due to the increasing number of variants, the more the flexibility, adaptability, and reaction speed of a company to external changes is reduced. Increased product variety reduces the success of a differentiation strategy by giving a company the ability to react, takes or reduce quickly and flexibly to customer requirements.
- Time delays: The temporal component is influenced several times negatively with increasing variety and complexity. On the one hand, the lead time tends to increase. As a reason this can be done by specifying the measure to bundle production volumes in order to achieve a better use and utilization of resources in this way. Many companies are trying to counteract the time lag that occurs due to the increasing number of variants with higher stock levels. However, with an increased product variety the forecast uncertainty and the probability of stock-outs increase. The resulting time delay thus goes directly to the burden of the customers. In addition to the increased throughput time, with an increasing number of variants, there is also an increase in product development times coupled with shortened product life cycles. This can lead to delayed market entry times, which result in significant price losses.

Figure 9 sets the effects of the variant variety on a company and its performance process.

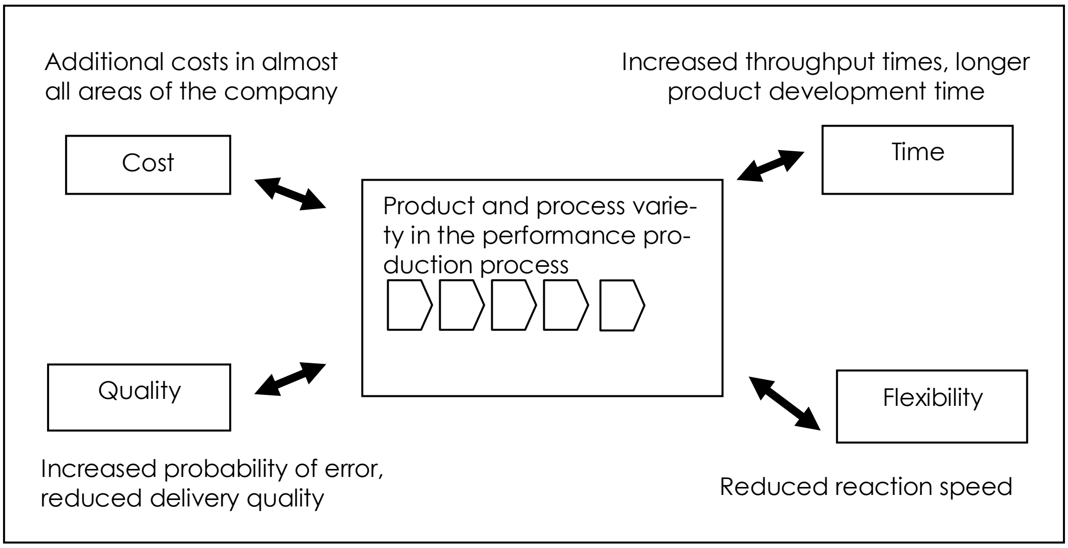

Figure 9: Effects of variant variety on significant performance criteria. [54]

2.4 The advantages and disadvantages of high variant variety

Advantages of a high variant variety

Out of competitive reasons (transform from supplier markets to buyer markets), the companies have to aware of the different requirements of customers. The products have to offer benefits to customers, and it is strategically important to fulfill increasing customer-specific products or individualized customer favors. For many customers, there is a dislike of a unified response to their requirements. In addition to the use-benefit, there is a value-benefit that the product can perform, which can be achieved through significant external changes.[55]

Through proper differentiation of product, products can be offered in different price ranges to meet different groups with buying power. Additionally, customer loyalty is impacted by the product classification. A wide and repeatedly updated product range stimulates purchase decisions both by new target groups and by subsequent orders from existing customers.[56]

Disadvantages of a high variant variety

In general, the costs of variants have less influence on the manufacturing cost part of the total costs. They increase the indirect costs in the sectors of marketing, design

[54]Cf. Adapted from Rohrhofer (2009), p.45
[55]Cf.Ehrlenspiel,Kiewert, Lindemann (2007),p.272
[56]Cf.Ehrlenspiel,Kiewert, Lindemann (2007),p.272

and development, logistics, quality assurance and computation. That is where the activities that was necessary only once in the past for a large amount of the same products now occur repeatedly for nearly every product sold. The high overhead costs are difficult to allocate to specific products through traditional cost accounting. The allocations of the costs that are not based on causes have the risk that expensive variants will not be identified. The costs of implementing and managing variants are much higher than the later profits.[57]

From the customer's point of view variety needs to be weighed. Customers are more inclined to find products that meet their needs with more choices. On the other hand, a wide range of choices makes it more possible that customers make suboptimal decisions. [58]

The development of the causes and effects of increasing variant variety in this chapter demonstrates that the variants variety can be both of value to a business and the source of complexity and cost. The increasing complexity in a company leads to a lack of flexibility, to not transparent internal processes, and high costs. Also the quality and the development times are negatively influenced because of the increasing complexity. For this, variant management can be defined as a management task. In the following chapter, variant management and its solution approaches will be described.

[57]Cf. Ehrlenspiel,Kiewert, Lindemann (2007),p.272
[58]Cf. Abdelkafi (2008), p.119

3 Variant management

The previous chapter has presented the different causes and effects of the variant variety. This leads to the necessity for a comprehensive management of the variety and complexity problem. In order to grasp the increasing variety of variants, a comprehensive and continuous variant management is necessary. In this chapter the concept of variant management will be discussed.

Variant management consists of all measures that influence variant variety within a company on purpose. This therefore is effective both for the products and for the affected processes. The goal is to reduce and control complexity, that is to say, minimal variant variety and/or internal complexity while at the same time providing sufficient number of variants to the customer.[59] The goals of variant management can be summarized as follow:[60]

- Minimizing internal variety
- Provision of required external variety
- Recognize and avoid unnecessary variations
- Minimize lead time and costs
- Use the same tools for different variants

From the internal causes of the increasing variants, it can be assumed that distinct company departments have different needs and duties with regard to variant management: [61]

- To understand the desires of customers is the task of the marketing department. People of the marketing department need to decrease the large number of different needs to a rational size.
- Design and development department is a key player in the variant issue of the company. Proper planning of technical interfaces can influence product flexibility. The quantity of individual adaptive designs can be limited by applying the identical components in different products. In the product realization sequence,

[59]Cf. Ehrlenspiel,Kiewert, Lindemann (2007),p.265
[60]Cf. Schmidt (2007), p.14
[61]Cf. Ehrlenspiel,Kiewert, Lindemann (2007),p.271

variants ought to appear as late as possible, which needs a proper product concept; this is also called “postponement”.

- Production is supposed to involve the least costs. The installation and setup time can be reduced with appropriate design of the parts that being produced. In manufacturing companies, variant management is unthinkable without the co-operation of production staff. For example, this department can provide decisive input to design for the development of production-oriented part families.
- A similar statement applies to the assembly. Awareness to information about assembly techniques at the right time can cause assembly-oriented part families.
- The customer service department requires a general view of the variants produced and possible different service policy for the individual variant.

3.1 Internal and external variety

There are two classification of product variety: internal variety and external variety. External variety represents the option visible to the customers. When an external variety (in the form of individual customer needs) is translated into tasks to generate a product, internal variety occurs within the company. [62] The effects of external and internal variety are shown in the following figure.

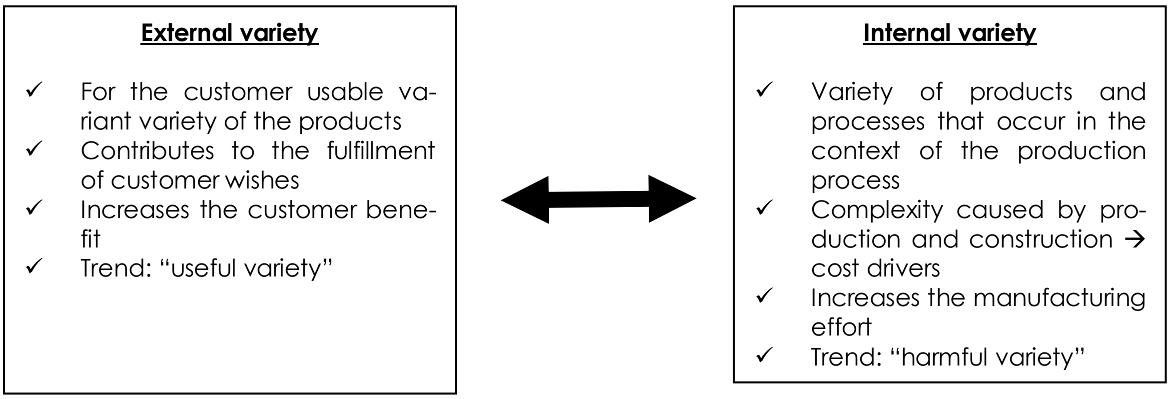

Figure 10: Comparison of the internal and external variety.[63]

External variety, which means the perception from the customers’ point of view, can be defined by three features: Fit, taste and quality.[64] When the customer shows a peak demand for a particular product attribute, fit is achieved. If the product cannot show this attribute, customer satisfaction will be significantly reduced. Contrary to

[62]Cf. Pil, Holweg (2004), p.394-403
[63]Adapted from Zenner (2006), p.52
[64]Cf. Ulrich (2006), p.143

the case of fit attributes, because customers accept different values, the differences of taste attributes do not necessarily result in a reduction in satisfaction. Fit and Taste are reliant on the preferences of individual customer. All customers perceive quality attributes in the same way. As long as customers are ready to pay the set price, satisfaction usually raises with higher quality attributes values.[65]

Internal variety can also be classified in three types: Fundamental, peripheral and intermediate.[66] Fundamental variety represents the changes in various basic products, platforms and models. Peripheral variety means the capability to provide a large amount of options without changing the design of the basic product. Intermediate variety is presented in the variation in parts which reflects the effects on product design and supply chain.[67] Figure 11illustrates the dependencies of these three classifications.

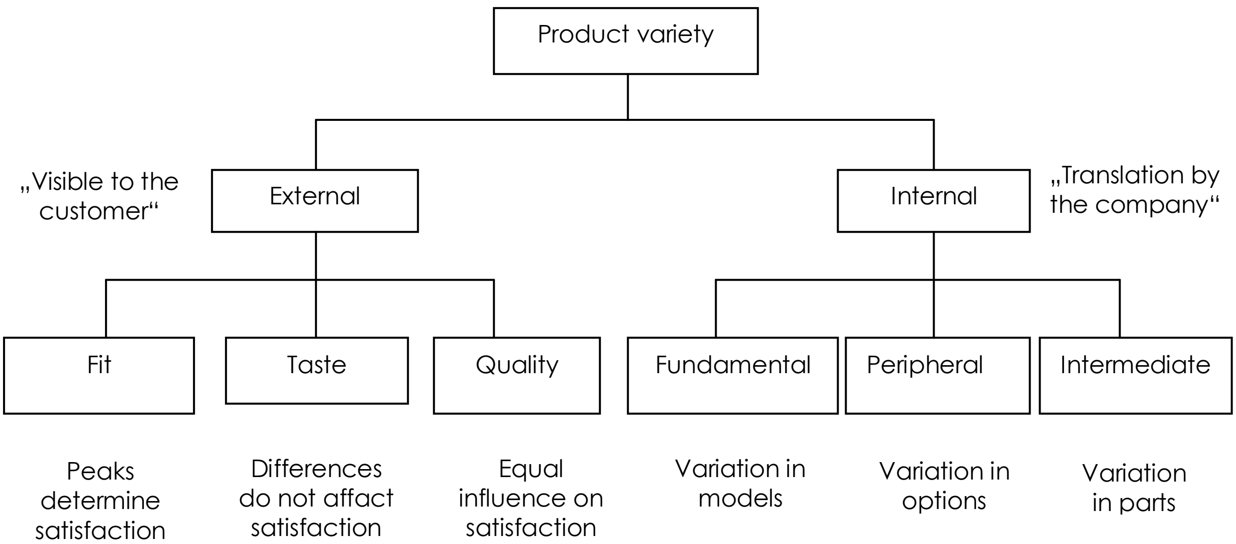

Figure 11: Categorization of product variety.[68]

Internal varieties are the results of external varieties and represent the variety of components, modules, resources and processes. This variety often results in increased complexity in the production system and the entire supply chain.[69]

A main task of variant management is considered to find and improve the optimal balance between external variety and the resulting internal variety. Manufacturing

[65]Cf. Götzfried (2013), p.16
[66]Cf. MacDuffie, Sethuraman, Fisher, (1996), p.350-369
[67]Cf. Götzfried (2013), p.16
[68]Adapted from Pil, Holweg (2004), p.394-403
[69]Cf. Boer, Refaelli, Boer, Gatti (2018), p.583

companies are willing to have as few variant varieties as possible internally and externally as many variant varieties as required to meet the requirements of existing and new customers.[70]

Although a large variety of products is a major problem because it adds cost and complexity to the system, manufacturers believe that the product variety determines profit, the more product variety, the higher the profit. For this reason, manufacturers have to extinguish the needless variants and concentrate on the variants according to the customer requirements and technological advancements.[71]

If the internal variety that used by the manufacturing company currently can create more end variants than what the marketplace requires, the internal complexity can be reduced without reducing external variety. Ideally, internal variety is reduced to the point, at which the number of components and subassemblies cannot be reduced any more without eliminating the final product variants.[72] The techniques that introduced in the following can solve this problem.

Product-related techniques include: part sharing, combination and functional congestion and synthesis of parts. Using these techniques, manufacturing companies can reduce the cost sensitivity of product variety. The product-related techniques are introduced as follow: [73]

- Part sharing

Part sharing means that using the same parts in different variants of a product family. Shared parts can reduce the number of overhead cost increasing activities.

- Combination

The combination technique does not concentrate on the individual components but rather on the subassemblies and their interactions. Combination can only achieved if the product family is built around building modules, which can be interchanged among a lot of end variants. The technique makes sure that the desired level of external variety is realized by combining a few units rather than a large amount of isolated components. Additionally, new designs are able to be used more efficiently because new products are not built from scratch, but by using existing units.

[70]Cf. Riedel, Eversheim, Korreck, (1999), p.29-48
[71]Cf. Kamrani, Azimi, Al-Ahmari (2013), p.114
[72]Cf. Abdelkafi (2008), p.127
[73]Cf. Abdelkafi (2008), p.127; Galsworth (1994), p.197; Suzue/Kohdate (1990), p.59-63

- Functional congestion and Synthesis of parts

Functional congestion is a technique that provides more functionality to the components. Synthesis refers to the integration of components in order to e.g., reduce assembly activities.

Not only can the product structure be influenced, but also the process structure. At the process level, three main techniques can be differentiated in: process sharing, decoupling, and changeover flexibility as described below:[74]

- Process sharing

The purpose of process sharing is to produce components and finished variants based on several processes. Process sharing is a key issue for companies, which are facing an increasing level of requirements for product variety and customization. In fact, it is more economic to create new parts and products through using existing manufacturing processes. High process variety is not only related to the additional investment in equipment, but also leads to problems in manufacturing planning and control because more processes have to be managed, arranged and adjusted.

- Decoupling

A high degree of coupling refers to that the relationships/interactions between processes are quite tight to the point that any change in one process can lead to many changes in other processes. There is no room for flexibility in a tight coupling on the workshop. Mass customization conceptually means a certain level of decoupling in the manufacturing system. In fact, the decoupling point separates the set of shared process from the process where the product assumes its unique identities.

- Changeover time reduction

At low set up time and cost penalty, the ability of a process to switch between different components and variants is called changeover flexibility. The changeover time depends not only on the characteristics of the technical equipment in manufacturing, but also on workshop organization.

In the company, product individualization is able to be structured on the basis of the so-called customer decoupling point. Customer decoupling points describe the customer-specific adaption points in the value chain. Piller believes that the sooner the customer's demands have to be taken into account, the greater the impact on cus-

[74]Cf. Abdelkafi (2008), p.129

tomization of product. In the manufacturing sector the involvement of the customer during the order process is characterized by a quite early decoupling point of customers. This leads to more individual customer orders compared with other industries.[75] The four potential customer-decoupling points are shown in figure 12.

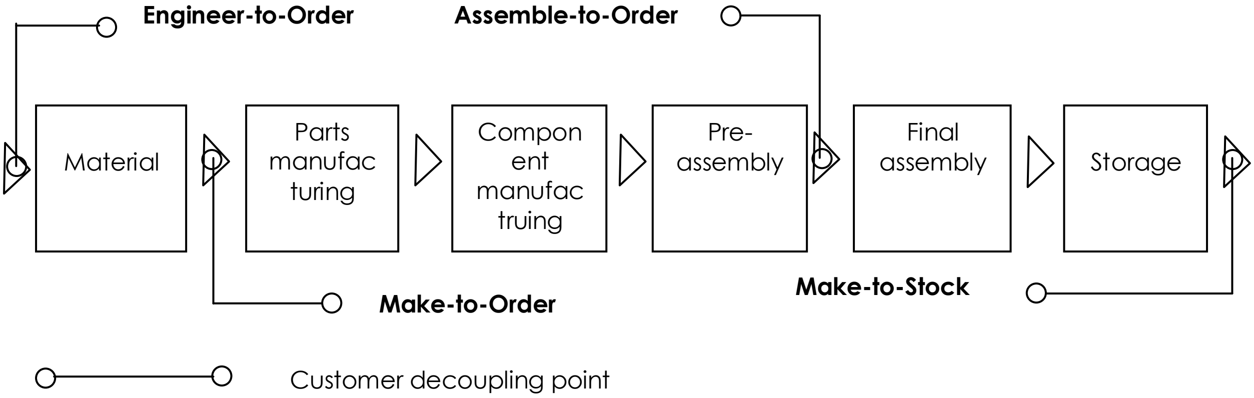

Figure 12: Different types of customer decoupling points in the order processing.[76]

Widespread variety makes decision-making complicate and can be confusing. But companies usually do not aware is that they can significantly impact customer's perception of variety.[77] Consequently the chance for manufacturing companies to enhance the benefits of a specific product series is to help customers determine what their real requirements are. The more customers can realize the benefits of product variety, the higher are the expected profit.[78]

To meet individualized customer requirements, a personalized offer relying on a broad range of products and services is required. This personalized offer is able to increase both customer satisfaction which reflects the difference between customer needs and actual achievements, and internal variety which influence the performance, which conversely influence the customer satisfaction. [79]

See figure 13, in this respect, the challenge of variety management is how to handle external varieties, at the same time reduce internal complexity and assure satisfactory performance in regard to flexibility, cost and responsiveness. A valid variety management enables to achieve economies of scope through creating wide range of variety on the basis of a limited quantity of references, and economies of scale by

[75]Cf. Piller (2004), p.313-334
[76]Adapted from Wortmann, Muntslag, Timmermans (1996), p.59-73
[77]Cf. Abdelkafi (2008), p.130
[78]Cf. Abdelkafi (2008), p.130
[79]Cf. Boer, Refaelli, Boer, Gatti (2018), p.583

succeeding standardization and commonality principles of mass customization. Through more flexible supply chain, commonality, modularity, and postponement are the major drivers of these economies.[80]

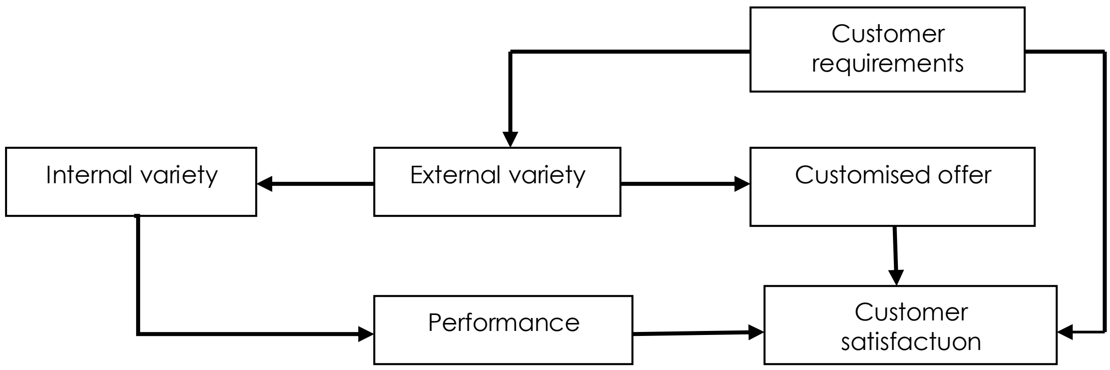

Figure 13: Conceptual framework.[81]

In order to control the variety of products that required by a wide range of customers, companies can use product and process-based strategies or the combinations, as shown in figure 14.

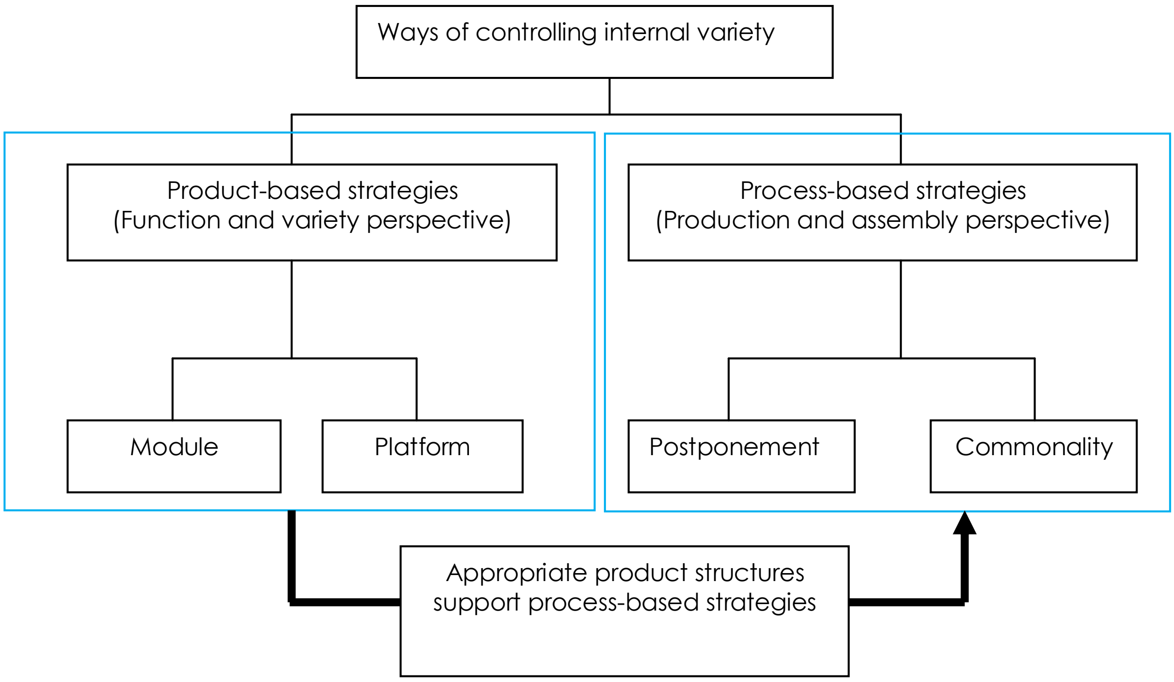

Figure 14: Product-based and process-based strategies for controlling internal variety.[82]

[80]Cf. Boer, Refaelli, Boer, Gatti (2018), p.583
[81]Adapted from Boer, Refaelli, Boer, Gatti (2018), p.584
[82]Adapted from Birkhofer (2011), p. 38

The goal of developing a modular product structure for a product line is to retain the external variety demanded by the market and decrease internal variety within the firm to reduce, control or prevent the related complexity of company processes in product development. [83]

The larger number of standard modules derived is a main advantage of this strategy. These standard modules can help to reduce costs, for example, with better use of learning curve results and economies of scale, particularly in procurement, production and assembly. Modular structures offer the chance to parallelize any processes, for instance developing different modules in parallel or to separately produce them.[84]

Modularity and modularly structured products are defined broadly and in different ways. A comprehensive definition allows the characterization of the common features of modular products: [85]

- Commonality of modules: components or modules are used at different positions within a product family.
- Combinability of modules: products are able to be configured through combining components or modules.
- Interface standardization: the interfaces between the modules are standardized.
- Function binding: the allocation between functions and modules is fixed.
- Loose coupling of components: the interactions among the components within a module are outstandingly higher than that between different modules.

In addition to the strategy of offering a modular product line, product-oriented strategies also consist of the platform strategy, which define platforms (as basic modules applied to product lines) as standard extensions. A modular product structure that fits the business objectives allow for reduced complexity of the process strategies because they are closely relevant to the product structure. Process commonality describes the strategy of applying the same processes for distinct products to offset the differences of product series through a unified process. The postponement strat-

[83]Cf. Birkhofer (2011), p. 36
[84]Cf. Birkhofer (2011), p. 36
[85]Cf. Salvador (2007), p. 219-240

egy supplies the highest possible part of the production process, have nothing to do with the variants.[86]

In the literature, a distinction is frequently made between strategic and operative variant management. Strategic variant management has the task of ensuring the cost-benefit-optimal alignment of the variant variety to implement the competition and production strategy specified by the company. It has a long-term character and has an impact on the entire product life cycle. In the contrast, operative variant decisions have a medium-term character and usually have no influence on subsequent product life cycles. It supports the company's competition and production strategy with the goal of efficiently managing a company according to the given strategic framework conditions.[87]

3.2 Strategic variant management

This section introduces two types of strategic variant management approaches: postponement strategy and mass customization.

Postponement strategy

Postponement is one of the main strategies for solving mass customization issues. The postponement strategy will delay the differences in form and place of the product until the latest possible point in the supply chain.[88] Van Hoek defines postponement "…as an organizational concept whereby some of the activities in the supply chain are not performed until customer orders are received. Companies can then finalize the output in accordance with customer preferences and even customize their products."[89]

Postponement can occur in manufacturing by postponing final assembly, packaging, and labeling. It also can occur in distribution by postponing decisions on delivering products to a certain distribution area. The overlap between logistical and manufacturing postponement takes place during the distribution phase by operating final manufacturing activities. Postponement offers a limited value for supplying full cus-

[86]Cf. Birkhofer (2011), p. 38
[87]Cf. Raubold (2011), P.30
[88]Cf. Bowersox, Morash, (1989), p.58-67
[89]Van Hoek (2001), p.161

tomization.[90] Figure 15 shows the impact of the postponement strategy on the variant tree.

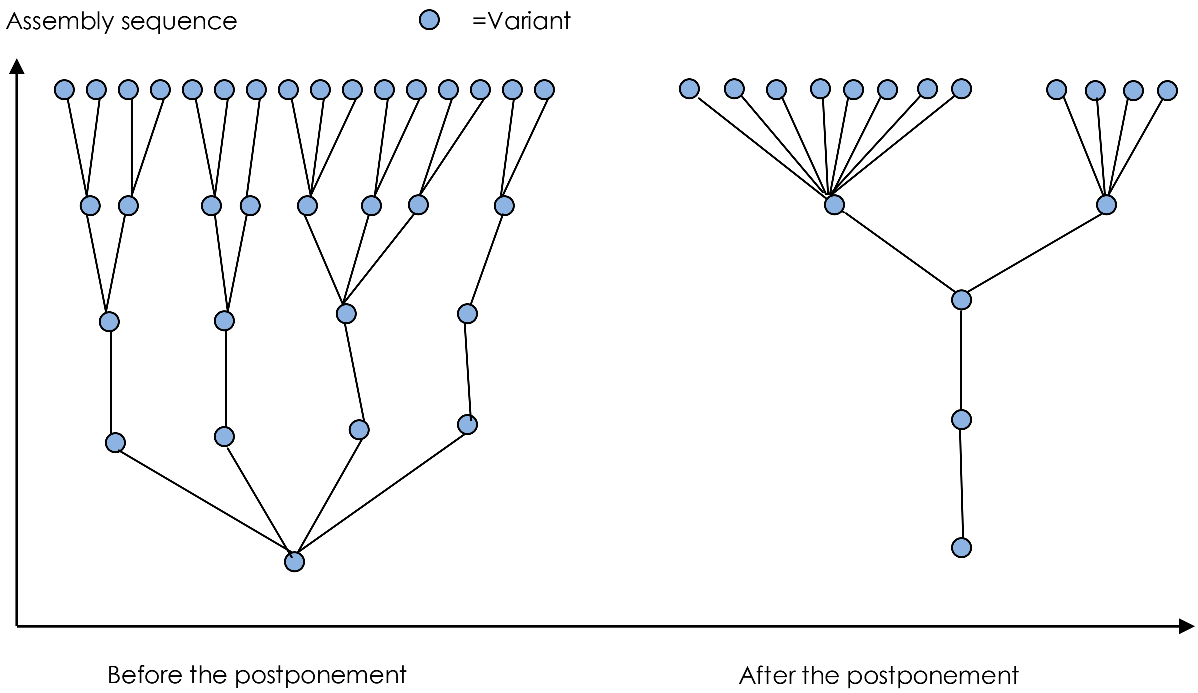

Figure 15: Impact of the postponement strategy on the variant tree.[91]

There are two benefits of postponement. First, postponement enables flexibility in product delivery. By delaying product differentiation in the production process, companies can customize generic semi-finished products into each product variant upon observing the newest requirements for each product variant. Therefore, the value is reflected in the solution of requirements until the point of differentiation. The second benefit of the postponement comes from delaying of the final product customization process, because the company can make the final customization later point in time. At this point of time, demand forecast is more accurate for each product variant.[92]

Mass customization

Pine defined mass customization as:" developing, producing, marketing and delivering affordable goods and services with enough variety and customization that nearly everyone finds exactly what they want". [93] What do people need, when do they

[90]Cf. Van Hoek (2001), p.161-184
[91]Adapted from Herrmann, Peine (2007), p.674
[92]Cf. Ho, Tang (1999), p.4
[93] Pine (1993), p.44

need it? In other ways, the aim of mass customization is to produce goods and services that meet the needs of individual customers and with mass production efficiency.[94]

The customers buy a product not only because they can choose from a variety of variants, but above all when they have the opportunity to express their requirements and then can be offered a product that satisfies them. In other words, instead of a broad range of options, a customized product can be the winning key for order acquisition.[95]

Lampel and Mintzberg introduces a remarkable classification as shown in figure 16, they distinguish between five strategies by considering a simplified view of the value-chain.[96]

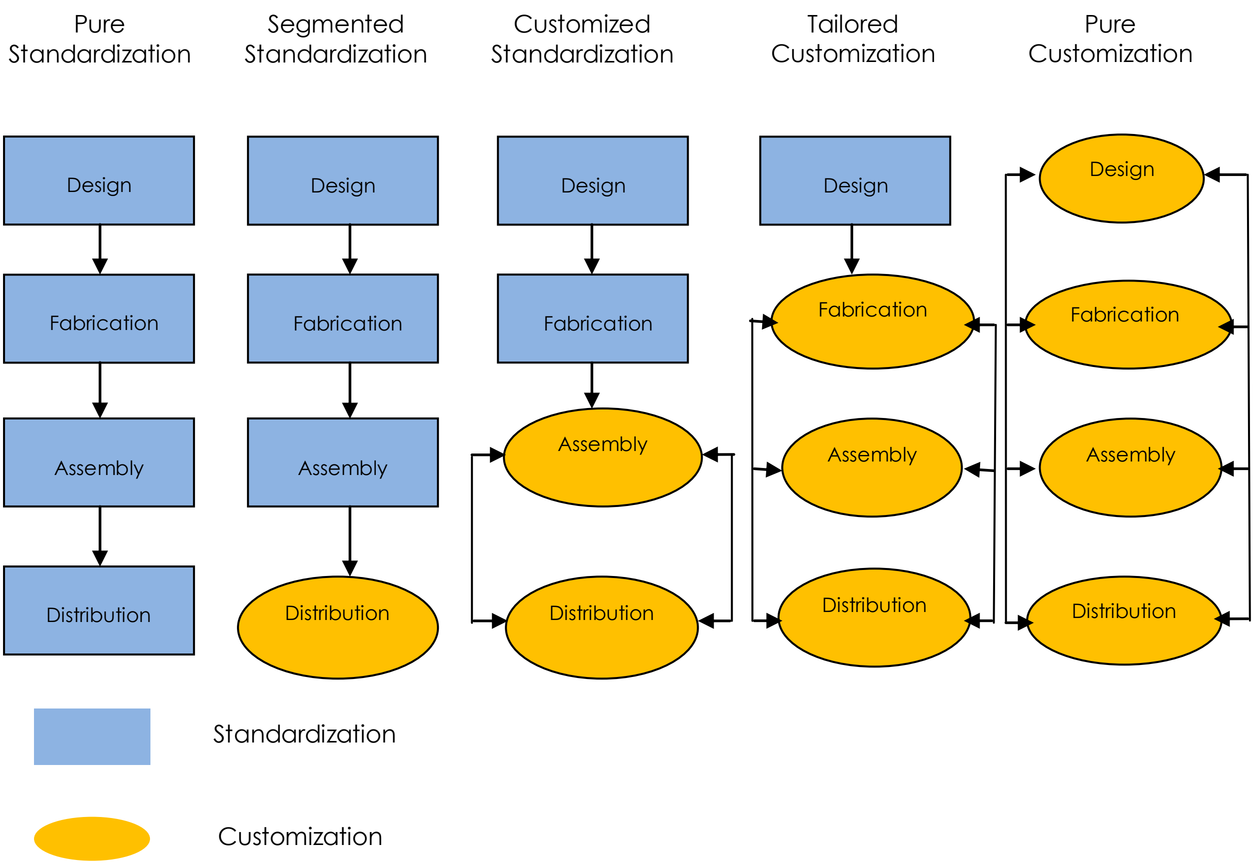

Figure 16: A continuum of mass customization strategies.[97]

[94]Cf. Tseng, Jiao (2001), p.684-709
[95]Cf. Forza, Salvador (2007), p.10
[96]Cf. Lampel, Mintzberg (1996), p.24
[97]Adapted from Lampel, Mintzberg (1996), p.24

As this figure shows, mass customization will follow the postponement principle, which leads to a delay in a certain stages or activities in the value-chain until a customer order directly impact the product. The value-chain perspective consists of a basic question about the so-called order penetration or decoupling point.[98] As for the "penetration" of customers in the value chain, this issue divides the value chain into two parts. In the first part, standardized activities occur in the upstream of decoupling points. In the second part, downstream activities are specially driven by the customer. More value-added activities are executed with a level of uncertainty, if the decoupling point is located more downstream. If it is placed more upstream, the activities will be on the basis of more specific information from customers.[99]

This series of events poses several challenges to achieving the seemingly conflicting goals of mass customization: first, to meet the different requirements of customers and, secondly, to achieve efficiency amount to mass production, without economies of scale. Similar problems in trading cost and time are also applicable to downstream processes like outbound logistics, installation, maintenance and service. These challenges consist of tasks at all phases of the value chain. A good mass customization system is characterized by the fact that it solves these challenges in a meaningful way.[100]

Piller and Tseng outline the challenges in satisfying individual customer requirements as follow:[101]

- Speed and lead time: In a mass production system products are manufactured in batches on a large scale to cover the fixed cost for example money spent for equipment installation. They usually accompany inventory in warehouses in diverse nodes of a supply chain, consisting of the shelves at the point of sales. Therefore, products can be easily gained from ready-made products. From product design, material procurement to product delivery, the actual net delivery cycle time for these products is usually in months or even years. However, customers finding the most "tolerable" goods from the shelf in retail stores usually think that the delivery time between perceived a requirement and its fulfillment is comparatively short. For customized products, it is however impractical to follow the same approach by establishing inventory along the supply chain. But by

[98]Cf. Ramdas (2003), p.79-101
[99]Cf. Blecker, Abdelkafi(2006), p.908-929
[100]Cf. Piller, Tseng (2010), p.3
[101]Cf. Piller, Tseng (2010), p.3

extrapolating the expectations from standard products onto customized products, customers may still hope to have the same order of magnitude within a short delivery period. In many industries, the gap between customer's expectations and the physical constraints of time needed by a customized production is usually significant.

- Customers' requirements: In contrast to traditional faith, customers usually have no idea what exactly they want. They lack specific knowledge about what manufacturers or suppliers in the value chain can offer or do, not to mention the relationship between product characteristics and variables. This is not the same as in mass production. Here, manufacturers design and produce large quantities of products based on customer requirements. Customers then make their own choice among the group of products from the manufacturer and their competitors. Customers must endure the choice and designs of manufacturers.
- Value: The provision of a selection may not automatically be of value to the customer. In the past, some manufacturers offered their customers a wide range of options. But most customers are not grateful to the options that are not suiting their interests. Additional options are often confusing. In consequence, customers need more time to understand the differences between these options. This extra psychological burden can hinder sales commitments; add extra sales work and even chasing customers away. Therefore, it is important to reconcile the type of product provided to the customer with the perceived value. Synchronizing the selection between characteristics, options and product attributes with customer perceptions and willingness to pay is a great challenge in customization business.
- Economies of scale: customization to the needs of individual customers intuitively results in fewer quantities and more varieties, making it difficult to achieve the necessary scale of economy. In response to this natural trend, various technologies have been developed. For example, although the end products may vary widely, they may contain the same components or subassemblies for mass production. Customers can then use the components that are manufactured with efficiency in the back end to configure their needs. Another method is to order the products or subsystems in the way that similar or same materials can be fulfilled through economies of scale.

- Complexity: Due to the high variety and small batches, it will be difficult to handle organizing, scheduling, and managing types and division of work. Complexity causes extra costs that can strike down the efficiency goal set by mass customization. Many algorithms and IT solutions have been adopted to manage complexity and simplify the management of customization systems.

Mass customization strategies has been adapted by plenty of companies and industries in order to better satisfy customer needs by providing products and services that were previously available only using a mass production strategy. [102]
The advantages of mass customization are:[103]

- Maximize market share through maximizing the number of customers and satisfying them.
- Reduce stock cost and material waste: material and input are brought to production just in time. In addition, finished goods inventory is very low due to the make to order and not make to stock.
- Reduce response time: organization structure and flexible manufacturing in mass customization allows the company to quickly adapt to different requirements.
- Ability to provide a full range of products or services at a lower cost: Mass customization distinguishes products to specific needs. This leads to a wider range of product lines of the company and reduces the inventory risk of obsolescence.

3.3 Operational variant management

Three operational variant management approaches will be introduced in this section.

ABC-analysis

In variant management, companies usually perform an ABC analysis in order to find out which variants customers rarely require and they will be eliminated by the company. However, if these product variants cause no or only a negligible extra effort in the production process and they cause only quite low costs, and the customers can share the necessary direct costs, the company should not eliminate them. The importance of product variants therefore comes from the efforts and the variety of process in the corporate process and determines whether the variants are managed or re-

[102] Cf. Chandra, Kamrani (2004), p.8
[103]https://www.slideshare.net/nepaleseboyBP/mass-customization-and-serategies

duced. For this purpose, the demands of the level of product structure, the business process and the supply chain and their interactions must be considered.[104]

This method should be done before any new design and constructive revision of a product. The product to be tested is evaluated on the basis of several criteria. These criteria may affect the market (e.g. Countries, industry) that the user (e.g., handling, service, design) or manufacturer (e.g., lead time, manufacturing costs, complaints) relate to. The collected data and information are compared and displayed in ABC analyzes. The ABC analysis of sales per product combined with ABC analysis of profit per product more easily identifies critical products that evolve or can be sorted out. 80% of the products are unprofitable, only 20% contribute to the company's turnover. The ABC analysis even supports the identification of the company's potential, whereby the potentials of the company and those of the competitors are collected and per company are developments, sales, after sales, production and procurement are broken down. The ABC analysis even supports the identification of the company's potential, with the potentials of the company and those of the competitors being collected and broken down into each business area development, sales, after Sales, production and procurement.[105]

Cost-benefit analysis

In order to ensure the efficiency of resource allocation and to maximize the benefits of social welfare, applying an evaluation procedure to systematically and carefully estimate all costs and benefits relate to the project under consideration may be necessary. Cost-benefit analysis (CBA) is one of such procedures. The CBA identifies all potential gains and losses of a recommended public project, transfer them into monetary units and arranges them based on the project selection criteria to decide whether the proposal is socially effective and desirable.[106]

Variant tree

An essential requirement for the analysis and systemic design of the range of variant is the clear introduction of the variant information in the shape of adaptive product segmentation. The variant tree supported by the computer offers relevant support. Variant trees delegate the product variants and assembly that develop in the

[104]Cf.Birkhofer (2011), p. 44
[105]Cf. Schmidt (2007), p.49
[106]Cf. Nas (2016), p.2

process of advancing assembly progress. To this end, every component of the product family is listed in the shape of a box in the variant tree and connected to the rest of the assemblies and components. Different parts and assemblies are marked by a box with bold frames. Variant strip indicates the variant variety accomplished by any amount of assembly segments to be specified. Therefore, the variant tree describes the sequence of assembly in the vertical direction and the diversity of variants and parts in the horizontal direction.[107]

A big advantage of the variant tree is that the variety of variants on each level of the product description can be read in so-called variant bars. With this information can be derived to reduce the variety of parts and the associated complexity. If the variant tree is supplemented with the frequency of use per property, this tool supports the early detection of product exits. The aim is to design the product range so that the variant tree is kept as narrow as possible until the final assembly. It means that the variant variety arises only as near to the end of value creation.[108]

Several approaches of variant management have been discussed in this chapter. The goal of this thesis is to find out the relationship between variant variety and Industry 4.0. Therefore the conceptual framework and main technologies of Industry 4.0 will be explored in the next chapter.

[107]Cf. Weck, Eversheim, Koenig, Pfeifer (1991), p. 56
[108]Cf. Rohrhofer (2009), p.67

4 Industry 4.0

The key to gain market competitive advantages are continuous innovation, optimization and efficiency. The classic business model is changing as the current production does not meet the increasing requirements of the customers. Customers have increasingly requirements and their increasing complexity and additionally expect to have everything as quickly as possible. The classic business model on the basis of mass production is no longer sufficient. All of this is the basis for the establishing of the concept Industry 4.0.[109] This chapter introduces the conceptual framework and main technologies of Industry 4.0.

4.1 A conceptual framework of Industry 4.0

Industry 4.0 is the name of the fourth technology generation of manufacturing history. Industry 1.0 was powered by steam and spanned 1700 - 1860. Industry 2.0 means assembly line and lasted between 1870 and 1969. Industry 3.0 refers to automation technology in the years 1969-2020 and Industry 4.0 involves the production based on cyber-physical systems to occur after 2020.[110]

Industry 4.0 has attracted a lot of attention from service systems and manufacturing companies in recent years. Industry 4.0 mainly includes the integration of supply chain, production infrastructure and service systems to establish value-added networks. Therefore, the state of the art technologies such as big data analytics, cloud systems, cyber physical infrastructure, autonomous robots, horizontal and vertical integration, simulation, augmented reality, additive manufacturing and industrial Internet are essential for a successful adaptation.[111]

Three features of Industry 4.0

In order to successful adapt Industry 4.0 system, three features should be considered:[112]

- Horizontal integration through value chains;
- Vertical integration and networking of manufacturing or service systems;
- End-to-end engineering of the overall value chain.

[109]Cf. Mindas, Bednar (2016), p.21
[110]Cf. Kagermann, Wahlster, Helbig (2013), p.4
[111]Cf. Ustundag, Cevikcan (2018), p.6
[112]Cf. Ustundag, Cevikcan (2018), p.6

Vertical integration needs digitization and intelligent interconnection of business departments in different hierarchal levels within the company. Therefore, vertical integration allows ideally conversion into smart factories in a highly flexible manner, and offers small batch production and larger number of customized products with acceptable degree of profitability. For example, intelligent machines establish a self-automated ecosystem that is able to be dynamically subordinated to influence the production of distinct product types, and process a large number of data to easily manipulate the manufacturing process. Horizontal integration uses the whole value creation among organizations with the adoption of information systems, material flow and efficient financial management to enrich the product life cycle. End-to-end engineering supports the product development processed through digital supportive technologies integration considering product design, maintenance, and customer demands and recycling.[113]

The concept of Industry 4.0 is not a single part of the value chain, but everything is effectively collaborated and connected. The relationship between suppliers, manufacturers and customers will be very close.[114]

4.2 The important technologies of Industry 4.0

To successfully implement Industry 4.0 transformation, the basic technologies are needed become part of the overall system. This section provides detailed information on some technologies for better understanding the proposed framework.

Internet of Things (IoT)

The Internet of Things contains a very large network of numerous connected objects. Through smart devices such as smart phones, tablets and smart watches people are connected with things such as automobiles, machines, or the “smart” home.[115]

The Internet of Things represents an interconnected world, where many items are equipped with actuators, sensors or other digital devices that enable them to be connected and networked to collect and exchange data.[116]

The Internet of Things has brought a new dimensionality to the communication concept, and as time goes on, not only human-to-human and human-machine com-

113Cf. Ustundag, Cevikcan (2018), p.6
114Cf. Mindas, Bednar (2016), p.22
115Cf. Andelfinger, Hänisch (2015), p.9
116Cf. Xia, Yang, Wang, Vinel (2012), p.1101

munications are available, but also machine-to-machine communication via the Internet of Things. IoT connects the real world with the virtual world and makes effective use of M2M interaction. The communication of things is also called the speech among things. Suppose everything will stay connected to the internet in the near future.[117]

Cyber physical system

Bauernhansl noted that the development of CPS takes place in three phases. The first generation of CPS consists of identification technologies such as RFID tags that permit distinctive identification. Analysis and storage must be supplied as a central service. In the second generation, CPS is embedded with sensors and actuators with limited functionality. The third generation of CPS is able to store and analyze data, is provided with diverse sensors and actuators, and is network-enabled.[118]

An example of a CPS is the intelligent bin (iBin) from Würth. It includes an integrated infrared camera module for C-parts management to define the number of C-parts within the iBin. If the number of C-parts is lower than the safety stock, iBin orders new parts automatically through RFID. This enables real-time consumption based management of C-parts.[119]

Cloud technologies

Another important topic that dedicate to the integration of networked systems in the Industry 4.0 transformation is cloud-based operating. The term "cloud" consists of cloud computing and cloud-based design and manufacturing. Cloud manufacturing means the connected and coordinated production is "available on-demand" manufacturing. Demand based manufacturing applies a set of distributed manufacturing resources to establish and manipulate reconfigurable cyber-physical manufacturing processes. The main goal here is to increase efficiency by decreasing product lifecycle costs and allow optimal utilization of resource by handling variable-demand customer-oriented work.[120]

The further development of cloud technology has the following consequences:[121]

- Reduced reaction times;
- Manufacturing data in cloud systems will be increased and more data-driven

[117]Cf. Demirer, Aydin, Celik (2017), p.3
[118]Cf. Bauernhansl (2014), p.9.
[119]Cf. Günthner, Klenk, Tenerowicz-Wirth (2014), p. 307
[120]Cf. Thames, Schaefer (2017),p. 9-11
[121]Cf. Ustundag, Cevikcan (2018), p. 9

decision makings for service and production systems will be provided;

- Increased productivity in advance.

Additive manufacturing

Additive manufacturing (AM) relates to many steps that transfer from a virtual CAD characterization to a physical part. Different products will relate to AM to varying degrees and in different ways. Small, quite simple products may take advantage of AM only for visualization models, but complex, larger products with greater engineering detail may involve AM during multiple stages and iterations all through the development process. Most AM processes include the following eight steps:[122]

- Step 1: Visualization with CAD;
- Step 2: Conversion to STL;
- Step 3: Transfer to AM Machine and STL File Manipulation;
- Step 4: Machine Setup;
- Step 5: Parts Build;
- Step 6: Material Removal;
- Step 7: Post –processing;
- Step 8: Application.

Additive Manufacturing has obtained the position of a main trend manufacturing process. This technique accelerates the building of components by adding materials layer by layer adopting computer-aided three-dimensional (3D) solid models. Additive manufacturing does not need cutting tools, coolants, or other equipment used in traditional manufacturing. This technology admits for optimization of design combined with the capability to create customized parts as needed.[123]

Smart factory

Smart factories will have the ability to handle demand fluctuations. Such factories will be more fault-tolerant and enable to produce with maximum efficiency. Human, Machines, and resources can not only communicate, but also work together. In addition, the machine claims themselves to maintain, and are capable of defining the problem accurately. With the help of RFID transponders products can control their

[122] Cf. Rosen, Gibson, Stucker (2015), p.4-6.
[123] Cf. Srivatsan, Sudarshan (2016), p.2

production processes. The product determines from which parts include and where to be sent later. The product itself is actively associated with the production process. The facilities of such company are interlinked with smart logistics, smart distribution, smart building and smart grid.[124]

In addition to the most important core technologies, ustundag and cevikcan illustrate a general framework for Industry 4.0 as seen in figure 17.

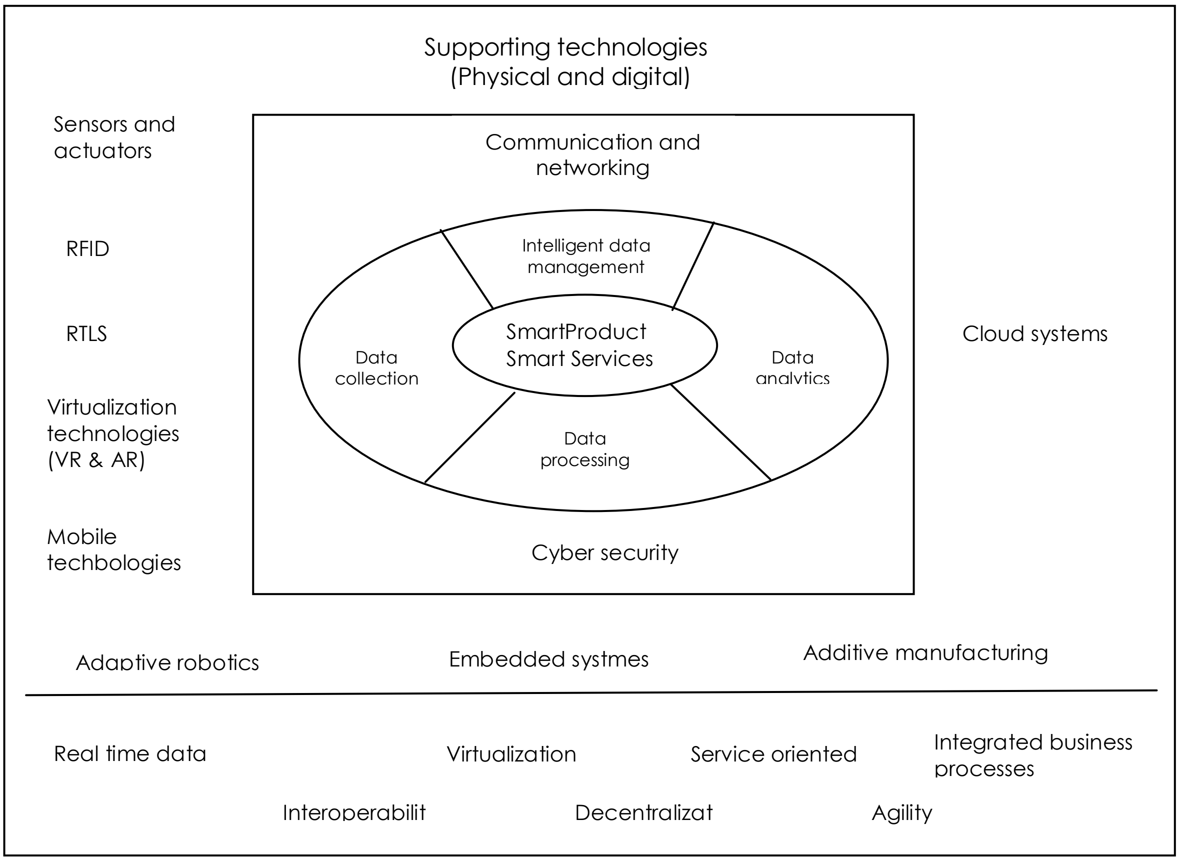

Figure 17: Industry 4.0 framework

Core technologies are emphasized for support technologies include sensors and actuators, RFID and RTLS technologies, mobile technologies and virtualization technologies. In order to fulfill the virtualization part of Industry 4.0, certain tools can be used such as augmented reality and virtual reality. In addition, sensor, RFID and RTLS technologies allow real-time data flow and data collection, which is important for intelligent data management in decentralized systems. The mobile technology supports

[124]Cf. Mindas, Bednar (2016), p.22

the reception and processing of large quantity of information for recording and transmitting information and assists agile-remote control of the whole company.[125]

The adoption of future manufacturing systems drives the industry to transform their way of operating, their business models and concepts. For example, today's enterprise resource planning (ERP) solutions require operators to manually enter data associated with processes and production. The extensive application of information and communication technology in manufacturing industry and conventional production systems weakens the border between the real world and the virtual world.[126]

Industry 4.0 has the possibility to positively impact individual customer needs, production flexibility, resource productivity and efficiency, optimization of decision making, value added through new services, human labor force work-life balance, changing in the workforce and a competitive economy with high payment.[127]

The goal of Industry 4.0 is to establish industrial background through the digitized components of industrial systems, applying information technologies via the small batch production in accordance with accurate specifications, allowing minimal lot sizes to single piece production for existing customers (pull system), and not to manufacture products for the shop (push system) with uncertain customer.[128]

[125]Cf. Ustundag, Cevikcan (2018), p.20
[126]Cf. Raza, Haouari, Pero, Absi (2018), p.218.
[127]Cf. Kagermann, Wahlster, Helbig (2013), p.19
[128]Cf. Mindas, Bednar (2016), p.29

5 The benefits of Industry 4.0 for variant variety

As already described in chapter 2, the number of product variants has risen continuously in recent years in many companies. And chapter 3 suggests that internally manufacturing companies are expecting to have as few variant varieties as possible and externally as many variant varieties as required to meet the requirements of existing and new customers. In this context, the challenge of managing variety is responding to external variety while reducing the internal complexity and ensuring satisfactory performance in terms of flexibility, cost and responsiveness.

Recently, advancement in information system technologies created new manufacturing opportunities. Particularly, the concept of Industry 4.0, that is to say, the application of intelligence and network concepts to the manufacturing environment, is offering instruments to reduce the complexity of managing production systems.[129] The main goal of Industry 4.0 is to meet individual needs of customers which have an impact on research and development, order management, manufacturing commissioning, delivery and utilization of product and product recycling.[130] In this chapter, the benefits of Industry 4.0 for variant variety will be discussed.

5.1 Meeting individual customer requirements (Increase external variety)

The classic business model is transforming as the production today cannot meet the increasing demands of customers. Customers have increasingly requirements and their increasing complexity. Additionally they expect to have everything as quickly as possible.[131] Industry 4.0 will result in the development of new business and partnership models, which tend to meet individual and last-minute customer needs.[132]

5.1.1 Customer-integrated engineering

The provision of a selection may not be of value to the customer automatically. In the past, some manufacturers offered their customers a wide range of options. But most users do not value choices that do not suit their interests. Additional options

[129] Cf. Raza, Haouari, Pero, Absi (2018), p.217
[130] Cf. Neugebauer, Hippmann, Leis, Landherr, (2016), p.2-7
[131] Cf. Mindas, Bednar (2016), p.1
[132] Cf. Kagermann, Wahlster, Helbig (2013), p.22

usually generate confusion. Therefore, customers need more time to understand the difference between these options. This extra psychological burden can hinder commitment of sales; add additional sales effort and even chasing customers away. In consequence, it is important to reconcile the variety of product provided to the customer with the perceived value.[133]

In recent decades, the status of customers has transformed in the creation of value from passive recipients to active co-designer. Customers are progressively looking for the way how their products are designed and manufactured, and want to involve into the development and production processes in an early phase. The earlier the needs of the customer is considered, the greater the impact on product customization.[134]

Successful innovators adopt capabilities within an expanded network, especially including the capabilities of customers. Many studies have proven that integrate customers in the development process as early as possible is able to significantly increase the success of innovation. In numerous industries, customers are accountable for the most successful development. Consequently, the capability to permit information about customers and their requirements to flow into the product creation process is decisive.[135] Manufacturing companies have the opportunity to increase the benefits of a specific product family by helping customers identify what they real want.

Manufacturers do not only directly and systematically provide direct channels for collecting needed information of customer, but they also enable customers to innovate themselves continually in collaboration with the company. This approach is on the basis of the admission that customers are not only in ownership of solution information. In fact, numerous customers have an exhaustive and specific knowledge of how their needs can be fulfilled.[136]

In Industry 4.0, customers can more participate in the design process and even providing their own modified designs, which then is able to be produced quickly and inexpensively.[137] Some methods of customer integration are discussed in this subsection.

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[133]Cf. Piller, Tseng (2010), p.3
[134]Cf. Piller (2004), p.313-334
[135]Cf. Damerau, Hayka, Stark (2013), p.52
[136]Cf. Reichwald, Engelmann, Meyer, Walcher (2007)
[137]Cf. Davies (2015), p.4

Virtual customer integration platforms (VCI platforms)

The Internet as a unidirectional or bidirectional communication channel between companies and customers is used by VCI platform. For example, customers are able to express their ideas for individual products and discuss with development engineers. The grade of richness can range from text communication to user innovation toolkits or multimodal interfaces that allow customers to control the end product. VCI tools can provide services to customers individually or through online communities thus realizing the origin of creativity, users can create and estimate products, avoiding intermediaries for example market research companies.[138]

Virtual customer Environment (VCE)

The virtual customer environment (VCE) intensely overlaps with the virtual customer integration platforms (VCI) platform. Unlike VCI platforms, VCEs can provide virtual product creation technologies in physical world to enable direct customer-engineer interaction. Examples of VCE include BMW's Customer Innovation Lab, Ducati's TechCafé or Volvo's Concept Lab.[139]

Virtual reality and augmented reality

Virtual Reality (VR) offers a simulation tool aided by computer that can reflect the reappearance of the real life environments the users perceive and see the simulated reality that they experience in real life. Augmented reality (AR) is advanced in applications to integrate digital elements with behaviors in the real world. The whole integration of VR and AR offers the richness of real life cases and behaviors.[140] For instance, customers will not need to go to a showroom or store to check the product in the near future. The customers can have an overlook of the virtual product from their comfort home by using the virtual reality goggles. Customers can see cars from inside and outside with the help of these glasses for virtual reality.[141]

Simulation

Simulation and modeling are going to be very important part in the process of the product design. The aim of this system is to offer a platform for testing products during the design phase. The product is able to be expressed, analyzed and redesigned without the need for physical prototypes. A new type of modeling tool needs to be developed; it will offer a platform for all the participants to access the design and

[138]Cf. Damerau, Hayka, Stark (2013), p.54
[139]Cf. Damerau, Hayka, Stark (2013), p.54
[140]Cf. Ustundag, Cevikcan (2018), p.20
[141]Cf. Mindas, Bednar (2016), p.25

get feedback. 3D printing and rapid prototyping are some of the factors that contribute to the achievement of a product before final production.[142]

Before applying a new paradigm, system ought to be tested and reflection ought to be thought carefully. Therefore, multiple simulation types, including 3D motion simulation and discrete events, can be performed in different cases to enhance product or process planning.[143]

Cloud based design

Cloud-based design means a design model that with the help of Web 2.0 and Web 3.0 to sustain the collection, processing, representation and use of product design-related information that is allocated on the Internet and social media. Traditionally, it has always been the view that the generation of design ideas and their implementation is the task only for the design teams. However, cloud-based design has the possibility to allow engineers, customers and other participants to exchange social media information by combining Web 2.0 tools into the process of product design. For instance, a Web 2.0 site offers consumers and service providers a tool to interact and communicate with one another via online product reviews. In this way, designers are able to easily receive feedback from user experience of customer.[144]

As the cost of error correction increases exponentially over time, the prediction of potential problems that caused by errors in product development can result in high cost potential. As a result, the virtualization improves the iterative development, and therefore also the very short development processes because virtual experiments are supported. To obtain valuable decision-making abilities on the basis of simulations, a large number of simulations must be implemented.[145]

Data analytics, cloud systems, and artificial intelligence technologies are also able to perform service-oriented architecture of Industry 4.0 framework and provide specifications of individual customer by evaluating the external information from digital manufacturing environment.[146] The time between the product design and the delivery to the customer can be reduced by the virtual modeling of manufacturing process and digital designs.[147] By using these technologies, customers are able to

[142]Cf. Sikhwal, Childs (2018), p.28
[143]Cf. Kuehn (2006), p.1899-1906
[144]Cf. Thames, Schaefer (2017), p.14
[145]Cf. Schuh, Reuter, Hauptvogel, Dölle (2015), p.16
[146]Cf. Ustundag, Cevikcan (2018), p.17
[147]Cf. Davies (2015), p.3

design products by their own. As a result, the number of product variants has increased significantly.

5.1.2 Mass customization

Since recent decades, product variety in the company has been increasing, therefore forcing manufacturers to produce increasingly customized products. To cope with this, manufacturing companies are applying mass customization, that is to say, a manufacturing strategy that intent to provide customized goods at low cost.[148]

Different from in the make-to-stock system, in the mass customization system the customers wait while their orders are processed or assembled. Hence the cycle time has to be as short as possible. In the mass customization industry, it is becoming increasingly important for customers to participate in all the product development stages.[149]

In chapter 3 it is found out that in the last decades mass customization has achieved. Customization according to requirements of individual customers intuitively results in small quantities and higher varieties. Many techniques have been created to achieve this. For example, although the end products can be widely different, they can contain large quantities of the same components or subassemblies for mass production. Customers are able to configure with components that are produced in the back end according to their needs. Another approach is to order the products or subsystems in this way that similar or the same materials can be achieved with economies of scale. Now the question is how to achieve Mass customization in the context of Industry 4.0?

Chapter 4 explores the objective of Industry 4.0 is to adopt information technologies in small batches production based on explicit specifications to ensure smallest lot size up to one-piece-flow production for existing customers. Mass customization is a strategy that can be used to produce small lots products. That is because the machines in the system can be quickly reconfigured and adapted to the specifications identified by the customer.[150]

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[148]Cf. Raza, Haouari, Pero, Absi (2018), p.217
[149]Cf. Raza, Haouari, Pero, Absi (2018), p.218
[150]Cf. Mindas, Bednar (2016), p.30

In the future of Industry 4.0, individual customer- and product-specific characteristics can be integrated into the ordering, design, configuration, planning, operation, production, and recycling phases. It can even include last-minute change requests immediately before manufacturing or during manufacturing and even possibly during operation. This advantageously leads to one-off items and quite small number of goods manufacturing profitably.[151]

Many authors are like to agree that mass customization is on the basis of flexible manufacturing technologies and information technologies, so that manufacturing systems can offer a high variety of products at a low cost.[152] One of the most possible technologies to realize mass customization is additive Manufacturing (3D printing).

Rosen et al. investigate that additive manufacturing is now often pointed out as one of a set of disruptive technologies that can change the way the companies design products and establish new businesses.[153]

Additive Manufacturing (AM) referred to rapid prototyping in the past and is normally referred to 3D printing. The Rapid Prototyping (RP) is adopted in many industries to characterize a process for rapidly building a system or component representation before final release or marketing. It concentrates on creating objects quickly, and the output is a basic model or prototype from which more additional models and at last the end product can be derived. In the product development environments, rapid prototyping was widely applied for representing technologies, which can build physical objects directly from digital model data.[154]

When it is said that the additive manufacturing technology is just useful for the production of the model, it would be not accurate and the technology is underestimated. When applied in combination with other technologies to set up process chain, AM is able to be used to reduce the time and costs of product development. Lately, some of these technologies have been evolved to the degree that the output is appropriate for final use.[155]

Additive manufacturing processes bring more advantages than conventional processes. From the point of view of application, AM provides a high level of personalization and customization with little effect on manufacturing complexity and cost,

[151]Cf. Kagermann, Helbig, Wahlster (2013), p.21
[152]Cf. Alfnes, Skjelstad (2010), p.47
[153]Cf. Rosen, Gibson, Stucker (2015), p.10
[154]Cf. Rosen, Gibson, Stucker (2015), p.1
[155]Cf. Rosen, Gibson, Stucker (2015), p.4

because the AM process does not include any tools and related cost components. In test phase and small batch production environment, material waste, material-related time and costs and stock levels are significantly decreased. Moreover, it is possible to produce geometrically complex, individualized and compositionally heterogeneous components, which can be expensive with conventional manufacturing processes.[156]

The additive process of 3D printing can realize customization of products and is flexible. It is possible to replace the requirement for assembly, completely eliminate transportation and energy, reduce the labor division, afford deserted the manufacture of products in bulk from production-distribution-consumption triad.[157]

Additive Manufacturing is a paradigm shift that investigates vertical integration to reduce the complexity of the supply chain. Simultaneously, the advantages of building up layer by layer rather than engraving materials allows for increasing degree of product complexity. Because product complexity is "free" to some extent, the influence is reflected in a great reduction of routing complexity because fewer components are required to be assembled to finish an end product. From the manufacturing point of view, another major advantage is the flexibility to move from product A to product B increasing customization with less effort.[158]

To cope with current mass production, mass customization enables very small batch production – even down to an individual specific product - and still can make profit.[159] This increases the cost-effectiveness of prototyping and customization therefore supports innovation. Small last-minute change can be made to the product or prototype. The technologies of Industry 4.0 enable increasing variant variety.

5.2 Flexibility (Reduce internal complexity)

Internal varieties are the result of external varieties and indicate the variety of resources, products, components, modules and processes. Such variety often results in increasing complexity within production systems and the entire supply chain. Industry 4.0 refers to the vision of smart factories that established with intelligent cyber physical systems. It will be able to allow manufacturing ecosystems driven by intelligent systems that with autonomous attributes such as self-monitoring, self-configuration

[156]Cf. Yang, Hsu, Baughman, Godfrey, Medina, Menon, Wiener (2017), p.6
[157]Cf. Birtchnell, Urry (2016), p.7
[158]Cf. Perez, Sauceda, Cruz (2018), p.30
[159]Cf. Kagermann, Wahlster, Helbig (2013), p.16

and self-maintenance. This technology will enable us to realize unprecedented levels of operation efficiency and stimulated increase in productivity.[160]

5.2.1 Flexible production

The demand of customers for customized products and high availability result in a more and more complex manufacturing environment for companies. This complexity is only able to be controlled by increasing the decentralization and autonomy of the production modules related to manufacturing.[161]

Smart factory

The creation of smart factories is the cornerstone of Industry 4.0. Smart factories will enable to handle demand fluctuations. Smart factories are more fault-tolerant and have the ability to produce with maximum efficiency. Human, Machines and resources are not only able to communicate, but also work together. The machines claim themselves to be maintained; in addition they can define the problem accurately. Products with RFID transponders can in charge of their own production processes. The products recognize from which components they compose of and where they are going to be delivered later. The products themselves actively participate in the manufacturing processes.[162]

Figure 18 shows the differences between current production and production based on the concept Industry 4.0. It is common knowledge that conventional assembly manufacturing lines are synchronized. That is to say, both workflow and material flow are predefined based on the orders of customers that are entered into the business enterprise system. Production and assembly procedures are continuously allocated to every single work station. Simultaneously, all line work stations are synchronous. With Industry 4.0 it is conversely, it is on the basis of asynchronous manufacturing, with variable product parts in the production process. With the help of RFID technology allocating tasks to every machine including workers, so that they know what have to be done, which variable part or module have to be picked and installed to create the customized finished product at every phase of the production process.[163]

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[160]Cf. Thames, Schaefer (2017), p.5
[161]Cf. Bauernhansl (2014), p.14
[162]Cf. Kagermann, Wahlster, Helbig (2013), p. 17
[163]Cf. Mindas, Bednar (2016), p.30

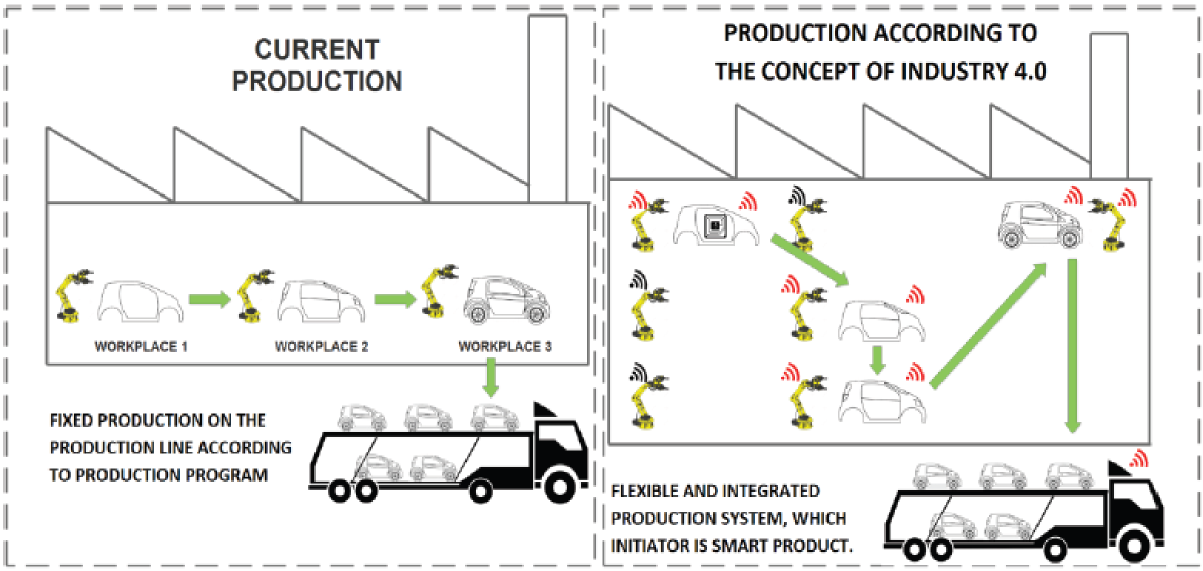

Figure 18: Current and future production in the Smart factory.[164]

On the basis of the analysis of the future production literature, features that required for smart factories will involve in low cost, re-configurability and flexibility, agility, variability and slimness.[165]

Factories in the future can be characterized by the following elements:[166]

- Intelligent objects: Intelligent objects consist of elements with advanced functions like data collection, processing, and storage, and the capability to communicate with their environment. An intelligent object could be an individual product that saves and transmits information about its processing steps and the entire intelligent system. This is understandable in the sense of CPS.
- Vertical Integration and data continuity: Stronger vertical integration resolves the hierarchical control architectures of the traditional automation pyramids.
- Communication technology network: A basic requirement for a smart factory is the capability of communicating and interconnecting with and among smart objects.
- User interaction and provision of information: As the process becomes more complex and the amount of data exponentially increases, it is necessary to provide new technologies to people. Therefore, the communication between human and machine (Human-Machine Interaction (HMI)) plays a significant role in the discussion today.

[164]Cf. Mindas, Bednar (2016), p.23
[165]Cf. Hozdic (2015), p.31
[166]Cf. Bauernhansl (2014), p.17

- Changeable production systems: The flexible integration of smart objects with self-controlled production systems can carry out flexible production system.

Smart factories enable increased production flexibility. The transmission of data related to a product across the manufacturing chain, the automation of the manufacturing process and the adoption of configurable robots indicate that various final products are able to be manufactured in the same production facility.[167]
Figure 19 shows that the Internet of things and services are as the basis for the smart factory in the Industry 4.0.

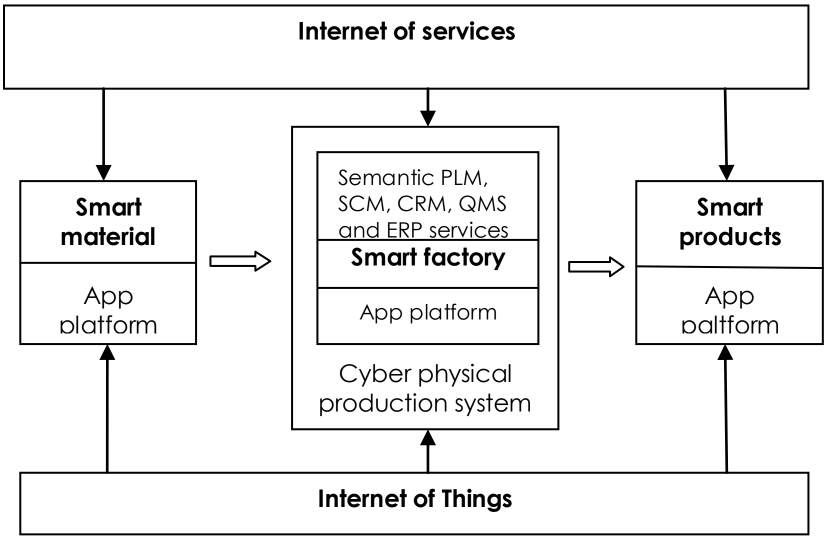

Figure 19: Smart factory.[168]

Internet of Things (IoT)

Technically, the Internet of Things is a series of physical objects that include embedded systems of mechanical, electrical, computational, and communication mechanisms that allow communication and data sharing using the Internet as a basis.[169]
The Industrial IoT is defined as the same core definition as the Internet of Things. However the things and objectives of the Industrial IoT are often different. Examples of an industrial IoT contain devices like sensors, robots, actuators, manufacturing equipment for example 3D printers, milling machines and components for assembly lines, engines and even cars, trains and airplanes.[170]
Products can communicate with machines while in charge of production with the help of IoT. Management, control and Information flow are carried out digitally via

[167]Cf. Davies (2015), p.3
[168]Adopted from Wahlster (2012), p.11
[169]Cf. Thames, Schaefer (2017), p.3
[170]Cf. Thames, Schaefer (2017), p.3

the Internet Protocol.[171]

The Internet of services

A deeper comprehension regarding the origin of Internet of services shows that the concept of Service-Oriented Architecture (SOA) can describe how Industry 4.0 operates in a technological and business point of view. In Industry 4.0, it operates as a service bus, in which various robots, machines and applications can be used in the production process. Service-oriented manufacturing architectures can be created by discovering and combining applications to access, match, and integrate different services.[172]

While making decisions with the help of its own sensors and actuators, the product itself is able to track the better configurable lines in the plant. By adopting this architecture, companies are able to create their own manufacturing services for the involvement in an external supply chain, additionally to the administration of the internal supply chain. Internet of service is generated.[173] Interactive applications in the Internet enable companies to serve more people and interact with customers directly, easily and quickly. Product planning and market research are no more accomplished in an isolation fashion, but these activities will be executed together in the customer community.[174]

Cyber physical systems

The most important thing to realizing the aforementioned smart factory is the application of CPS. With the help of this technology, all in real time machines and equipment are able to control the production process to realize high efficiency, optimize material usage, tailored and optimizing production cycles based on customer needs, and insuring low-dose products in different adjustments.[175]

The components in the manufacturing factory turn into cyber-physical devices that have more intelligence and communication capabilities than machines today. With these capabilities, cyber-physical systems are able to participate in some planning and decisive tasks. The machines are responsible for sufficient supplying of materials; convert the production method in the best way to the actual product or to decide a new method by itself (self-learning machine). These machines have social features

[171]Cf. Mindas, Bednar (2016), p.23
[172]Cf. Reis, Goncalves (2018), P.23
[173]Cf. Reis, Goncalves (2018), P.24
[174]Cf. Luetke-entrup (2014), P.32
[175]Cf. Mindas, Bednar (2016), p.23

and create their own "social" networks.[176]

Although the initial input and the end output are typically physical, during the manufacturing process information usually exchange between physical and digital status. For instance, if an object is on the basis of the scans, it is able to scan the physical part and model a digital representation. The digital data can then be converted back to physical information through 3D printing the part.[177]

In smart factories, cyber-physical systems observe physical processes, establish virtual copies of the physical world, and take decentralized decision makings. Cyber physical systems communicate and collaborate with one another and with people in real time over the Internet of Things. Through the Internet of services, participants provide and adopt internal and cross-organizational services in the value chain.[178]

In the virtual factory all devices have counterparts and are interconnected to the cloud. Virtual factory is permitted to operate almost at the same time with physical factory. In this way, the interaction from virtual factory to physical factory is achieved. Several controllers and agents are working hard to achieve the functions to dominate the physical factory by changing the virtual factory. The agents are going to investigate and obtain the signal that transmitted from the virtual factory and look for the counterpart in the physical factory as quickly as possible. The commands are then sent to the physical equipments or material and are thus adapted assisted by controllers.[179]

Employees monitor the states of the virtual factory and get data back from the cloud. They can also enter identified instructions into the cloud to indirectly dominate the factory and administrate the resource library. Sales orders and detailed demands of customers are also stored in the cloud. The product conditions are able to be checked and followed at any time, because there is always a tag on the materials. Customers are therefore notified about the extent of fulfillment and the delivery performance of their orders. More importantly, they can even connect to the cloud after the possession has been shifted to them from the company.[180]

Employees in various departments can access to the cloud so that they are notified of the orders simultaneously. The production department does not have to wait for comprehensive information from the business department. Likewise, the adaptation

[176]Cf. Wittenberg (2015), p.239
[177]http://www.tlu.ee/~pnormak/ISA/Analytical%20articles/2-Industry%204.0%20-%20Kusmin.pdf
[178]Cf. Hermann, Pentek, Otto (2016), p.11
[179]Cf. Zhang, Li, Wang, Cheng (2017), p.144
[180]Cf. Zhang, Li, Wang, Cheng (2017),P.144

of plan accomplished by the production department is also transparent for the department of business sector and logistics. As a result, various departments are connected via the cloud, and many devices are also connected. The information islands problem is solved in smart factories.[181]

Additionally, the disadvantages have also been resolved are:[182]

- Man: smart devices have replaced manual work to some degree, so as to achieve increasing efficiency and consistency of quality. Also labour costs are saved.
- Machine: these devices are not easy to implement like straightforward-designed machine, but offer smarter and better control over the cloud. They enable to perform more complex tasks and work together more harmoniously.
- Materials: materials are managed according to policies stored in the cloud to ensure a cleaner and more refined work condition.
- Methods: in the resource library all of the information is managed successfully. The operation modes have a higher throughput to cope with the market requirement.
- Measurement: the cloud makes full use of historical data to ensure the devices perform well. Self-inspection and self-adjustment are achieved so that employees do not need regularly check. Smart meters have high accuracy and can even send measurement data to the cloud.
- Environment: air conditioners and humidifiers are intelligently adjusted under the instructions of the cloud intelligently. Environmental factors like temperature and humidity are controlled at a reasonable level so that people feel comfortable and the machine runs well.

The integration of these elements mentioned above make it possible to react quickly and flexibly to customer demands and an automated production with a large amount of variants for small batch sizes. An example of a smart factory is the electronics factory of Siemens in Amberg (Germany). The Factory adopts the advanced "smart factory" that integrates product management, manufacturing and automation systems to create customized programmable logic controllers (PLCs). In this smart factory, smart machines coordinate the distribution and production of 950 products, which includes more than 50,000 different variants. And they need to source approximately 10,000 materials from 250 suppliers. Innovation cycles are

[181]Cf. Zhang, Li, Wang, Cheng (2017),P.145
[182]Cf. Zhang, Li, Wang, Cheng (2017),p.145

shortened, productivity increased and quality improved through combining intelligent machines with data-rich components and employees: the Amberg plant records 12 errors per million (around 500 in 1989) and realized a 99% reliability rate.[183]

With the adoption of smart factories, highly configurable and intelligent machines enable more flexible production, resulting in more product variety being manufactured in a certain manufacturing facility, more agile production processes and respond to changes and temporary bottlenecks.[184] This enables the production of small lot sizes (even if it is a single unique item), as the machine can be quickly adapted to customer specifications and additive manufacturing. This flexibility also promotes innovation as new products or prototypes are able to be made quickly without the need for complicated re-tooling or new production line setups.[185]

Smart products

A smart product consists of three fundamental components:[186]

- 1)Physical parts consist of mechanical component;
- 2) Smart parts with sensors, microprocessors, controls, data storage, embedded operating systems, software and digital user interfaces;
- 3) Connectivity parts with ports, protocols, antennas and networks that allow the communication between product and product cloud.

The smart products in Industry 4.0 are individually recognizable and are able to be positioned at any time. These components know what they are and are able to interact with the devices via RFID technology. They will understand the details of their own production process even during they are being produced. After they get to the right workstation, they will let it know which component and variant they are and ask it to work on them using the suitable methods. It means that smart products can control the individual production steps of their production semi-automatically in some certain sectors. In addition, it can be ensured that the finished product knows the parameters within which it will function optimally and can realize signs of abrasions during its entire life cycle. This information can be collected to optimize smart factories considering deployment, logistics and maintenance, and for combination with the applications of business management.[187]

[183]Cf. Davies (2015), p.4
[184]Cf. Kagermann, Wahlster, Helbig (2013), p.21
[185]Cf. Davies (2015), p.3
[186]Cf. Porter, Heppelmann (2015), p.1
[187]Cf. Kagermann, Wahlster, Helbig (2013), p.21

Smart products use their embedded control software as an active sender to communicate with other smart products. Therefore, when a smart product reaches the action and communication phase, it can transmit data that another smart product can obtain.[188]

Smart products also require product design principles to stay away from tradition:[189]

- **Low-cost variability.**
  Variability is very expensive in traditional products, as it needs to change physical components. But with the help of software in smart products, variability is becoming much cheaper. For instance, John Deere built several versions of engines, each with individual horsepower ratings. Now the software can be used alone to change the performance of the standard physical engine. Similarly, dials and buttons can be taken over by digital user interfaces to simplify and reduce costs in modifying a product through changing the control options. Satisfying customer needs for variability via software, is an important new design subject.
- **Evergreen design.**
  Products were designed in various generations in the old model. The new product merged a number of required enhancements and then the design was settled to the next generation. However, smart products are able to be updated remotely by software. Products can also be adapted to satisfy new customer needs or resolve performance problems. For instance, the performance of ABB Robotics' industrial machines is able to be remotely observed and modified by the end user during operation. Companies can post new, not finalized features that are working-in-process. Lately, Tesla started to install "autopilot" systems in its vehicles. The goal, however, was to improve the functionality of the system through remote software updates.
- **New user interfaces and augmented reality.**
  The smart product digital user interface can be placed remotely in a tablet or smart-phone application, allowing remote operation and even without having to control in the product itself. As mentioned above, these interfaces are less expensive to operate and easier to convert than physical controls, and can achieve greater mobility of operator.

So far, the manufacturing industry has advanced to a standardized platform, and the process of customize products takes place in the assembly process as late as

[188]Cf. Anderl, Picard, Albrecht, (2013), p.4
[189]Cf. Porter, Heppelmann (2015), p.1

possible. This approach can achieve economies of scale and reduce inventory. After the product is delivered, field service technicians and even customers can load or configure the software in the product or in the cloud. They can add new applications or set up touch-screen keyboards for different languages. Changes to the product design can be made at the last minute, even after delivery.[190]

Products made by smart factories are going to be more reliable and will monitor themselves on their functional conditions. This will lead to satisfied customers.[191] This enables the companies to manufacture a large range of products to meet the demand of customers and adjust rapid to temporary increases or even reduce in market requirements.

5.2.2 Increased production speed

The aggregation and processing of data that collected from manufacturing processes and different resources of the environment in real time can help to integrate organization functions. These data also allow the machines to make decisions by themselves.[192] The production speed with which a product is able to be created will also increase. The data driven supply chain can accelerate the production process by about 120% in the field of time required to deliver orders, and reduce time that required bringing the product to market by about 70%. By collecting, preprocessing and analyzing all available plant data, the entire manufacturing process becomes transparent and bottlenecks and potential for improvement points are identified. For instance, in the automotive industry, design standard are usually dictated by the customer. If the modification of design influences production speed, it is able to investigate this change and offer proof to the customer, this helps to quickly eliminate faulty design specifications.[193]

5.2.3 Higher product quality and decreased error rates

Although production with higher speed previously related to decreases quality, product quality will increase and error rates will decrease regarding to the data-

[190]Cf. Porter, Heppelmann (2015), p.1
[191]Cf. Mindas, Bednar (2016), p.27
[192]Cf. Ustundag, Cevikcan (2018), p.14
[193]Cf. Davies (2015), p.3

driven manufacturing, because the methods of sampling for error identification are substituted with real-time data from sensors.[194]

Successfully combination of robots, embedded systems on the basis of cyber physical infrastructure, big data analytics and cloud systems can achieve autonomy and self-decision making. For example, knowledge discovery is able to be extracted and provision activities can be assured for every cyber physical component with the help of using data processing, sharing and analysis.[195]

One way to reflect the overall production is to improve the activity of the processes by using automated robots to reduce failures in simple tasks.[196] Some advantages of automation in manufacturing processes are as follow:[197]

1. Reducing production loss by reducing in non-production time through automated decisions for:
   - Making the factory online or restarting the factory more rapid during startup, after reconfiguration to new needs or failures.
   - Maximizing production by improving the entire availability of the factory and keeping the factory online.
   - Enhancing the process productivity by improving performance and making repetitive tasks faster.
2. Respond more faster as there is no human intervention needed to:
   - Deal with emergency situations.
   - Decrease the possibility of human error and reduce defects.
   - Make sure to run of each process effortlessly and constantly every time.
3. Resource optimization by reducing in:
   - Employees including reliance on very qualified personnel.
   - Inputs to process consist of energy.

In a smart factory, machine-to-machine communication (M2M) refers to the automatic data exchange between terminals, and there is also a classical human-machine communication, for example human can communicate with machine via touch screens. For instance, if the machine fails, the service engineer of the machine can receive the information through the mobile terminal and are informed what the

[194]Cf. Kinzel (2016)
[195]Cf. Ustundag, Cevikcan (2018), p.17
[196]Cf. Kagermann, Wahlster, Helbig (2013), p.16
[197]Cf. Sharma (2017), P.13-14

failure is. With the help of this information maintenance can significantly be speeded up and machine downtime is reduced.[198]

Data-driven simulation, advanced analytics and predictive maintenance will assist to prevent machine downtime and plan changes of the shop-floor.[199] Data analysis allows real-time detection, monitoring, and forecasting of the assets. Emerging models can be adopted to forecast future activities, as large amounts of data can be collected from different systems for combination and analysis. Real-time data management is performed through an online monitoring tracking and tracking system to avoid system lacks in the event of an error.[200] Stored information often assists communication and enhances decision making, but it also eliminates human mistakes in the design and production process.[201]

With the help of advanced analytics in preventive maintenance procedures, companies can prevent machine fails and reduce downtime by about 50%, and improve production by 20%. Some companies will be capable of establishing a “light-out” factory, in the factory automated robots will keep on producing with no light or heat after the workers has returned home. Company can use the employees more effectively for tasks that are really important to them. For instance, philips manufacture electric shaver in a "dark factory", there are 128 robots and only 9 employees, the task of the employees is only to make sure of the quality.[202]

5.2.4 Optimized decision-making

In order to be successful in the world market, it is often important to make the right decisions in a very short time. Industry 4.0 offers end-to-end visibility in real-time that enables early validation of design decisions in the field of engineering and a more flexible response to breakdowns, as well as worldwide optimization across all of a company’s locations in the production area.[203]

End-to-end digital system engineering

End-to-end digital system engineering and the generated optimization of the value chain indicates that customers are not forced to make choice from a predefined

[198]Cf. Braun (2017), p.7
[199]Cf. Kagermann, Wahlster, Helbig (2013), p.16
[200]Cf. Ustundag, Cevikcan (2018), p.17
[201]Cf. Plinta (2016), p.7
[202]Cf. Davies (2015), p.4
[203]Cf. Vossen, Schönthaler, Dillon (2017), p.255

product line defined by the manufacturer anymore, but can combine components and customize individual functions according to their specific requirements.[204]

Nowadays, value chains (from customer needs to product design to manufacturing) often appear over many years and are inclined to comparatively static. IT support systems exchange information through diverse interfaces, however, can only use this information regarding in particular individual situations. From the point of view of the product to be produced, there is no worldwide overview. Consequently, customers can not choose all features and functions of their products freely, even if they are technically allowed to do so.[205]

The development based on models enabled by CPS permits the advancement of end-to-end, digital methods that overlap every respect from customer needs, product architecture and production of the end product. This allows all the interdependencies to be determined and described in an end-to-end engineering tool chain. Manufacturing systems are developed in parallel on the basis of the identical paradigms, which means that they are always synchronized with product development. Consequently, it turns into realizable to manufacture customized products. By progressively migrating to this tool chain over multiple stages, it is feasible to retain the value of the present installed base.[206] Figure 20 illustrates the different value chains between today and the future.

[204]Cf. Kagermann, Wahlster, Helbig (2013), p.33
[205]Cf. Kagermann, Wahlster, Helbig (2013), p.33
[206]Cf. Kagermann, Wahlster, Helbig (2013), p.33

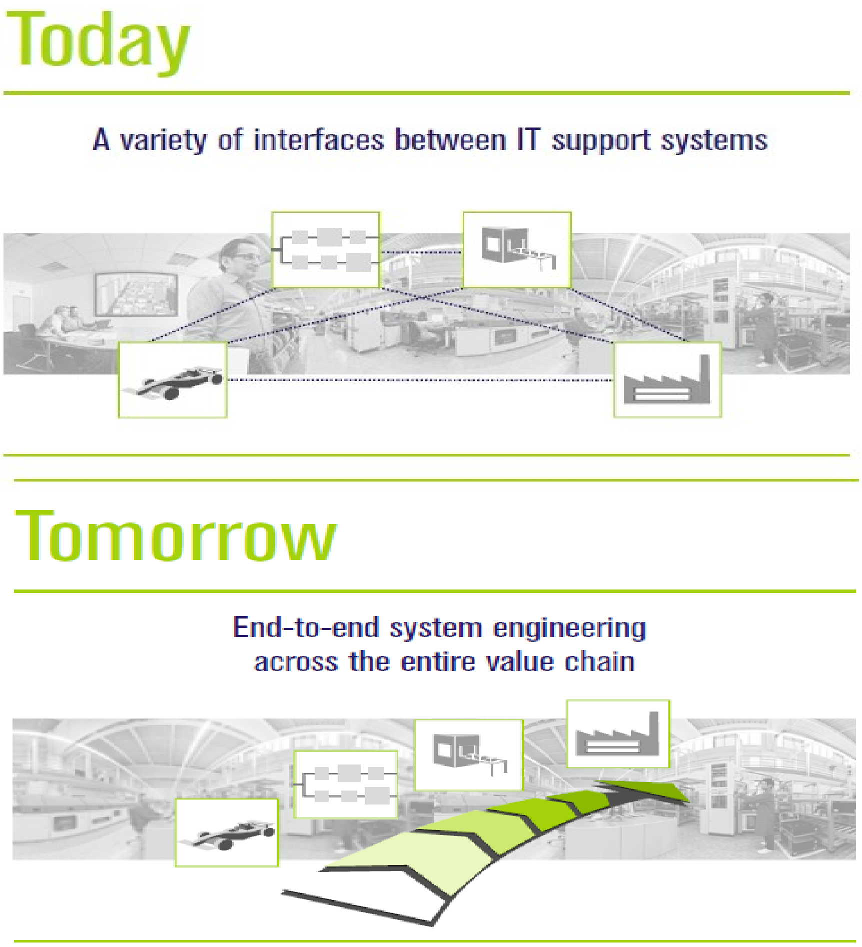

Figure 20: Different value chain between today and the future.[207]

The integration of different technologies can result in greater flexibility, more individualization potential and less resource utilization.[208] In the future, the platforms will connect the entire value chain so that suppliers, manufacturers and their customers can communicate and response to changes quickly. They will help the company to decide faster and more accurate which products to produce and how to manage the team. Flexible manufacturing enables shorter production life cycle and more customization, thus improves the product range.

There are many benefits of Industry 4.0 for variant variety. In the contrast to this, there are also some restrictions. In the next chapter, the restrictions of Industry 4.0 for variant variety will be discussed.

[207] Adapted from Kagermann, Wahlster, Helbig (2013), p.33
[208] Cf. Brecher (2015), p.5

6 Restrictions of Industry 4.0 for variant variety

Offering a variety of attributes in products is a significant way to attract customers, but it tends to increase costs, particularly in the Industry 4.0 environment, where products are produced with many new technologies. This section describes the restrictions posed by the concept of Industry 4.0. The main threats in this respect are especially the costs and data security related to the implementation.

6.1 Investment

The biggest limitations of Industry 4.0 typically are knowledge, laws and not much familiarity with the concept. This concept will be extremely expensive for small enterprises. Due to the complex and fully automated manufacturing, it will be necessary to adopt a variety of support systems, sensors, and transponders. This requires an expensive preliminary investment. If the company is not fully prepared, there will be difficulties and delays in the transformation of Industry 4.0. In this context, companies need to focus on this concept and plan of operation and financial plans appropriately.[209] The decision for this transition must be at the CEO level. Nevertheless, the risk must be measured and taken in to consideration seriously.

The execution of Industry 4.0 must be specially designed for different organization and production schemes, for instance with regard to variety production structures or the dimension of the company.[210] Synchronizing and cooperation with existing manufacturing facilities and processes can lead to a high degree of complexity and cost, which is a particular challenge for small and medium-sized enterprises (SMEs). [211] In terms of costs, expensive investments are needed to establish the digital technology platforms required for smart manufacturing plants. Furthermore, the performance and expansion of digital technology systems needs high variable costs.[212]

For example RFID is the important technology of Industry 4.0. Different from cheap barcode technology, RFID technology is much more costly. Because RFID is on the basis of radio waves, it lacks radio communication: radio waves do not behave properly in wet environment where there is more metal in the environment and "electronic noise". Due to encode the various data in the RFID tags, it is needed to pro-

[209]Cf. Mindas, Bednar (2016), p.28
[210]Cf. Müller, Voigt (2017), p.14-18
[211]Cf. Müller, Buliga,Voigt (2018), p.7
[212]Cf. Abdi, Labib, Edalat, Abdi (2018), P.35

duce larger memory chips, results in more expensive products. This increases the time needed to read and transfer data. It is necessary to record information in subsequent RFID tags to offer a safety mechanism to avoid unauthorized people from recording incorrect information.[213]

The workers have to be qualified for adopting this new technology concept, the employees have to be willing to learn, have ability to solve problems in a social environment, have capability to find feasible solutions, and have knowledge of data analysis and processing and the network technologies.[214] It is required to invest in advanced training and knowledge. This can also result in high costs.

Davis addresses that if companies want to transfer to Industry 4.0, they need a high investment. Until 2020 Germany alone will have to invest to be estimated 40 billion Euros per year (Europe can be as high as 140 billion Euros per year). For small and medium-sized enterprises (SMEs), which are concerned about the transition to digitization, these investments are especially daunting as they have no idea how it will influence their value chains. Until now, it has been cautious: even in Germany, it is estimated that only a fifth of enterprises adopt interconnected IT systems to dominate their manufacturing processes, although nearly half plan to do so. Some critics believe that the systems are not reliable, too costly, and too large, and that mainly equipment manufacturers instead of customer requirement are forcing the development of Industry 4.0.[215]

6.2 Data ownership and security

Industry 4.0 conversions need exhaustive data collection and processing activities. Therefore, the basic concept for enterprises is the security of the data storage and transformation process. Security has to be ensured in cloud technology, robots, machines, and automatic systems.[216]

As large amounts of data are gathered and shared with value chain partners, organizations have to identify who owns the industry data and make sure that the data they generate cannot be used by competitors or copartners in the way that they do not authorize. Particularly, smart services will be on the basis of data processed by smart devices in the process of their production and utilization. For instance, car manufacturers are unwilling to share data processed by their cars because they are

[213]Cf. Hozdic (2015), p.33
[214]Cf. Erol, Jäger, Hold, Ott, Sihn (2016), p.13-18
[215]Cf. Davies (2015), p.5
[216]Cf. Ustundag, Cevikcan (2018), p.15

afraid that digital competitors will limit their profits. Some European rules on data storage, privacy and copyright that counterpoise trust and data protection are seen by someone as an essential step to protect European competitive strength.[217]

6.3 Legal issues

Advanced Manufacturing increases several legal issues, consists of employee administration, intellectual property and product liability. For instance, data from "smart gloves" that directly conducts and records workers' movements can be applied to monitor or estimate workers. If a self-automated production system that connects different value networks produces imperfect or hazardous products, how can the courts determine who is responsible for them in the network? If a customer applies for a personalized product, who retains the intellectual property (IP) rights to the design of the product? The French Conseild' analyseé conomique has already appealed to a balance among the acceleration of innovation through the protection of intellectual property and the sharing of knowledge, both are origins of future advance.[218]
Autonomous management of the production processes with no human intervention is the nature of a smart factory, which view is not legally realistic. A lot of European Union (EU) countries have already legislated that the control of machine needs human. In this respect, to drive an autonomous managed vehicle is impossible in many countries. Also because of this, companies need to be familiar with the country's laws before this concept is adopted. Also from this point of view, the concept of a smart factory is not easy to use as it requires a range of systemic but lawmaking modifications.[219]

[217]Cf. Davies (2015), p.6
[218]Cf. Davies (2015), p.6
[219]Cf. Mindas, Bednar (2016), p.28

7 Conclusion

Due to ever individual products that expected by customers, the product lifecycle is greatly shortened, so work on the technology required for production and the innovation of the product must be kept up-to-date. Companies are increasing product variety by providing customized products.

The objective of the company nowadays is to produce the product variety required by the customer as cost-effectively as possible. There are many approaches to increase variant variety, but the most efficient way is the adoption of technologies for enterprises to keep their competitive advantage. And the most modern way nowadays is to apply the technologies of Industry 4.0. Industry 4.0 will be able to gather and analyze data across machines, enabling fast, flexible, and efficient processes to produce customized products at a lower cost.

The starting point of this work was that, due to increasing market and customer requirements, the issue of variant variety and the management of increasing number of variants is becoming increasingly important. Thus, more and more companies are facing drastically increased variety requirements, where due to inadequate variant management, unwanted cost increases often occur. Thus, dealing with a growing variant variety has become a central task of the company. To this end, the causes for the increasing variety of variants and their effect on the divisions were explained first. The following chapters have shown numerous methods and strategies for coping with the problem of variants.

The aim of this work was to find out if it is possible that Industry 4.0 increase variant variety. This thesis describes the effects of Industry 4.0 on product variety from two perspectives. On the one hand is to meet individual customer requirements, also as the reason of increase external variety; To increase external variety, company can use many method and technologies to help the customer design their individual products, and to achieve mass customization. Industry 4.0 contains a higher priority on individualized products which means more variants, higher customized products, and smaller quantities of the identical product. And on the other hand is to increase the flexibility, also as the reason of reduces of the internal complexity. To reduce internal complexity, company can implement variety of technologies to increase flexibility and productivity. Smart factories allow individual customer requirements to be

met and mean that even one-off items can be manufactured profitably. High internal flexibility and efficiency in processes is the key to realize a high variety strategy.
There are not only benefits of Industry 4.0 for variant variety, but also restrictions of it as discussed in the last chapter. The main restriction is the costs that caused by the investment of new technologies. Data security and legal issues are also restrictions of Industry 4.0 for variant variety.

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