MASTER THESIS

Production technology requirements with respect to agile manufacturing

A survey on how the metal forming industry can adapt to volatile times

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Abstract

Agile manufacturing is a production concept that was originally developed at the Iaccoca Institute of Lehigh University (USA). The original purpose was to develop a proposal on how the US could regain its supremacy in manufacturing.
The objective of this thesis is to apply the agile manufacturing concept to the metal forming industry and to develop a recommendation of action how the industry can deal with volatile markets in an efficient way. For that reason production technology requirements are developed that should highlight characteristics of a production line that is essential to become “agile”. Furthermore a business model is developed that should allow the industry to adapt to volatile markets in accordance with the agile manufacturing concept.
As a point of departure a literature research has been carried out to determine what has already been published about “agile” production requirements and how other industries deal with volatile markets. Furthermore the basics of how to develop a business model have been researched as well as guidance tools that facilitate the development of the very same.
In a next step interviews with industry experts have been carried out to verify the findings of the literature review. The findings where documented in case studies which where the basis for the derivation of the production technology requirements that are relevant for the metal forming industry. The developed service-based business model is also based on the findings of the interviews.
Together, the production technology requirements and the business model enable the metal forming industry to deal with volatile markets in an efficient way.

Kurzfassung

„Agile manufacturing” oder Agile Produktion ist ein Produktionskonzept das ursprünglich am Iaccoca Institute der Lehigh University in den USA entwickelt wurde. Ziel war es, Vorschläge zu erstellen, wie die USA ihre verlorengegangene Vormachtstellung in der Produktion und Fertigungstechnik wiedererlangen kann.

In der vorliegenden Arbeit soll das Konzept auf die Metallformende Industrie angewandt werden, um sie besser auf volatile Märkte vorzubereiten. Dazu wurden Anforderungen an die Produktionsanlagen (Pressen und Pressenstraßen) entwickelt, die zu mehr „Agilität“ beitragen. Des Weiteren wurde ein Geschäftsmodell entwickelt, das es der Branche ermöglichen soll sich besser an volatile Märkte anzupassen.

Zu diesem Zweck wurde eine Literaturrecherche durchgeführt um zu eruieren welche Produktionsanforderungen schon beschrieben wurden und wie andere Branchen mit volatilen Märkten umgehen. Ferner wurde ermittelt, wie Geschäftsmodelle entwickelt werden und Richtlinien zur Erstellung von Geschäftsmodellen wurden recherchiert.

Darauf aufbauend wurden Interviews mit Industrieexperten durchgeführt um die Relevanz der theoretischen Ansätze für die Metallformende Industrie zu verifizieren. Die Ergebnisse wurden in Fallstudienreporten zusammengefasst und dienten als Basis für die Ableitung der Produktionsanforderungen. Das entwickelte Geschäftsmodell fußt ebenfalls auf den Ergebnissen der Interviews.

Die Produktionsanforderungen und das Geschäftsmodell ermöglichen es der Metallformenden Industrie sich optimal auf volatile Märkte vorzubereiten.

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1 Introduction

During the last decade the manufacturing industry was faced with dramatic changes at an increasing rate that is expected to further accelerate. What makes this so alarming is the fact that these changes cannot be predicted anymore. These uncertainties and turbulent or volatile environments are believed to be the main reason for failures in the manufacturing industry. To survive and prosper in such an environment is only possible if organizations are able to recognize and understand the changes and furthermore respond in an appropriate way. [1] [2]

In order to develop measures to do so the US government launched an initiative at the Iaccoca Institute of Lehigh University. The group consisted of senior executives of leading US companies and researches. The report, that was the output, focused on how the US could regain its supremacy in manufacturing. The result was a new production concept called "agile manufacturing". [3]

At first agile manufacturing was gaining currency among practitioners and academics not only in the US but also in Europe. However, soon researches argued that agility was still ill defined and needs to be reworked. The discussion went on to this day without any generally accepted definition. [4]

It is one of the concerns of production management that quantities in manufacturing industry are gradually declining over the last few years and this tendency is expected to continue. This statement is true indeed, but has to be treated with caution as it is important to understand the reason behind that.

One cause is the decline in security of demand and of sales forecasts. This leads to orders being divided into smaller partial orders that are separated in time. [5]

Customers expect to always get the newest technology which accelerates the innovation cycle and with that the frequency of releases of new variants and face-lifts raises. This is also shown by the "Duration of product lifecycle"

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[1] c.f. Nagel and Dove 1991

[2] c.f. Goldman *et al.* 1995, p. 47

[3] c.f. Nagel and Dove 1991

[4] c.f. Yusuf *et al.* 1999

[5] c.f. Lorenzer 2011, pp. 1–3

graph in Figure 1 which was taken from a study by Roland Berger Strategy Consultant. The average lifecycle of products across all industries (automotive, chemicals, machinery, fast moving consumer goods (FMCG), pharmaceuticals) decreased by 24% from 1997 to 2012 and is expected to continue to decrease. [6] [7]

This has also on significant impact on the production equipment. Obviously they would have to be change for the new product. This means either replacing it with completely new equipment or adapting its functionality in order to fit the production requirements of the new product. Another possibility would be to broaden the functionality in order to be able to produce multiple different products on the same machine. [8] [9]

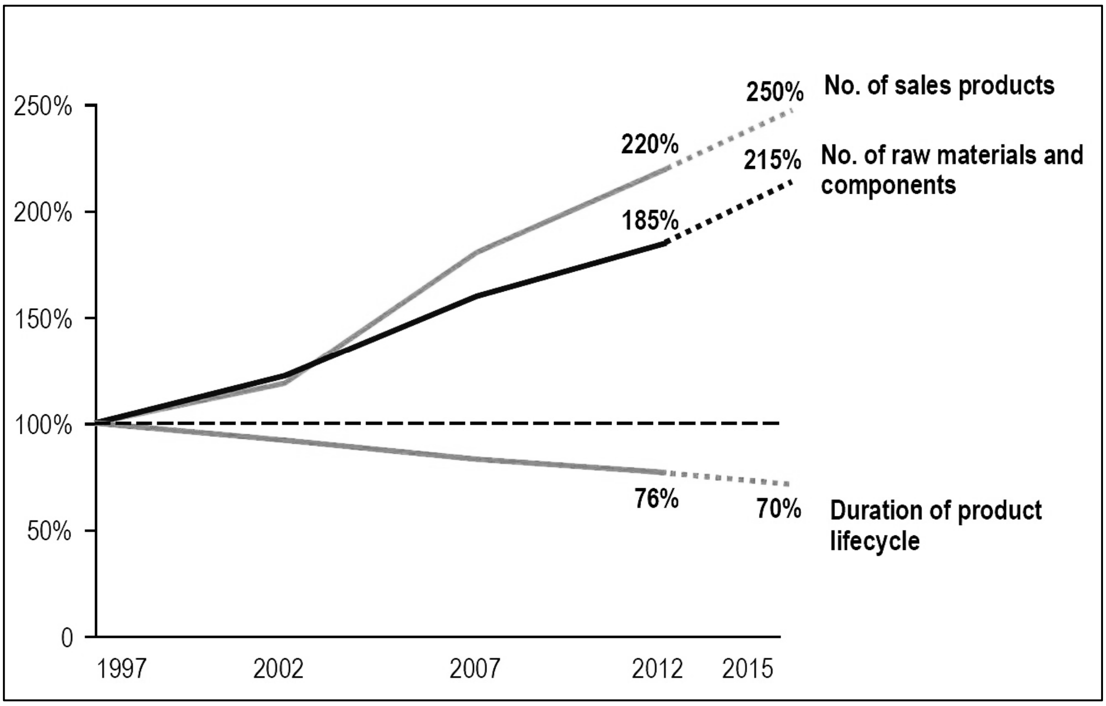

Figure 1: Increase of product variety across all industries [10]

The trend towards customization leads to more diversity of variants. Consequently the number of variants increase and the batch size decreases in an extreme case down to one. The graph "No. of sales products" in Figure

[6] c.f. Lorenzer 2011, pp. 1–3

[7] c.f. Roland Berger Strategy 2012

[8] c.f. Hauschild *et al.* 2005

[9] c.f. Koren *et al.* 1999

[10] Roland Berger Strategy 2012, p. 5

1 describes how the number of offered products increased between 1997 and 2012. [11] [12]

To define the statement in the first paragraph of this section more precisely it is to say that even though the production quantity of individual products and variants of products decreased in the past and will continue to decrease in the future, possibly down to a batch size of one, the total number of produced products will not necessarily decrease. [13]

Knowing the reasons and the mechanisms behind the alleged decline in production, it is now the time to develop new tools and strategies to cope with the new situation.

The production goals described in the “Magic Triangle” as cost, quality and time are still valid, although there has been a shift in the importance of the three goals to achieve a competitive advantage. In classic mass production the lever to success was clearly and only costs. A leading manufacturer nowadays competes on quality - defined as the ability to satisfy the needs and expectations of the customers [14] - and time or ability to react. It is critical to understand that costs are still a significant part of the triangle, but nowadays almost everyone has mastered this production goal and therefore won’t bring along any competitive advantage. Consequently, it is still important to work on costs. If an organization fails on a goal that everyone else easily achieves it is doomed to fail in the first place, no matter how good the organization is with the others. [15] [16] [17]

The purpose of research questions is to give a better understanding of the goals of this thesis. They should be a guideline that helps to follow the train of thought and the arguing. [18]

- **What is agile manufacturing?**
- **What has already been published about production requirements with respect to agile manufacturing?**

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[11] c.f. Lorenzer 2011

[12] c.f. Roland Berger Strategy 2012

[13] c.f. Roland Berger Strategy 2012

[14] c.f. Bergman and Klefsjö 1994

[15] c.f. Koren 2010, p. 227

[16] c.f. Yusuf *et al.* 1999

[17] c.f. Narasimhan *et al.* 2006

[18] c.f. Töpfer 2012, pp. 155–158

- **What are important production requirements for the metal forming industry to become an agile manufacturer?**
- **How can a business model expedite the process to become an agile manufacturer?**
- **How and to which extend should the industry use the developed concepts (recommendations of action)?**

The goal of this thesis is to develop a proposal on how press manufacturer can support their customers to become agile manufacturers and use this as a business opportunity for themselves. This will help the manufacturers and their customers to better deal with the new business environment that emerged in the last few years.

2 Definition of agile manufacturing

Agile manufacturing itself and the related terms, even though the topic is now more than 20 year old, lack a clear definition. [19] Thus it is imperative to give a definition what is meant by the different terms when they are used in this thesis. There is no claim for universal validity of the used definitions. They may though, facilitate a better understanding of what follows in the thesis.
In the context of agile manufacturing terms like volatile markets or turbulent environment oftentimes arise. As the latter is the more established and more clearly defined, it should be briefly described here. Throughout this thesis the terms turbulent and volatile are used as synonyms.
Modern day's companies have to adapt to an unpleasant environment that is very much different from what they were used to. This environment is in literature referred to as "turbulent". According to Heleen Stigter, turbulence is a situation that is subject to continuous and substantial changes that are uncertain and unpredictable. To be more precise; the difference between a dynamic and a turbulent environment is the unpredictability of the second. [20]
As the environment in which an organization operates cannot be changed by the organization itself the best recommendation is to take advantage of it by trying to deal with this new situation better than the competitors. [21]
This section also answers the first research questions that were stated in section 1: What is agile manufacturing?

2.1 Flexibility and transformability in manufacturing

For the purpose of this thesis it is important to distinguish between flexibility and transformability, two terms that are not clearly defined, neither in literature and much less so in common speech.
The intrinsic flexibility of a production system is capable of absorbing a range of variations. Flexibility describes the potential of a production system to react to a change in circumstances in a fast and cost-efficient way. [22] [23]

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[19] c.f. Yusuf *et al.* 1999

[20] c.f. Heleen Stigter 2002

[21] c.f. Kidd 1994, p. 23

[22] c.f. Abele *et al.* 2006

[23] c.f. Azab *et al.* 2013

A production system can be adapted to variation of different requirements. Flexibility is thereby limited by the flexibility corridor. Figure 2 illustrates how fast and pronounced variations of different requirements (e.g. quantity, variants, costs, time, quality …) in turbulent environments occur (actual variation) over time. The dark grey areas (flexibility corridor) represent the variation that can be handled by the system through flexibility. [24]
The surface area which is stretched by the different corridors in Figure 2 can be linked to the related costs. Along with an increase of flexibility the investment and running costs of the system increase. If all the variations would be covered only with flexibility it is easy to see that the costs would be proportional to the area of the whole transformability corridor. This suggests that flexibility is not an appropriate tool to handle vaster variations. [25]
Moreover, Wiendahl et al. suggest that flexibility refers to the ability of a production area to switch between products in a fast and efficient way. [26] Thus the influence is restricted to the production or manufacturing area resp. the machine level.

2.2 Transformability

In the afore-mentioned turbulent environment bigger variations that are unpredictable occur occasionally. Transformability, as a change factor that goes beyond flexibility, enables production systems to adapt to variations outside the flexibility corridor. Transformability is, in-line with that, defined as a system property with the potential to make changes to technology, logistics, organization and staff outside the flexibility corridor of a production system in short time, with little expenditure and considering interdependencies of different components of the system. [27] [28]
With these changes in the configuration of the system the range of variability that can be covered in a cost-efficient way is wider. It can also be seen as shifting the flexibility corridor to where it is needed. This means that in Figure 2 with transformability only the costs proportional to the dark grey area of the flexibility corridors plus the costs to reconfigure the system (e.g. cost of new

[24] c.f. Eggert 2010, p. 68

[25] c.f. Nyhuis *et al.* 2013, p. 24

[26] c.f. Wiendahl *et al.* 2007

[27] c.f. Nyhuis *et al.* 2009

[28] c.f. Azab *et al.* 2013

machines or machine modules, costs of shifting the material handling, costs of lay-offs or recruitment, …) apply. So the costs related to the light grey areas, minus the costs to reconfigure the system can be saved compared to the situation where the whole variation is covered by flexibility only. [29]
Consequently, transformability is the best practice to manage the bigger variations in an appropriate way. Yusuf suggests that it is important to manage transformability in a proactive way rather than in a reactive way as applied in most companies so far. [30]
Transformability is, according to Wiendahl et al. the ability of an entire factory to switch between different products. Thus it requires structural changes of the production and logistic system as well as of the organization and the processes. [31]

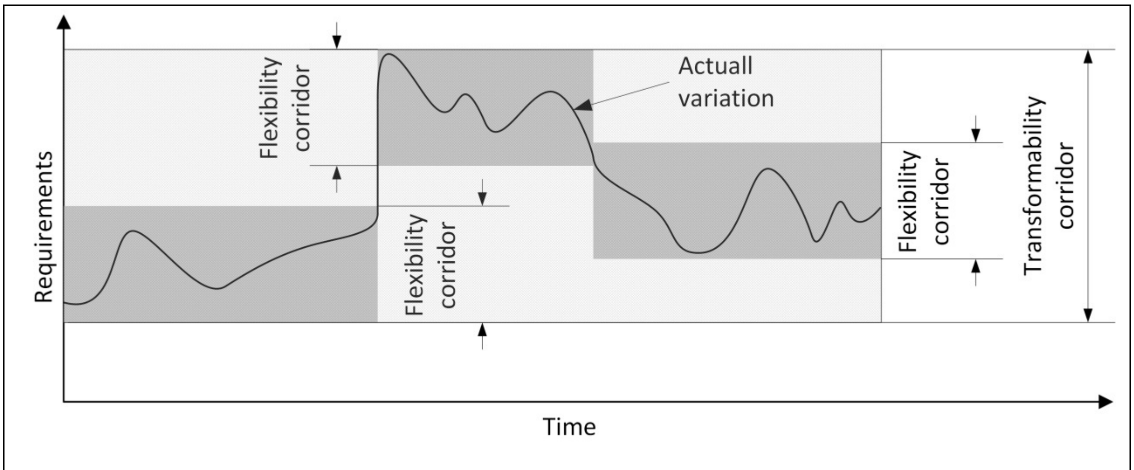

Figure 2: Differentiation between flexibility and transformability. Own representation based on Nyhuis [32]

The transformability corridor needs to be planned with the process itself. This involves, for example, to provide for spare for additional equipment or to provide infrastructure like power or water supply. If it is foreseeable that the variations exceed the flexibility corridor the provided transformability needs to be activated. This activation is cost-intensive and takes time. [33]
Thus it is necessary to install mechanisms that detect jumps in variation early enough to be able to shift the flexibility corridor towards the expected change.

[29] c.f. Heger 2005

[30] c.f. Yusuf *et al.* 1999

[31] c.f. Wiendahl *et al.* 2007

[32] c.f. Nyhuis *et al.* 2013, p. 24

[33] c.f. Nyhuis *et al.* 2013, pp. 23–24

It is important to mention that the term transformability is, almost exclusively used in the German publications (N.B. more common is the German word: “Wandlungsfähigkeit”). Not only the word, but also the concept of transformability is only known among German researchers. Nevertheless there are other, quite similar concepts, which are described in the following. [34]

Reconfigurability or Reconfigurable Manufacturing Systems (RMS) [35] are terms that are used a lot in research if it comes to the application of concepts of agile manufacturing. These terms are more common in the English literature. Therefore it is necessary to properly define what is meant by it when used in this thesis.

Reconfigurable manufacturing is a manufacturing paradigm that covers many aspects related to transformability. [36] According to the definition by Azab et al. it is closely related to transformability (see section 2.1) and can be seen as the manufacturing application of transformability. Hence, unless otherwise stated, the terms transformability and reconfigurability are used interchangeably in this thesis.

Furthermore, as transformability is a necessary condition to achieve agility (see section 2.3) and reconfigurability is considered the same it is also part of agile manufacturing.

2.3 Agile manufacturing

Agility is basically a collective term that incorporates all tools and methodologies which help a company to adapt to a turbulent environment. It is further defined as a strategic ability of the entire company to open up and adapt to new markets, to develop the products and services demanded by the customers, and to provide the necessary manufacturing capacity exactly at the time when it is needed. [37]

Thus it has a broader scope than flexibility or transformability and implements many different parts of an organization. Kidd points out that flexibility is a necessary condition to achieve agility, but does not automatically lead to

[34] c.f. Nyhuis 2008

[35] c.f. Koren *et al.* 1999

[36] c.f. Azab *et al.* 2013, p. 110

[37] c.f. Wiendahl *et al.* 2007, p. 786

agility (N.B. Kidd's term "flexibility is equal to "flexibility and transformability" as it is used in this thesis.). [38]

This is also in-line with Wiendahl *et al.* who point out that agile manufacturing incorporates the lower levels (N.B. transformability and flexibility) but not the other way around. [39]

Apart from existing manufacturing paradigms like mass production or lean manufacturing, where optimization of profit was the ultimate goal, agile manufacturing is more of a necessity to be able to survive in a turbulent environment. [40]

Built on the strategic scope, agile manufacturing can be defined more precisely as the capability to survive and furthermore succeed in a turbulent environment by reacting quickly and effectively to changing markets, driven by customer-designed products and services. [41]

It is essential to understand what the customer - independent of if it's a business to consumer or a business to business relationship - actually wants. This development will blur the borders between production and service industries. The goal of a manufacturing company that wants to become agile must therefore be to develop a solution exactly to its customer's needs - and not just a product. A producer of consumer goods will achieve this by learning what the consumers need now and will need in the future. For business customers, agile manufacturing translates into co-operation with the customer that enhances competitiveness. An "agile partnership" crosses company borders and works together to achieve more agility. [42]

Schurig et al. tried to further develop the concept of agile manufacturing and attempted to define it more concretely. According to their publication it is important to be proactive and to develop measures to react to changes of the market or the environment in advance. It is important to actively scan the business environment in order to not be surprised by any changes. To test the effects of the detected developments and to draw the right conclusions the management should use scenarios and simulations. This should help to activate the pre-defined measures in a fast and efficient way. The objective of

[38] c.f. Kidd 1994, p. 43

[39] c.f. Wiendahl *et al.* 2007

[40] c.f. Francis 2007

[41] c.f. Gunasekaran 1998, p. 1225

[42] c.f. Gunasekaran 1998, p. 1226

agile manufacturing, as of every economic activity, is to improve the economic situation of the organization. Depending on the environment and the situation of the organization, this refers to different characteristics such as EBIT, return on investment, cash flow or the increase of the market share.[43]

[43] c.f. Schurig *et al.* 2014

3 Literature review of production requirements with respect to agility

The definitions in section 2 are an academic basis of this thesis. In the next step it is necessary to translate these definitions into practical requirements for production processes.

Since the late 90s of the last century a lot of research was done on this topic, unfortunately under different terms. [44] One very important name be mentioned is reconfigurability as defined in section 2.2. [45]

The second research question that was listed in section 1 is answered here: What has already been published about production requirements with respect to agile manufacturing?

The scope in this section is to unify all the outcomes found in literature to use this as a basis for the practical part. This was done by reviewing the literature that deals with the topics:

- agile manufacturing
- flexible machines
- reconfigurable machines and related terms.

The literature was situated mostly in the areas of manufacturing systems and assembly lines, even though it was not exclusively restricted to them.

Looking at all the production requirements that where described in literature, finally eleven turned out to be independent and are described in the following sub-chapters.

3.1 Lead time

As mentioned in section 1 the number of products of the same variant that are produced declined over the past and will continue to decline. Thus it is necessary to focus on the individual product that undergoes the production process and not the entire “stream of products” as with lean manufacturing. “Lean” is described as achieving the shortest possible product cycle time by eliminating waste, while agile manufacturing is about achieving the shortest possible lead time while adding quality and reducing costs. [46] [47]

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[44] c.f. Yusuf *et al.* 1999

[45] c.f. Azab *et al.* 2013, p. 110

[46] c.f. Francis 2007, p. 15

Narasimhan *et al.* suggest that not only production lead time, but also the entire product development lead time need to be reduced. [48] This would be in-line with Chakravorty et al. who argue that in a turbulent environment with more and more demand for customization the overall time-to-market needs to be faster. [49] Thus it is important to decrease the lead time of the production process for new manufacturing systems and also for reconfigurations of existing systems. [50] [51]

3.2 Ramp-up

Due to the increasing number of different products (or variants of products) produced on the same production line, and the decrease of the life cycle of products, shifting within the production system will occur more often. After each of these shifts it takes some time until full capacity is achieved again and quality parts can be produced. Thus this so-called ramp-up is expected to occur with increasing frequency during the lifetime of the system and may become a critical factor to successful production. [52] [53]

The “ramp-up period is defined as the period of time a newly introduced system or a reconfigured manufacturing system needs to reach its designed levels of production in terms of both throughput and part quality.” [54]

With traditional manufacturing systems like classic mass production or lean manufacturing this typically takes several months to multiple years, depending on the industry. This is inacceptable in a turbulent environment. Rapid ramp-up of a manufacturing system after installation, but especially after each reconfiguration, enhances responsiveness and reduces costs and is therefore essential to the success of the agile manufacturing paradigm. If this cannot be achieved the advantage of these systems is lost. [55]

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[47] c.f. Yusuf *et al.* 1999

[48] c.f. Narasimhan *et al.* 2006

[49] c.f. Chakravorty *et al.* 2014

[50] c.f. Mehrabi *et al.* 2000

[51] c.f. Roland Berger Strategy 2012

[52] c.f. Koren *et al.* 1999

[53] c.f. Francas *et al.* 2009

[54] Koren 2013, p. 6823

[55] c.f. Mehrabi *et al.* 2000

Unfortunately this is a very problematic period in the life cycle of a production line. Fjällström *et al.* have found six categories of problems that occur within the ramp-up period: [56]

- process (e.g. disturbances in the production line, additional work tasks, change of line balancing)
- suppliers/supply (e.g. quality on incoming material)
- product/quality (e.g. output quality, temporary products/adjustments of products)
- equipment/technique (e.g. lift equipment, machine handling)
- personnel/education (e.g. lack of educated assembly operators, personnel situation)
- organization (e.g. implementation of a third shift, the team around the factory project leader and equipment technique)

3.3 Convertibility

Convertibility is the ability to easily transform the functionality of existing systems and machines to suit new products and production requirements within the product family. [57] It includes contributions due to machines, their arrangements or configuration and material-handling devices. [58]

3.3.1 Machine convertibility

Convertibility of the system is directly dependent on the inherent convertibility of the machine. This characteristic of a machine is based on the premise that some machines fulfill certain criteria that other machines do not. Such characteristics are: [59]

- endowment with an automatic tool changer or multiply usable tools
- flexible software that is easy to reprogram
- modular, with flexible hardware components
- flexible work-holding
- a large capacity tool magazine

[56] c.f. Fjällström *et al.* 2009

[57] c.f. Koren and Shpitalni 2010, p. 132

[58] c.f. Koren 2013, p. 6820

[59] c.f. Maler-Speredelozzi *et al.* 2003

3.3.2 Configuration convertibility

Configuration convertibility refers to the arrangement and connections of machines in a manufacturing system. Pure serial configurations have only one part flow path through the system. Pure parallel configurations have as many flow paths through the system as there are machines. In other words, each machine can process the work piece from start to finish. Hybrid configurations are combinations of serial and parallel instances. Configuration convertibility is dependent upon the minimum increment of conversion, the routing connections and the number of replicated machines.

The idea of minimum increment of conversion is to show how quickly new or different products can be introduced. For example, in a pure serial configuration with only one possible flow path the entire line must be shut down, changed over and restarted to conduct a product change. In a system with two parallel lines, on the other hand, only half of the machines have to be shut down and reconfigured and the other half can keep up production. This is valuable when a company wants to introduce a new product to the market as quickly as possible and then later ramp up to full production. [60]

In a manufacturing system, a greater number of routing connections indicates a higher degree of convertibility. More connections allow for more possibilities to handle unexpected changes or problems such as a broken machines or a higher demand for one product. It includes connections between machines as well as connections to an input and output station. [61]

The minimum number of replicated machines at a particular stage in the process plan dictates the number of part types that can be produced without requiring changeovers. For example, in a serial manufacturing line with only one flow path exactly one machine is present at each stage. Thus the line must stop, parts must be removed from the system, the line has to be reconfigured and ramped up again if a different product is to be produced. All of this devours valuable production time and costs. E.g. pure parallel systems are able to produce as many different products in parallel as there are machines. This is important when a company expects part mix to vary over time or if manufacturers want to produce prototypes of future products while current products are still being manufactured, albeit at a reduced rate. [62]

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[60] c.f. Maier-Speredelozzi and Hu 2002

[61] c.f. Spicer *et al.* 2002

[62] c.f. Maler-Speredelozzi *et al.* 2003

3.3.3 Material-handling convertibility

One important factor in a system's performance is the nature of the material-handling devices that are used, the so called material-handling convertibility. This characteristic is found by assessing if the individual device is: [63]

- following a free route or not
- multi-directional
- re-programmable
- asynchronous motion
- automatic

It is important to mention that, in general, the more flexible a solution is, the larger investments are necessary and the more error-prone the system will be. For material handling as an example, having people carry work pieces from station to station is very flexible. This solution however may be very expensive and is not always the best usage of human resources.
Convertibility additionally has positive impacts on the reconfiguration time on productivity and life-cycle costs. [64]

3.4 Customization

In a turbulent environment the customer specifies the products and services. The organization has to be able to react fast and efficiently to the customer's demand. [65] Customization is the ability of a system or machine to produce customized output limited to a single product family. Therefore, the definition and formation of part families are essential for design and operations. [66]
The design of a Dedicated Manufacturing Line (DML) focuses on a specific part to be produced. Thus, if a part is not defined, a DML cannot be designed. In contrast, typical Flexible Manufacturing Systems (FMS) are composed of CNC machines and are designed to manufacture any part (within an envelope). A process-planning procedure is needed to fit the processing of each specific part to the existing FMS. FMS design focuses on

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[63] c.f. Maler-Speredelozzi *et al.* 2003

[64] c.f. Koren 2006, p. 39

[65] c.f. Gunasekaran 1998

[66] c.f. Goyal *et al.* 2013

the machine rather than on the part, which is one reason for the large quantity of waste and low production rates of FMS technology. [67]

Borrowing from dedicated lines that are designed around a single part or product, Reconfigurable Manufacturing Systems (RMS) focus on families of parts, such as cylinder heads of car engines. [68] The core idea is to avoid excessive flexibility, which means that flexibility should be limited to the part family in question. [69] This will impose new constraints on future product designers who will have to fit the design of a new product to the boundary conditions of the product family with the structure and capabilities of the manufacturing system in mind. In other words, the future product designers will have to design "process-driven products". [70]

Higher component commonality makes it possible to develop many derivative products so that the demand volatility risk is pooled by using fewer types of components. [71]

Customization has an essential impact on productivity and life-cycle costs. [72]

3.5 Modularity

One of the key goals in developing reconfigurable manufacturing systems is to develop machine modules, which allow for a fast and efficient exchange of these modules between different manufacturing systems. This exchangeability can be accomplished by equal structure of the machines and the control systems and the standardization of interfaces combining the modules, which enables a short-term adaptability of the manufacturing system. [73] The rapid adaptability of reconfigurable manufacturing systems is possible by the use of mechanical modules, control modules, hydraulic and electric modules that can be exchanged and integrated. [74]

Modularity is defined as “the compartmentalization of operational functions into units that can be manipulated between alternate production schemes for

[67] c.f. Koren 2013

[68] c.f. Koren and Shpitalni 2010

[69] c.f. Rösiö and Säfsten 2013, p. 1000

[70] c.f. Koren 2005, p. 1

[71] c.f. Carrillo and Franza 2006

[72] c.f. Koren 2006

[73] c.f. Koren *et al.* 1999, p. 532

[74] c.f. Koren *et al.* 1999, p. 533

optimal arrangement." [75] It has a major impact on the reconfiguration time and is therefore crucial for achieving agility in a manufacturing system. [76]

One of the major challenges at the early design stages of a production line is to select a system configuration that satisfies the production requirements and is easy to operate and manage, especially in terms of its adaptability to changing environmental factors. [77]

For the effective use of modular systems Paredis et al. suggest a "Task Based Design software". This will be critical to successfully establish modular systems in industry since there is no time for a tedious planning process in a turbulent environment. Such a software would have the description of the task and the available modules as input and generate an assembly configuration as an output. Several approaches to solve simplified problems with this concept have been applied successfully; nevertheless it must be the goal to develop an integrated software that is able to solve the problem on the machine as well as on the factory level. [78]

3.6 Scalability

System production capacity must be adjusted to cope with fluctuations in product demand. This type of adjustment requires rapid changes in the system's production capacity, also referred to as system scalability. It is defined as the ability to easily modify production capacity by adding or subtracting manufacturing resources (e.g. machines) and/or changing components of the system. [79]

The development of modular machine tools is the basis and a necessity to achieve scalable systems, because modular machine tools facilitate rapid addition and removal of productive modules as required for scalability. [80]

According to Spicer et al. there are three major implications of production system design with respect to scalability: [81]

[75] Koren and Shpitalni 2010, p. 132

[76] c.f. Koren 2006, p. 39

[77] c.f. Matt and Rauch 2013, p. 439

[78] c.f. Paredis *et al.*, p. 1435

[79] c.f. Koren and Shpitalni 2010, pp. 131–132

[80] c.f. Spicer *et al.* 2005

[81] c.f. Spicer *et al.* 2005, p. 4840

- Design of small production units and expandability by duplication of these small units.
- Allocation of infrastructure to facilitate system growth.
- System design that allows for expandability without requiring significant new designs.

In order to achieve a rapid and cost-effective scalability, the system has to be designed at the outset for scalability, which may require some additional capital investment when the system is originally built. [82]

Adding or removing machines (so called station paralleling) to match the new throughput requirements and concurrently rebalancing the system for each configuration, is a method to accomplish the system reconfiguration that is widespread in industry. [83] [84]

As an alternative to this approach the number and functionality of stages in a production process can be adapted. When production demand is low, a system can be designed to have fewer stages that perform more tasks. Conversely, for higher demands it is possible to design a system to have more stages with more distinct tasks. Nevertheless, it is important to mention that there are limitations to this approach. Because of loading and unloading time of each station and restrictions in atomizing tasks the number of stations cannot be increased infinitely to obtain more production capacity. [85]

Which approach to choose ultimately depends on the specific case. Regardless of that, the impacts are basically the same; the productivity of the system under turbulent conditions is improved compared with a conventional system and the life-cycle costs are lowered. [86]

To achieve a balanced production line a scalability planning methodology has to be developed that can incrementally scale the system capacity by reconfiguring an existing system. One approach was developed by Wang and Koren with a Genetic Algorithm to determine the most economical way to reconfigure an existing system. [87]

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[82] c.f. Wang and Koren 2012

[83] c.f. Wang and Koren 2012, p. 83

[84] c.f. Son *et al.* 2001

[85] c.f. Son *et al.* 2001, p. 501

[86] c.f. Koren 2006, p. 39

[87] c.f. Wang and Koren 2012

The "Task Based Design software" to achieve modularity and the algorithms to achieve scalability should be implemented in one generic production planning software. This would enhance responsiveness that is necessary to react to the fast changes that occur in a turbulent environment.

3.7 Integrability

To implement the new configuration fast and effectively into the physical system it is important to have an appropriate technology in place. The realization of modular sets requires a standardization of the interfaces connecting the modules. [88] Integrability is defined as "the ability to integrate modules rapidly and precisely by a set of mechanical, informational, and control interfaces that facilitate integration and communication." [89]
The interfaces of a machining system can be divided into three levels: [90]

1. The system-interface determines the connections between machining systems, needed to combine several machines to a manufacturing system. Appropriate interfaces prescribe the logistic connection and the connection to further machining systems. This type of interface is standardized in order to combine different systems.
2. The module interfaces represent interfaces between singular modules. They are standardized in order to integrate modules of different manufacturers into a machining system.
3. Submodule-interfaces determine the connections inside the modules and make it possible to assemble modules from sub-modules. This makes it possible, for example, to combine different driving motors (sub-modules) with a spindle system (sub-modules) to generate different spindle-unit-modules (modules).

Interfaces can also be divided into mechanical interfaces and interfaces for data, energy and auxiliary material transmission. Mechanical interfaces transmit forces and moments, align elements and join them. The other interfaces care for the component supply with required media. [91]
To achieve an agile reconfiguration of the system a "quick-coupling mechanism" needs to be introduced. Ideally such a mechanism includes all

[88] c.f. Koren *et al.* 1999, p. 533

[89] Koren and Shpitalni 2010, p. 132

[90] c.f. Koren *et al.* 1999, p. 533

[91] c.f. Koren *et al.* 1999, p. 533

the required interfaces (e.g. mechanical, data, energy and auxiliary material transmission) in one connection and enables an assembly of the system with tools that are not standardized or have only limited standardization. [92] In practice, especially for large-scale industrial applications, this is hard to achieve, due to the level of complexity and their sheer size. Nevertheless, a reconfiguration without additional lifting equipment or calibration must be the objective. [93] This is because integrability is an important characteristic that reduces the time it take to reconfigure a system and helps to keep down the life-cycle costs. [94]

3.8 Diagnosability

As production systems are made more reconfigurable, and their layouts are modified more frequently, it becomes essential to rapidly tune the newly reconfigured system such that it produces parts that fulfill the quality standards. This requires that problems and errors in the production system causing the quality issues, are detected at an early stage. [95]

Diagnosability is "the ability to automatically read the current state of a system to detect and diagnose the root causes of output product defects, and quickly correct operational defects." [96]

Systematic measurement methods were developed to help identify the sole sources of product quality problems in the production system rapidly, and to correct them by utilizing control technologies, statistics, and signal processing techniques. In practice in-line inspection machines are added to the system and root-cause analysis are performed in real-time during production.

Systems with in-line inspection have to be designed with regard to: [97]

- a distribution of measuring stations for effective diagnostic control
- selection of measuring criteria of the work piece at each intermediate station

[92] c.f. Paredis *et al.*, p. 1437

[93] c.f. Padayachee and Bright 2012, p. 101

[94] c.f. Koren 2006, p. 39

[95] c.f. Koren 2006, pp. 38–39

[96] Koren and Shpitalni 2010, p. 132

[97] c.f. Koren 2013

- identification of the root-cause of errors, in terms of which manufacturing machine or station caused the error

Diagnosability is an essential characteristic of agile manufacturing systems as it positively affects the reconfiguration time, the productivity and the life-cycle costs. Apart from that it is an important prerequisite to achieve another requirement of agile manufacturing: a fast ramp-up. [98] [99]

3.9 Employee emancipation

For organizations that intend to become agile manufacturers it is important to include the development of a well-trained and motivated workforce, with the right set of skills, expertise and knowledge, as an essential element of their strategies. Such organizations are driven by knowledge and information available to the work force.

The success of any organization ultimately depends upon its ability to convert the collective knowledge and skills of its employees into solutions and products. The use and manipulation of information, as a key competitive instrument has also revolutionized the way we think about manufacturing and how we operate it. The ability to control the new product introduction process from the conceptualization and design stages through manufacturing to shipment and product support requires the exploitation of a knowledge-rich work force and sophisticated information technology in most industrial sectors. [100]

Employee empowerment is a well-rehearsed concept within manufacturing strategies. It enables employees to make decisions and provide solutions quickly and right where they are needed. Such speedy responses will have a significant impact on the rate of order fulfillment and the agility of the system. [101] [102]

The practical realization of the agile manufacturing concepts and concepts that are similar revealed a high risk of installation as the investment costs are considerable large. However ElMaraghy states that the risk can be

[98] c.f. Koren 2006, pp. 38–39

[99] c.f. Koren 2013

[100] c.f. Yusuf *et al.* 1999, pp. 39–40

[101] c.f. Yusuf *et al.* 1999, p. 40

[102] c.f. Wiendahl *et al.* 2009

compensated by an experienced engineering team and intensive teamwork with the line builder. [103]

3.10 Detection of change

Successful organizations do not only have to be able to adapt and respond to change but also detect it in advance "using tactical initiatives to achieve strategic objectives." As it is difficult or even impossible to predict change in a turbulent environment it becomes even more important to detect it as soon as it occurs. [104] [105] The inertia, that is unfortunately also present in agile manufacturing systems, and the time it takes to transform a system to the intended production state (see section 2.1) render the detection of change crucial. If changes in output requirements (e.g. quantity, variants, costs, time, quality …) are not detected early enough the system will not be able to react fast enough. Another way to look at it is that a good change detection allows the system to react more slowly and eventually even save investment costs.

This necessitates the development and implementation of mechanisms or methods to detect and recognize the changes in the turbulent business environment. Thus a reaction of the system in time and in an appropriate way is possible. [106]

[103] c.f. ElMaraghy 2009, pp. 384–385

[104] Yusuf *et al.* 1999, p. 35

[105] Heleen Stigter 2002

[106] c.f. Sharifi and Zhang 1999

4 Literature review of business model development

The pursued objective with this thesis is to make suggestions on how a business model can make a company more agile rather than to develop a business model for a specific company. For that reason it is important to figure out how the industry works in general and what customers and press manufacturers usually expect.

The thesis should reveal new and innovative ways on how business can be done differently and to start thinking outside the traditional industry context. In difference to the preceding section there is no specific literature about “agile business models”. Therefore general rudiments to the subject of business model development have been used. The final business model was developed in consistence with the definition of agile manufacturing.

A Business model is the foundation that defines how the organization creates and delivers value to its customers. It is part of the business strategy. [107] The business model is used to describe different aspect of a business such as: [108]

- purpose
- processes
- target customers
- offerings
- infrastructure
- organizational structure
- trading practice
- operational processes
- and policies

In the following, it is described why it is desirable to increase the market and how a business model can be developed. The white space and the blue ocean strategy are purely used to argue for the meaningfulness of entering new and unknown markets. They are not used to develop the business model.

[107] c.f. Osterwalder and Pigneur 2011, p. 5

[108] c.f. George and Bock 2011

4.1 The white space

Figure 3 is a good representation of where the business model is intended to be located. The core business is where the company operates and where it makes money. In a mature company this core business is well defined and the boundaries are clearly established. The efforts and capabilities are concentrated on this space and business growth is achieved by developing it. To be a leader in the industry or to ensure to stay the leader it is sometimes necessary to develop fundamentally new ways of serving customers. Some of these new ways fit well in the organization and are therefore called adjacency. Others do not fit the organization and therefore require a completely new approach and strategy and are referred to as white space. These radically new business models comprise the most potential and opportunities but also the highest risk. [109]

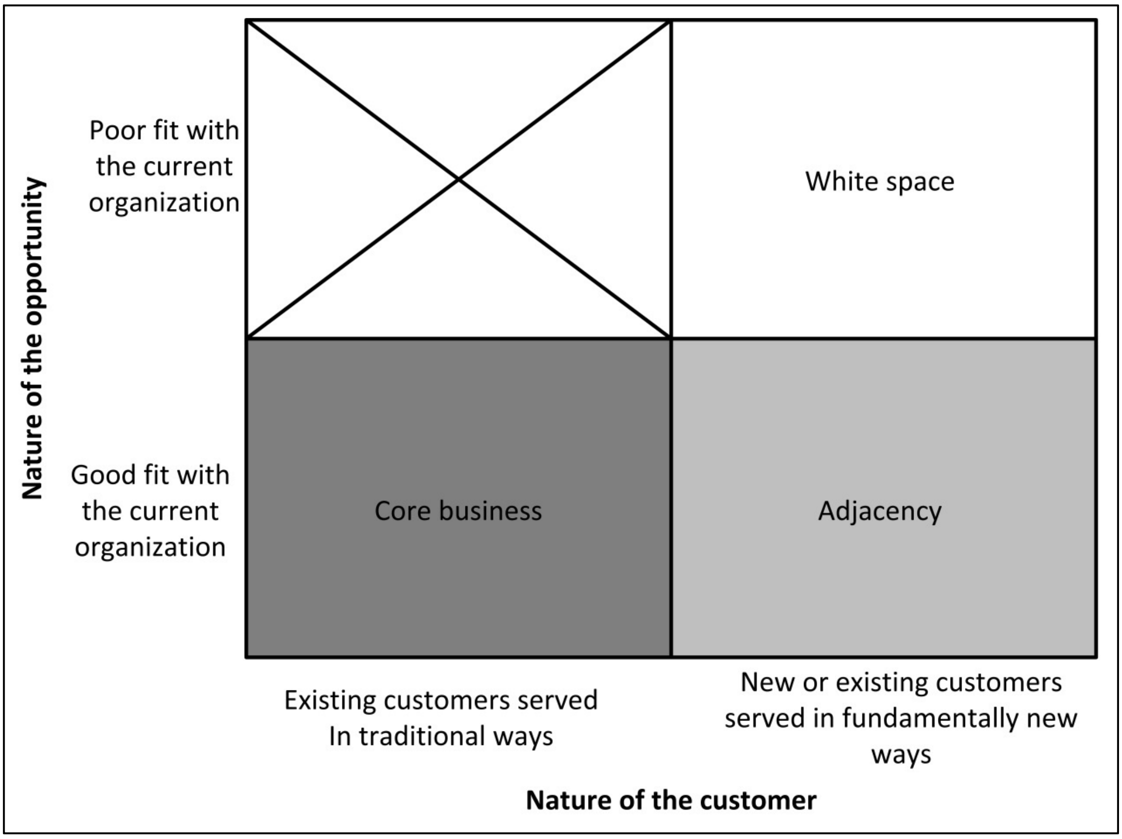

Figure 3: Defining the white space. Own representation based on Johnson [110]

[109] c.f. Johnson 2010

[110] c.f. Johnson 2010, p. 8

The white space is exactly where the new business model is anticipated to be located; a fundamental new way of serving new or existing customers that does not fit in any current organization. In other words it can also be described as the attempt to create a blue ocean by altering the boundaries of an existing industry. [111]

4.2 Blue ocean strategy

At first sight it does not seem reasonable why it is desirable to push forward to a "white space" that has poor fit with the current organization and where you have to deal with new customers in fundamentally new ways. [112] The blue ocean strategy gives a good explanation of the opportunities and potential of such markets.

The underlying idea is to avoid competition and all the effort and trouble that are related to it by seeking for a new and untouched market. There are basically two ways to achieve that; create a market that is beyond existing industry boundaries or, as in most real cases, expand existing industry boundaries. [113]

Blue oceans are not about technology innovation, even though leading-edge technology is sometimes involved in the creation of blue oceans. It is about linking existing or new innovative technology to functions and benefits that customers value. [114] This is the same idea as the "customer value preposition" described by Johnson (see section 0).

In a blue ocean you cannot do benchmarking at all because it is all about avoiding competition. Moreover it is about breaking the value – cost tradeoff by always offering the products and services that the customers actually value at the lowest possible price. [115]

4.3 Basic information for a new business model

There is a variety of different methods described in literature to generate the necessary information to develop a business model. Some of which are quite

[111] c.f. Kim and Mauborgne 2004

[112] c.f. Johnson 2010

[113] c.f. Kim and Mauborgne 2005

[114] c.f. Kim and Mauborgne 2004

[115] c.f. Kim and Mauborgne 2004

complex and require in depth knowledge of an organization, like the business model canvas by Osterwalder and Pigneur. [116] In their article "Reinventing Your Business Model" Johnson *et al.* suggest that it takes four basic sets of information to develop a new business model. These sets of information ultimately deal with what the customers want and what the company is good in. They are called "the four-box business model" and illustrated in Figure 4. The explanation follows in the subsequent sections.[117] The approach by Johnson *et al.* was chosen for this thesis as it offers quite a comprehensive information base that does not require in depth information about a specific organization. This turned out to be useful for two reasons:

- First of all the purpose of this thesis is to make suggestions on how a business model can make a company more agile rather than to develop a business model for a specific company, as already mentioned.
- Second, the companies where, understandably enough, not willing to share in depth knowledge about their business processes, customers and operational policies.

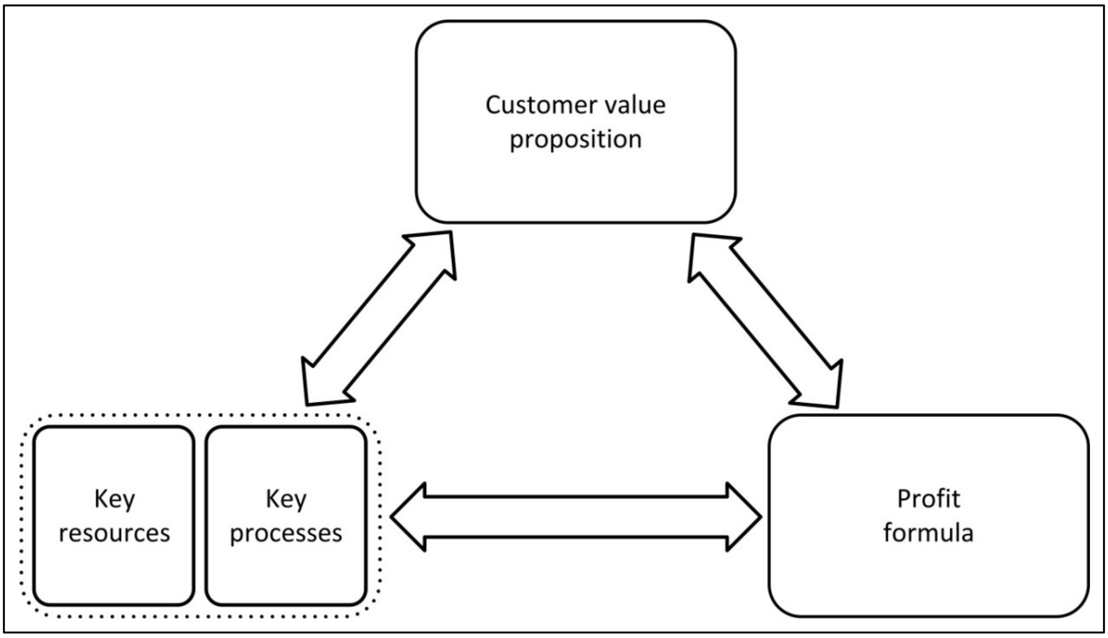

Figure 4: The four-box business model. Own representation based on Johnson [118]

[116] c.f. Osterwalder and Pigneur 2011, p. 15

[117] c.f. Johnson *et al.* 2008

[118] c.f. Johnson 2010, p. 8

The four-box business model is in many ways similar to the four dimensions of a business model that are described in the “St. Galler Business Model Navigator” by Gassmann et al. [119]

Customer value preposition

In the end it is always the customer who defines what is valuable and what is not. Thus it must be the goal of an organization to propose values to their customers that are intended to support their value creating activities. [120]

Johnson *et al.* suggest that defining the customer value proposition is the important first step for the creation of a new business model. It can be defined as the intersection of the customer needs and what the supplier can offer. In other words it is the way a supplier can support his customer in his value creating activities. [121] [122]

In general a customer value proposition should: [123]

- provide a benefit that the customer perceives as relevant;
- build on competencies and resources that the company is able to utilize more effectively than its competitors;
- be recognizably different from competition;
- result in a competitive advantage for the customer and the supplier.

Profit formula

The profit formula describes how the company creates value for itself, or in other words, how it makes money. This can be by selling products or supplies, planning facilities, or other services. [124]

In more detail the profit formula includes the revenue model, the cost structure, the target unit margin and the resource velocity. [125] As all this information is not or only partially available, this point can only be treated with proviso.

[119] c.f. Gassmann *et al.* 2013, p. 6

[120] c.f. Vargo and Lusch 2004

[121] c.f. Johnson *et al.* 2008

[122] c.f. Anderson *et al.* 2006

[123] c.f. Vargo and Lusch 2004

[124] c.f. Johnson *et al.* 2008

[125] c.f. Johnson 2010

Key resources and processes

Key resources are the "transmitters" that deliver the promised values to the target customers (e.g. people, technology, products, facilities, equipment, channels or brand). The focus is on the key elements that distinguish a company from its competitors and that create value for the customer and the company. [126]

The key processes describe the way that a company delivers the value preposition best. These managerial or operational processes can be repeated and increased in scale. Examples for such processes are; training, development, manufacturing, budgeting, planning, sales, and service but also a company's rules, metrics, and norms. [127] [128]

The next section describes an approach of how different criteria of a business model can be derived from the basic information, in a structured way.

4.4 Performance-based Contracting

Performance-based Contracting (PBC) intends to reshape the service supply chains in capital intensive industries in the sense that it replaces commonly used fixed-price and cost-plus contracts to improve the availability and reduce the cost of ownership. Similar to other service-based business models it is characterized as changes in ownership, maintenance responsibility and payment. In PBC the focus is on contracting a performance goal or outcome, rather than how the provider is to achieve this goal. [129] [130]

This model would serve the industry in a fundamental new way. It also allows defining the different criteria that describe a business model and a structured and easy to understand way. Therefore it is used as a basis to develop the concept for the new business model.

In their paper "Clarifying the concept of performance-based contracting in manufacturing industries" Hypko et al. identify eight criteria that distinguish the different kinds of PBC in manufacturing industries related to machinery or

[126] c.f. Wernerfelt 1984

[127] c.f. Nelson and Winter 1982, pp. 72–85

[128] c.f. Johnson *et al.* 2008

[129] c.f. Hypko *et al.* 2010

[130] c.f. Kim *et al.* 2007

equipment which can be seen in Figure 5. This figure also illustrates the various options that are available for each criterion. [131]

This morphological box is used as a basis to clearly define the business model. In a next step the developed business model is compared to other already established business models. These business models are:

- Pay-on production
- Capital or property leasing
- Contract manufacturing
- Direct sales

The theory to these four models is described and discussed in the respective section 7. This is, to provide the necessary information where it is needed, and to make it easier to read.

PBC offers a structured approach to define important criteria, which is quite helpful if one cannot draw on a rich experience in business model development. Moreover the morphological box can be used to show the uniqueness of the developed model in a descriptive way.

Criteria	Options			
Performance provider	Independent service provider	Machinery or equipment manufacturer		
Ownership during contract period	Leasing company	Special purpose vehicle (SPV)		
Ownership after contract period	Leasing company	Special purpose vehicle	Customer	
Responsibility for maintenance	Independent service provider	Machinery or equipment manufacturer	Special purpose vehicle	
Responsibility for operation	Independent service provider	Machinery or equipment manufacturer	Customer	
Payment model	Pay-on-Availability	Pay-per-Unit	Pay-per-Use	Pay-on-Customer´s Economic Results
Location of operation	Performance provider´s in-house	Fence-to-fence	Customer´s in-house	
Exclusiveness of operation	Single Customer	Multiple customers		

Figure 5: Morphological box as a framework to describe new business concepts. Own representation based on Hypko et al. [132] and Lay et al. [133]

In the following the criteria with their options are discussed.

[131] c.f. Hypko *et al.* 2010

[132] c.f. Hypko *et al.* 2010

[133] c.f. Lay *et al.* 2009

4.4.1 The background of performance providers

In the general definition of PBC the customer contracts out tasks or responsibilities concerning the operation of machinery or equipment. [134] In that sense it needs to be clarified to whom the customer is contracting out.
For the manufacturing industry there are basically two alternatives: [135]

- the manufacturer of the machinery or equipment could appear as a performance provider
- independent service provider could take over tasks and responsibilities related to the operation of machines and equipment as a service.

The second approach bears the advantage that the service provider could focus purely on operating the machines and develop this as his core competence. On the other hand the manufacturer would not be able to contribute his superior knowledge about the machines, which is in most cases essential for the operation of the machines. [136]

4.4.2 Ownership during the contract period

The topic of ownership is basically linked with the problem of financing. This is an important issue, as machine manufacturers or service providers might not be able to raise enough money for one of even multiple manufacturing facilities especially as they may cover their investment only gradually by the service fee. [137] Basically two models have emerged in the manufacturing industry for the ownership respectively financing issue.

- The first one is the so-called Special Purpose Vehicle (SPV) model which is based on conventional project financing. An SPV, exclusively founded for financing and balancing an operation and either ensuring availability or actually operating the machinery of equipment, owns the facility and machines. [138] [139]

[134] c.f. Markeset and Kumar 2005

[135] c.f. Frauendorf *et al.* 2007

[136] c.f. Hypko *et al.* 2010

[137] c.f. Decker and Paesler 2004

[138] c.f. Siemer 2004

[139] c.f. Decker and Paesler 2004

- The second is the operator lease (OL) model. Here a leasing company (in the broader sense) owns the machinery and equipment and is responsible for financing and balancing it. As in a classic leasing contract the customer pays fees to the leasing company. On top of that he has to pay a service fee to the performance provider, who is still the manufacturer or a pure service provider, for operating and/or maintaining the machines. [140]

4.4.3 Ownership after the contract period

In many industries, especially in construction, a change in ownership is quite common. Many infrastructure projects are realized as PBCs for pure financing reasons and become the property of the customer after the contract period. [141]

In manufacturing industry, on the other hand, the customer typically does not strive for ownership. In many cases for the manufacturer to become a customer of a service-based business model is to get temporary excess to the machines and facilities. Another common reason is a lack of know-how to operate them. Thus it is not common that the ownership is transferred to the customer after the end of the contract and the leasing company or the SPV retains ownership. [142] Therefore the three options for ownership after the contract period are:

- The leasing company remains the owner for the entire lifespan.
- The special purpose vehicle remains the owner for the entire lifespan.
- The ownership is transferred to the customer (for the sake of completeness).

4.4.4 Responsibility for maintenance personnel

One of the basic concepts in PBC is that the maintenance of the machines and the responsibility for the maintenance personnel is carried over to the performance provider. The performance provider in that case is either the

[140] c.f. Siemer 2004

[141] c.f. Brady *et al.* 2005

[142] c.f. Hypko *et al.* 2010

independent service provider or the machinery or equipment manufacturer as indicated in section 4.4.1. [143]

In the case of the SPV model it is also possible that the responsibility for maintenance personal can be assigned to the SPV. In this case the maintenance would be their core task and obligation. [144]

4.4.5 Responsibility for operation personnel

The increase of complexity of the machines and equipment lead to more complex production processes that furthermore require more knowledge and skills. Thus it can make sense that the performance provider is not only responsible for maintaining but also for operating the machines and equipment. This is due to the fact that the performance provider has a lot of experience with the machines. In that case the performance provider guarantees a performance goal or outcome. Similar to the responsibility for maintenance personnel the SPV could also become responsible for the operation if SPV is chosen as the owner model. [145] [146]

The customer may also stay responsible for operation as in some industries they have long-term experience and superior knowledge of the process which they might not be willing to give away. [147]

4.4.6 Payment model

Instead of becoming the owner of the machine or equipment in PBC the customer only pays for measurable performance. [148]

The first option is the so-called Pay-on-Availability. The payment is purely based on the provided availability of a good or service and independent of the actual utilization. Thus the customer pays for a performance that is held available for him. [149]

What is referred to as Pay-per-Use in literature actually allows for two different approaches. In actual Pay-per-Use the customers pay for the time

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[143] c.f. Markeset and Kumar 2005

[144] c.f. Decker and Paesler 2004

[145] c.f. Markeset and Kumar 2005

[146] c.f. Decker and Paesler 2004

[147] c.f. Hypko *et al.* 2010

[148] c.f. Markeset and Kumar 2005

[149] c.f. Freiling 2003

and extend they use machines or a facilities. This concept is similar to the lease contracts of professional office equipment like photocopiers. [150] Another concept that is often also called Pay-per-Use is better referred to as Pay-per-Unit. In this payment model the performance provider is responsible for operation and the customer only pays for those units that are actually produced. [151]

The Pay-on-Customer's-Economic-Results option is based on the economic results as a consequence of using the machines or equipment. Indicators to determine the amount that has to be paid by the customer can be; cost savings realized, revenues generated, or even the contribution to the margin/profit generated. [152]

4.4.7 Location of operation

The best solution for the location of operation heavily depends on two other criteria which have already been discussed before; the responsibility of maintenance and operation: [153]

- The operation can be located inside the customer's production process. This is most common if the performance provider is only taking over the maintenance responsibility.
- In cases where the performance provider has the maintenance and operation responsibility the operation is most likely locate right at the performance provider's site.
- The third option regarding the location of operation is to establish a supply park where suppliers launch their services "fence-to-fence" next to their customers' facilities.

4.4.8 Exclusiveness of operation

Especially in models where the customer only pays for the performance he actually demands, the performance provider takes over a big piece of the market risk from the customer. In these cases a multiple customers approach can be seen as risk spreading strategy. [154]

[150] c.f. Martin 1997

[151] c.f. Gassmann *et al.* 2013, p. 191

[152] c.f. Hypko *et al.* 2010

[153] c.f. Hypko *et al.* 2010

[154] c.f. Hypko *et al.* 2010

If, for example, the performance provider only takes over maintenance responsibility at a customer's site he is fully dependent on that one customer. If on the other hand the location of operation is independent of a customer and the performance provider has the responsibility for the site he can contract multiple customers and spread the risk of unexpected order cancellations. [155]

[155] c.f. Decker and Paesler 2004

5 Survey of agile manufacturing in the metal forming industry

For the empirical part of this thesis a survey with experts in the field of press manufacturing and metal forming from university and industry is carried out. The purpose is to find out if and to what extent the requirements of agile manufacturing found in literature have practical significance. Furthermore questions concerning the situation of the industry and the focus of press manufacturers are asked to derive recommendations for action.

According to Yin and Albers a single-case design is the appropriate tool to challenge theoretical findings or to get insights into unexplored phenomena. In a single-case design the data of each case is gathered, processed individually (not compared to each other) and conclusions are drawn from the comprehensive picture obtained through all cases. [156] [157]

The style and structure of the interview is based on the so-called expert interview. Here the experiences and the interpretations of the interviewee have priority. The expert interview is a balance between openness and structure for data collection. To enable this balance an interview guide is used which makes sure that none of the important subjects are forgotten. [158] [159]

The guideline for the Interview describes the basic structure of the interviews. Every question is related to one specific production requirement. In the actual situation of the interview the interviewee often had a different way of thinking and jumped from one point to the other.

The Interview was basically divided into two parts:

- Questions concerning the production requirements
- Questions concerning the market situation and the business model

At the end of each interview the interviewee was asked to review the case study report in order to avoid misunderstanding and wrong interpretation.

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[156] c.f. Yin 2003, pp. 39 ff.

[157] c.f. Albers 2006, pp. 36–37

[158] c.f. Bortz and Döring 2003, p. 315

[159] c.f. Garz and Kraimer 1991, pp. 441–471

5.1 Introduction of the interview

The use of the words “agile” or “agile manufacturing” was avoided. As people have very different understandings of the word it rather leads to confusion than to a clarification of the purpose of the interview. Instead, the purpose and goals of the interview where described in short:
The purpose of this thesis is to develop a proposal on how press manufacturers can support their customers on their way to become agile manufacturer and use this as a business opportunity for themselves. For that eleven general production requirements were derived from literature. The purpose of the interview is to evaluate the importance and relevance of these requirements for the metal forming industry.

5.2 Questions concerning the production requirements

- How do you see the increase of products and variances in the industry?
- How did the ramp-up time of the press lines change over the last few years?
- To what extent are the press lines automated?
- Is an automation similar to CNC machines possible and what are you aiming at?
- How do you rate the importance of a fast and efficient tool change?
- To what extent can your machines be rearranged?
- Are press lines purely serially arranged or are parallel or hybrid arrangements intended?
- Is the material flow within the machines and before and after the press line flexible?
- Does customization or “batch size one” matter to the metal forming industry?
- Do your machines have a modular structure?
- How do you deal with fluctuations in demand?
- Is it possible to scale press lines in order to adapt production capacity?
- Do you allocate space and infrastructure in order to extend the facility when planning it?

- Are there any industry or company standards for interfaces between machines, modules or components?
- Do you have systems in place to monitor the machines and automatically detect the cause for production errors?
- Do you offer trainings for the professionals operating the machines?
- To which extent is the lifespan of a press line predictable?
- Do you think it is possible to find a general ranking of production requirements?

5.3 Questions concerning market situation and business model

- How does your company make money?
- What would you consider the key resources of your company?
- What would you consider the key processes of your company?
- What is the limiting factor that keeps your customers from getting their job done?
- What superior features differentiate your products and services from those of your competitors?
- What is it, that customers value about your products and services?

5.4 Interviewees

The interviewees for the empirical part were carefully selected. Two are technical sales managers of leading press manufacturers and two are experts working in the metal forming industry. This allows for a holistic view on the industry. The interviewees but more importantly the companies they work for are described in the subsequent sections. This should allow for a better understanding of their situation and consequently of their statements and remarks.

5.4.1 Andritz Kaiser

Andritz Kaiser is a leading system supplier of punching and forming technology. They are active on a global-scale as a manufacturer of ready to

use presses and press lines. The range of products also includes complete production lines with conveyor systems and automation. [160]
The Interview was conducted with Mr. Wolfgang Wiedenmann who is the deputy sales manager.

5.4.2 Schuler AG

Schuler, as the global market leader in the metal forming industry, provides machines, facilities, tools, process know-how and services. Their customers are automobile manufacturers and contract manufacturers (together about 80%) as well as companies from the appliance-, forging-, energy- and electrical industry. [161]
The Interview was conducted with Mr. Lothar Gräbener who is the Vice President of Sales.

5.4.3 Cosma International

Cosma International is part of Magna International and offers body, chassis and engineering solutions to global customers. It is a global automotive supplier. The company evolved from a manufacturer of stampings and welded assemblies to a supplier of light trucks and SUV frames and became a market leader of suspension modules and complete body-in-white systems. [162] The interview was conducted with Mr. Christian Juricek who is R&D Manager at Cosma International.

5.4.4 Magna Heavy Stamping

Magna Heavy Stamping is a producer of pressings and components for OEMs in the automotive industry. The necessary tools and facilities are designed and built in cooperation with highly qualified suppliers. The company processes about 120.000 tons of steel and 8.000 tons of aluminum. They have three hydraulic press lines, one transfer press and a blanking line. [163] The interview was conducted with Mr. Otto Fauster who is the foreman of maintenance.

[160] c.f. ANDRITZ 2014

[161] c.f. Schulergroup 2015

[162] c.f. Magna International 2015b

[163] c.f. Magna International 2015a

5.5 Case Study Report

During the interview, keywords of the answers where written down. These keywords sometimes could not be written down in the right context due to the lack of time during the interview. Right after the interview the notes were translated into a case study report. For that purpose the notes were assigned back to the corresponding production requirement resp. basic information concerning the business model. After the interviews have been conducted, the case study reports where prepared and got reviewed by the interviewees. This is, so misunderstandings can be sorted out and do not sophisticate the results.

These reports are the basis for the development of the production requirements and the business model. They are attached in the Appendix and discussed in the subsequent sections.

5.6 Discussion of the case study reports

The next step is to summaries the results and draw conclusions. Therefore all four case studies are pooled to get a comprehensive view on each aspect. This should on the one hand ease the evaluation of the importance of each requirement. On the other hand this allows discussing the individual points. For example is it possible to extract statements that are only relevant for the specific organization of the interviewee and have no general impact on the industry.

In general this section provides the basis for the derivation of the production requirements, as well as the development of the business model. Therefore they are quite essential to the output and the results of this thesis as well as for the whole project.

5.6.1 Production Requirements

This sub-chapter deals with the importance and the scope of the production requirements, found in literature, for the industry. These requirements where quite general and some turned out to be not applicable for this specific industry. Others would have no impact at all on the adaptability to volatile markets.

All these aspects are summarized and discussed here to give a holistic few of what is important to the metal forming industry. Thus the following sub-

chapters are the basis for the derivation of the production technology requirements.
The results concerning the production technology requirements are presented in section 6 where examples for the implementation are given as well.

Throughput time

The number of variants of sheet metal parts increased over the last few years and is expected to further increase in the near future. This leads to a reduction of the batch size.
Some industries, like automotive, cope with this problem with a module or platform strategy. With that they basically try to have two kinds of parts. Structural parts that are used for many different products. They have only few variants and huge batch sizes and can be produced with high volumes. For these parts the output quantity and a high availability are still the determining factor. Other parts are the so-called outer skin parts. These parts determine the shape and appearance of the car and are used to individualize the products. They are produced in a number of different variants and therefore have relatively small batch sizes.
As the number of variants goes up, product changes occur more often. Therefore it becomes important to get the individual products faster through the process as the tool changeover for the next product can only start when all previously produced products have fully made it through the production process. Consequently the leisure time during a product changeover can be reduced.

Ramp up

Due to the increase of the number of products, ramp-ups occur more often. This tendency is expected to develop further as the number of different products is expected to increase.
The ramp-up of a new product on a press line is today mostly dependent on the tools and how they run-in. To optimize that, toolmakers work a lot with simulations. On top of that they invest a lot in tryout presses to assure that the tools are perfectly adjusted already before they are installed on the actual press line. Due to the huge effort that has been invested in ramp-up, the potential of this area is pretty much exhausted.

Machine Convertibility

For press technology machine convertibility is limited to the tool changeover. The pure tool change is a major field of research due to the still increasing number of variants of outer body parts, even though the tool changeover times decreased from multiple hours to three minutes in the last five to ten years in automotive industry. This is achieved by fully automated press lines where not only the tool changeover but also the changeover of the grippers is automated.

For smaller presses and blanking machines systems have been developed where the tools are stored in high racks. This facilitates for an automation of the tool change similar to what is already state of the art for CNC machines. These systems are not suitable for tools that are used in car body manufacturing due to the sheer size and weight of the tools. For bigger tools programmable cranes can be a solution. They automatically pick the right tools from the storage area and bring them to the moving bolsters at the press line.

This topic will only become an issue at the point when the batch size goes down so drastically that the transportation of the tools to the moving bolsters becomes the bottleneck.

Configuration Convertibility

Most press lines, especially in automotive industry, are built for a special purpose or product. Even though these press lines are re-used after the product has been taken out of production, rearranging or reconfiguring the press line itself is not intended.

Multiple parts can be produced parallel on the same press or even with the same tool. The path flow of the individual parts cannot be changed and follow a strictly serial path within the press line. Consequently, configuration convertibility is not relevant for press lines.

Material-handling convertibility

The material flow within the press line is flexible in that respect, that the material handling equipment can be adapted to the requirements of the produced parts. For example, the grippers can be changed from magnetic to vacuum grippers if aluminum parts are produced instead of steel parts. The flow path of the parts is given and cannot be changed. The press technology does not allow for a material-handling convertibility within the press line. The material handling at the end of line is done manually. This results from the fact that quality control is still a manual job.

Customization

There is a market for customization and there is a clear positive trend towards it. The customization trend is relevant mostly for sports cars and special vehicles. Also in normal passenger cars, variants like sunroofs in different sizes for one and the same car are already offered. Technological limitations of blanking and metal forming processes do not allow for a customization down to the consumer level (batch size one). This would require other production technologies like laser cutting and edging.

For the purpose of this thesis, customization is not a production requirement per se. It is considered to be one level above the actual production requirements. These production requirements that where found here are enablers for mass customization. Thus, even though customization or mass customization is not considered in section 6 it is nevertheless considered important and is indirectly considered through the other production technology requirements.

Modularity

Many press manufacturers uses a modular principle to design metal forming presses that are dedicated to their customers' wishes. Nevertheless, the purpose of this modularity is not to redesign or reconfigure the machine in order to adapt to different requirements from the market.

One big topic is the ability to process different products with different requirements (e.g. steel – aluminum, structural parts – outer skin parts). This is so far realized by combined plants. These plants are highly flexible and have the basic technological requirements to process different jobs with only a few adjustments. The problem here is that the features allowing for such high flexibility are not necessary and are unused for most of the time.

It would be a new approach to realize these features with add-on modules. These modules could be added to a press line when they are needed, removed after that specific job is done and reused at another plant. This would be a shift from a purely flexible machine to a changeable machine.

Scalability

Companies have different approaches to deal with production fluctuation. One is to have highly flexible machines and to accept more orders than they can process. If some of these offers are rescinded by the customers the company is still able to operate the plant on full load. If on the other hand the orders remain in place, some of the orders are awarded to their competitors.

Another approach is to operate the machines in on/off mode which means that the machines run on full load until the order is fulfilled and then switched off until a new order arrives.
The third strategy is to simply run the machines on partial load according to the average quantity of sales.
Bigger companies with production networks also try to shift production between their own plants to maximize utilization.
Production plants are not prepared for a scaling strategy by the means of adding or subtracting manufacturing resources (e.g. presses) in order to adapt the production capacity. This is due to the fact that delivery times for a press range from eight months to two years and therefore processes cannot be adapted in due time. On the other hand metal forming machines are too expensive to keep them on stock and only add them to the process when needed.

Integrability

It used to be the case that interfaces and standards did not just differ between OEMs but also between plants of the same OEM. It becomes more and more important to be able to shift production between different plants and also to different contract manufacturers. When the demand for a product decreases, the production is often shifted from the big press lines of the OEMs, to contract manufacturers or smaller plants, that are better adapted to small batch sizes.
An industry standard is an important enabler to allow for fast shifts without adapting the interfaces of the tools and the software. Some of the bigger press manufacturers put a lot of effort in trying to find a standard for press lines across the industries. In the automotive industry such a standard has already been established and is getting more and more popular.
To be able to deal with a volatile market it will be crucial to further implement these standards all across the industry and to enhance integrability.

Diagnosability

Monitoring production machines in real time can be done on different levels dependent on the customer specifications. The offered systems range from emergency systems which only switch off the machines before they get damaged to fully-fledged monitoring systems that are able to measure different forces and temperatures during the entire production process in real-time.

The long-term vision is to have a control loop in place which automatically changes the parameter responsible for a defect detected at the end of line. The ability to detect and diagnose the root cause of an output defect fails so far due to problems in automating quality control. A lot of efforts have been made to automatically detect flaws and defects. By now, quality control is still made manually. Another issue is that the causes of defects are oftentimes material variations and can therefore not be influenced by the forming process itself. Nevertheless it is important to detect these defects in the raw material in order eliminate the problem from the internal error search as the error is an external and cannot be eliminated by modifying internal production parameters.

Especially when product changeovers occur more frequently, the ability to detect and treat output defects in an efficient way is an important production requirement.

Employee emancipation

The running-in of the system is performed by professionals and the tool change is executed by specialists. Apart from that the machines run unmanned. Unskilled labor is only used for auxiliary activities (e.g. for material handling activities).

All press manufacturers offer different levels of education to their customers' employees. A basic enrollment lasting one to two weeks is typically within the scope of supply. For greenfield facilities additionally basic education is offered in metal forming and maintenance. Furthermore, the bigger press manufacturers like the Schuler AG have an academy where employees of customers can participate in classes covering everything from basics to in-depth maintenance operations.

As press lines are already run by highly educated professionals, the potential of this area is pretty much exhausted.

5.6.2 Business Model

The pillars that are the basis to develop a business model are summarized and discussed here. This will become important for the development of the business model (see section 7). The four characteristics (profit formula, key resources, key processes, customer value preposition) that are discussed in the next sub-chapters provide the basis for the development of the business model.

Profit formula

The lion's share of machines and equipment is still sold directly to the customer. The financing in that case is done by the customer in cooperation with his house bank as they get good conditions there. In some rare cases leasing (described in section 7.3) and pay-on production (described in section 7.2) has already been offered, but these models are way less popular due to the higher aggregated costs. The second big source of revenues for machine manufacturers is maintenance, service and overhaul of machines.

The press users make their money by manufacturing sheet metal parts which is complemented by the related design tasks and auxiliary tasks like tool making.

Key resources/processes

The press manufacturers have the best knowledge of the press itself. Their key processes are innovation, design and production processes. This knowledge is sustained and applied by their employees.

In order to develop and build complete press lines it takes more than just the press manufacturer. Most press manufacturers only offer the presses itself. Supplementary machines and devices like handling system or ovens for press hardening are supplied by other companies.

The press users, on the other hand, are the experts in tool making and operating the machines. They have the best knowledge about process parameters. Additionally, the ability to understand the customer specifications and quality requirements and transform them into solutions that are globally available is essential to them. This is again realized by their employees. Some customers are supported by the services of external too makers. They work closely together with those tool makers in order to develop the best possible tools.

Customer value preposition

The limiting factor for the customers of most press manufacturers is the lack of financial resources which is mostly a consequence of the high investment costs of such machines. This is closely followed by time: As press lines typically get ordered for a specific job, so the start of production is already fixed before the press line gets ordered. The start of production is an important prerequisite for the press users, to get contracts with their customers. So if the press manufacturer is not able to deliver a fully functional machine until the planned SOP their customers will lose the order. Consequently the press manufacturers will lose subsequent orders.

6 Derivation of production requirements from survey

After discussing the interviews this section summarizes the production technology requirements that are important to the press manufacturing industry with respect to agile manufacturing. Even though most, if not all, of the found requirements are also important to other industry the structure and execution of the survey does not allow for a generalization. This is because the interview where conducted exclusively with experts from the metal forming industry.

Relating the production technology requirements back to the definition of flexibility, transformability and agile manufacturing it is to say that they are on the level of flexibility of transformability. Agile manufacturing is a term that is used for the strategic measures that are necessary to adapt to turbulent or volatile markets. Thus the production requirements are essential enabler of agility, but not sufficient to achieve agility.

The classification of the production requirements is illustrated in Figure 6 and explained in the following sub-chapters.

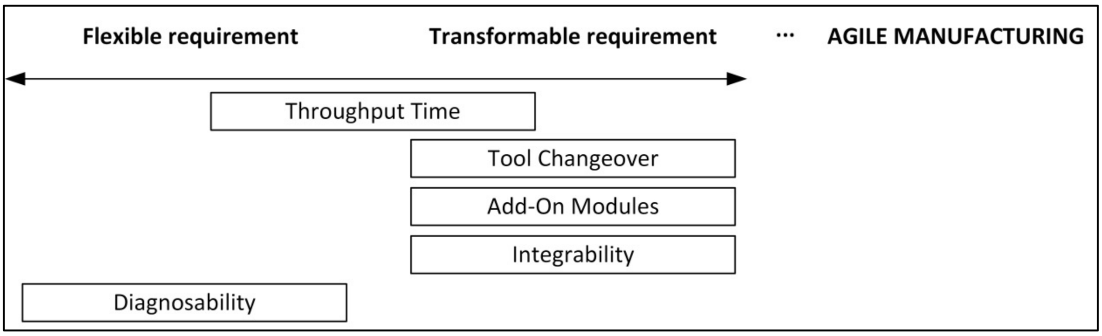

Figure 6: Classification of the production technology requirements in flexible and transformable

This section answers the third research question which is: What are important production requirements for the metal forming industry to become an agile manufacturer?

The production requirements that where found here are not the exact same that were found in literature. Some of them are completely new and emerged during the interview. These requirements are especially important to the metal forming industry.

Some of the requirements that were found in literature got adapted according to the outcome of the interviews. These requirements got specialized according to the needs and the specific situation of the metal forming industry.

Other requirements from literature turned out to be important to the industry exactly the way the where described originally. Nevertheless the importance to the metal forming industry was described and examples on how they can be implemented are given.

6.1 Throughput time

With a reduced throughput time the individual products get faster through the process. This is particularly important to be able to react fast and efficiently on product changes. In order to change the production from one product to the next it is necessary to first get all the old products out of the system. Only then the tools can be changed and the machine can be adapted to the new product. Thus a reduced throughput time cuts down the idle time during a product changeover.

As the number of products and variants goes up, these product changes occur more often. Consequently the throughput time becomes a pivotal criterion.

One attempt to increase the throughput time of press lines that has already been made is according to Mr. Lothar Gräbener from Schuler the so called cross bar feeder. In press lines the transportation of the sheet metal is typically done with industrial robots. These robots are cheap but require lots of space. This leads to presses being placed far apart from each other and, consequently, to longer transportation times. Also the quite big robot arms need a lot of space for manipulating the parts and require the tool to open wide. The cross bar feeder is a special purpose robot that was developed especially for the material handling within press lines and does not have the general disadvantages of the industrial robots. However, this is a more expensive solution.

The throughput time cannot be clearly assigned to flexibility or transformability. It does obviously also not have a strategic component and can therefore not be directly assigned to agile manufacturing. It should be understood as a basic enabler for the flexible and transformable requirements.

6.2 Tool changeover

A fast and efficient tool changeover is a requirement that becomes important with the occurrence of different products and variants that are produced on one press line.
For smaller presses and blanking machines, systems have been developed where the tools are stored in high racks. This allows for an automation of the tool change similar to what is already state of the art for CNC machines.
These systems are not suitable for tools that are used in car body manufacturing due to the sheer size and weight of the tools. Programmable cranes as described in section 0 are a possible solution. As the tools are typically stacked on top of each other, it is necessary to have a storage logic in place that allows to get the tools with as few movements as possible. Nevertheless it will be necessary to have at least two industrial robots in place to be able to also get the tools that are stored underneath. The moving bolsters, which are already established in industry, perform the actual tool change right at the machine. For that an automated positioning of the tools and automated tool holders are necessary.
An important feature that cannot be forgotten in this context is the changeover of the grippers that transport the parts between the presses. Another important step related to a production changeover are the grippers that move the parts from one press to the next. Especially for high volume production it is state of the art to only produce parts on one press line that are very similar and can be handled by the same grippers. In small volume production, where lots of very different products are produced on the same press line within a short period of time, this is not possible anymore. In the future, with an increase of volatility, this problem will also concern high volume producers like OEMs. Consequently, for a fast changeover between different parts it is important to also adapt the grippers to the new part. In a first attempt flexibility can be achieved with automatically adaptable grippers that adjust the position and alignment of the suckers or magnets. This would increase the complexity of the grippers and with that the costs. The transformable attempt would be to automate the changeover of the grippers. The grippers are relatively small compared to the tools. Thus an automated storage rack could be used to store the grippers and get them from and to the press lines in an efficient way. On the long-term the latter would be less

expensive as the costs for automation occur only once and the grippers could be as simple and inexpensive as they are now.
The tool changeover is a production requirement that enables transformability as it allows switching the production process from one product to another. The different tools are also not inherent to the machines but are added and changed as the production plan requires.

6.3 Add-on modules

On press lines different products with different requirements for the functionality of the presses (e.g. steel – aluminum, structural parts – outer skin parts) are produced. add-on modules can be added to a press line when they are needed and removed after that specific job is done. They sure can be reused at another plant. This would allow switching functionality between different press lines when and where they are needed. Moreover it would be a shift from a purely flexible machine which has a vast functionality to a transformable machine that has exactly the functionality that is required.
add-on modules increase the utilization of modules and decrease unused capacity. Thus it increases the effectiveness and is an important enabler of transformable manufacturing.
Looking at aluminum processing examples for such modules could be:

- The grippers need to be changed from magnetic to vacuum as aluminum is non-magnetic.
- The transfer rolls for outer skin panels need to be made of plastic in order to avoid surface damage.
- Blank separation is done with an air stream to avoid surface damage.

6.4 Integrability

It becomes more and more important to be able to shift production between different plants and also to contract manufacturers. Looking on the product life cycle it might be useful to start the production of a new product on a small press line. This is because sales forecasts are not reliable anymore and thus no one knows how many units can be sold. When the product is established on the market and sales are high and stable it might make sense to switch the production to a bigger production line. Finally at the end of the product life cycle when only spares parts are produced, the production might be switched to a contract manufacturer. The ability to allow for this shifting is a strategic

and therefore an “agile” ability. A lot of different enablers on different underlying levels are necessary to be able to achieve this ability. On the production level, general industry standards are important enablers to allow for these fast shifts without adapting the interfaces of the tools and the software.
To be able to deal with a volatile market it will be crucial to further implement these standards all across the industry and to enhance integrability. Perhaps the most important example for integrability in the metal forming industry is a standard for the tool holder that is a key enabler to be able to shift the production to different press lines. Not forgetting the interfaces of the grippers with the robots that are used for material handling between the presses. Also the integrability of information (e.g. software) is important in order to avoid the necessity to recode the program for another machine. Of course, the add-on modules described in section 6.3 need to be standardized and integrable in order to allow for a use at different sites.
This integrability enables the adaptions of a production line that are necessary to process different kind of parts or different materials. Furthermore it enables to switch the production of a part between different production sites in order to optimize utilization of the machines. Therefore integrability is a transformable production requirement.

6.5 Diagnosability

The long-term vision is to have a control loop in place which automatically changes the parameter responsible for a defect that is detected at the end of line.
Especially when product changeovers occur more frequently and when different people operate the machines it is only natural that defects and problems occur more often. Therefore the ability to detect output defects and to react efficiently is an important production requirement.
To this end, quality control needs to be automated with, for example, thermographic cameras, ultrasonic devices, ring tests or photometry. It is important that the used technology checks the parts fast enough to be usable at the end of the line. The pre-product (e.g. coils or blanks) can already have defects. Therefore the incoming material needs to be checked as well. Also different critical process parameters like forces of the punch and temperature of the tools need to be monitored in real time. This huge amount of data can be used to understand the process better which helps to support error

detection and elimination. Furthermore a better understanding of the process helps to improve it.

If the data that is gained during the process can be analyzed and understood the parameters can be pitched like instruments of an orchestra to create synergies and enhance the overall result. The crucial point in the realization of such a system is to analyze and understand the data. A lot of literature that is concerned with this problem has been published lately, like "Big data - A revolution that will transform how we live, work, and think" by Mayer-Schönberger and Cukier. [164] Big data shall not be treated in this thesis in more detail but it is important to show the interconnectedness of the topics.

Finally diagnosability is an inherent functionality of the press line. It adapts and furthermore improves the production process automatically without the intervention from outside the system. Therefore it is a flexible production requirement.

[164] c.f. Mayer-Schönberger and Cukier 2013

7 Development of a Business Models for the metal forming industry

On the basis of the theory reviewed in section 4 and as a consequence of the survey that is described and discussed in section 5 a new business model is developed. This business model is tailored the given boundary conditions and parameters of the metal forming industry. This business model is especially developed for helping the industry to survive and prosper in a turbulent, volatile market.
In a next step other business models that have already been established are described and classified into the morphological box (see section4.4) in order to compare the service-based business model with them and to show its uniqueness and novelty.
The business models that are used for the comparison are the pay-on production model, because it is in some ways quite similar to the developed service-based model. It could not be established in the metal forming industry so far. The second model that is used for comparison is contract manufacturing as it is the most common service model in the metal forming industry. Leasing is something that has, so far, not been seen in the industry, but is discussed here due to its similarity to the service-based business model. Finally the direct sales strategy is described here. This model does not have a lot in common with the here developed business model as it does not offer a service but physical products. As it is the by far most widespread strategy in the metal forming industry it is important to discuss it for comparison reasons.

7.1 Service-based business model

The business model developed here facilitates the metal forming industry to become more agile focuses on those parts of the business that are difficult to make money with. It is not designated for the comparative stable production of OEMs or other high volume manufacturers. Instead, it should be understood as an addition, allowing the industry to deal with the hardly predictable, low volume orders in an efficient way.
The idea is that press manufacturers build facilities with the financial support of investors and allow the metal forming industry to rent these facilities according to their schedule. The intended contracting time is between half a

year and one year. The basic characteristics are illustrated in Figure 7 and are described below. The chosen options are highlighted in grey.

Criteria	Options			
Performance provider	Independent service provider	Machinery or equipment manufacturer		
Ownership during contract period	Leasing company	Special purpose vehicle (SPV)		
Ownership after contract period	Leasing company	Special purpose vehicle	Customer	
Responsibility for maintenance	Independent service provider	Machinery or equipment manufacturer	Special purpose vehicle	
Responsibility for operation	Independent service provider	Machinery or equipment manufacturer	Customer	
Payment model	Pay-on-Availability	Pay-per-Unit	Pay-per-Use	Pay-on-Customer´s Economic Results
Location of operation	Performance provider´s in-house	Fence-to-fence	Customer´s in-house	
Exclusiveness of operation	Single Customer	Multiple customers		

Figure 7: Illustration of the Service-based business model

The performance in this model is provided by the press manufacturer. The press manufacturers have a good understanding of the industry and the market as they may have been making business in this environment for decades. They also know the potential customers of such operations as they have already worked with them under different circumstances.

An independent service provider, on the other hand, would potentially have experience with financing issues and organizational processes. Some of the bigger press manufacturers already have experience with operator models, according to Mr. Lothar Gräbener which would weaken this argument made for the independent service provider.

As a conclusion, the experience of the press manufacturers with the market and the potential customer's results in an advantage compared to independent service providers that would take years to catch up.

One of the concepts of this business model is to have multiple customers (see section 4.4.8) who can rent the facility as they need it (and as it is available). As soon as the contract with one customer ends, another contract with the same or a different customer starts. Therefore it is not useful to distinguish between "before" and "after" the contract period. The ownership of the facility rests with the investor.

This investor referred to as "Leasing Company" in Figure 8 purchases the facility from the press manufacturer referred to as "plant manufacturer". In return he gets a turnkey contract and is now the owner of the facility. The leasing company has the responsibility to make contracts with customers and to ensure a high utilization of the facility. The leasing company is reassured by a bank. If the press manufacturer is able to finance the new facilities an external leasing company is not necessary. The structure in Figure 8 would still be valid as the press manufacturer would establish an affiliated company that is responsible for the operation of the new business model. The leasing company would then be equivalent to this affiliated company.

The customers have one contract with the leasing company that covers two things. A user agreement with the leasing company that guarantees the availability of the facility with all the contracted technological add-ons for the press lines. For that they pay a utilization fee that is made up of the time when the facility is rented, the add-ons that the customers demand and also incorporates the maintenance fee. The maintenance is done by the press manufacturer as described in the case study reports in the appendix.

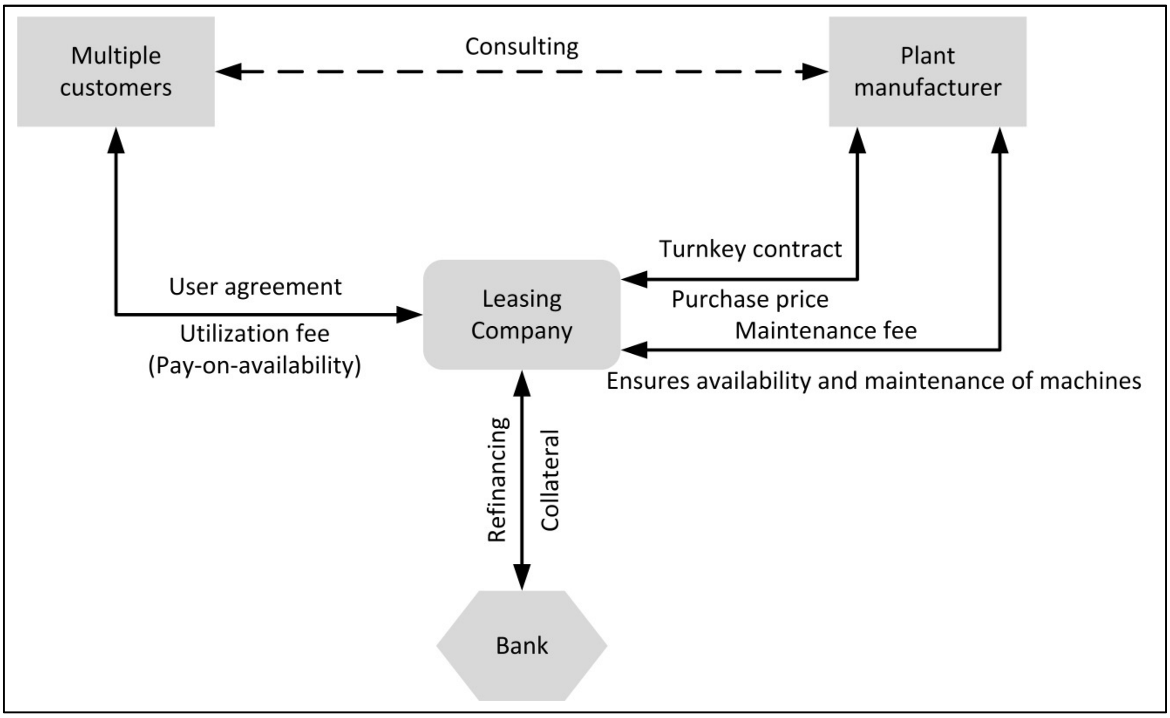

Figure 8: Constellation of the Service-based business model

The press manufacturers have the best knowledge about the presses itself. They put a lot of effort in educating their customers especially about maintenance issues. This effort would seem wasted in this business model where the customers use the facility only for a limited amount of time. Therefore the responsibility for maintenance remains with the plant manufacturer.

The leasing company has a maintenance contract with the plant manufacturer and pays a maintenance fee out of the utilization fee they get from the customers. This is so the customer has only one contact and does not have to deal with multiple contracts. In return the plant manufacturer gives an availability assurance and maintains the machines. The maintenance personnel of the plant manufacturer would not necessarily need to be at the sight all the time. Nevertheless they have to be available to deal with emerging problems within a contracted time.

As the press users are the experts for operating the machines the responsibility for the operation of the presses and the operation personal remains with them.

The customer sends his operation professionals to the facility where they work together with the employees of the press manufacturer that are responsible for maintenance. This cooperation assures a knowledge transfer and an optimization of the processes. The strict separation of tasks in maintenance and operation assures that for each problem the responsible expert is at hand.

For the payment the so called Pay-per-Use model is applied. The customer only pays for the time when he actually uses the facility. The period during which the customer is allowed to use the facility needs to be defined beforehand in the user agreement. If the customer does not use the facility during the pre-contracted period he still has to pay. This is necessary to ensure a certain amount of planning security for the performance provider who already carries the risk of and underutilized plant.

The user agreement also contains the exact conditions of use like the required functionality of the presses which, together with the length of use, determines the amount the customer has to pay. This amount has to be paid as a utilization fee to the leasing company. The maintenance of the facility by the press manufacturer is mandatory. Thus the maintenance fee is already included in the utilization fee.

The performance provider can cancel the contract without notice as soon as the customer has default. Furthermore, he can claim damages.

It is obvious that it does not make sense to locate the operation right in-house of a customer's site, as the customers change regularly. Additionally, it cannot be predicted who the customers will be at the beginning of the planning phase. However, it is possible to figure out potential customers of the new plant. Therefore it makes sense to locate the new plant close to these potential customers to make sure that the impact on the supply chain remains fairly small. Also the trip to work for the operation professionals of the customer that will run the external plant will not change by much. This will lower the threshold for the customers to outsource the production to the external production site.

The business model is, as already mentioned; open to anyone who is able to procure the money. The only actual limitation is the availability of the facilities. The advantage of this it, that the contingency risk is spread amongst many different customers. This is especially important for the long-term viability of the operation.

The downside of the multiple user approach is that it is the performance provider’s responsibility to ensure a high utilization of the facility. Together with the plant manufacturer they have to put a lot of effort in attracting customers that are interested in shifting their production to the external site.

7.1.1 Potential customers

The expected customers are composed of two different fractions: Companies with an extensive experience in metal forming that lack of short-term production capacity. Small and medium sized companies that cannot afford to buy press lines and use this business model to produce the parts themselves. Both these customer groups have to be treated differently.

The former have the knowledge and experience to operate the machines themselves and use the business model to overcome capacity bottlenecks. Examples could be:

- A metal manufacturer gets a long-term contract but does not have enough production capacity and is also not able to build new press lines until the contracted start of production. In this case the manufacturer could use the service-based business model to overcome the lack of capacity until the new press lines are ready undertake production.
- A metal manufacturer has a contract with a small production volume and does not want to replace the long-term productions of his own press lines. In this case the sheet metal manufacturer can use the service-based business model so he does not have to cancel the contract.

The small and medium sized companies would have to out contract the production if they are not able to finance a press line themselves. This

means, they would have to share their knowledge and eventually lose a competitive advantage. To avoid this, the company can use the service-base business model to keep the intellectual property in house.
The problem here is that those customers typically do not have any experience or knowledge about operating presses or press lines. One option to overcome this problem would be that the companies organize operating personnel themselves. This appears to be rather difficult for companies that have no experience in metal forming. Therefore it makes sense that the plant manufacturer offer personnel leasing for those customers. The plant manufacturer have skilled personnel that can support the customers and eventually also gradually teach them to operate the machines themselves.

7.1.2 Add-on pricing

The add-on modules that are described in section 6.3 enable an add-on pricing strategy that can be combined with the business model explained above. The value proposition is offered for a price that is as low as possible. A variety of add-on options drive up the price.[165] This strategy allows for a higher profit compared to other models. [166] The advantage for the customer is that he can adapt the product or service to his needs and does not have to pay for things he does not need. [167] This means that the press line with its basic functionality is offered to the customers for a low price. If the customer wants to produce for example aluminum parts, he would need the corresponding add-on modules. These modules can be rent together with the facility but make the utilization and maintenance fee accordingly higher.
The add-on modules could also be offered to customers who do not use the service-based business model. If customers want to add functionality to their own press lines they could rent the modules for the time they need it and give them back afterwards. This could on the one hand help to increase the utilization of the add-on modules and on the other hand help the customer to avoid extensive functionality. Obviously, this external rentals would cost much more compared to the rental related to the service-based business model. This is to increase profit margin but also to decrease the threshold for the service-based business model.

[165] c.f. Gassmann *et al.* 2013

[166] c.f. Ellison 2005

[167] c.f. Gassmann *et al.* 2013

7.1.3 Opportunities of the service based business model

In economically difficult times it can make sense to relocate production back in-house that was outsourced before. The attempt for this business model does not include an actual in-house production. As production is done with internal personnel and own tools the know-how is kept in-house. Therefore it can be seen as a partial in-house production.

The customer gets new and efficient plants and equipment without restrictions due to a lack of resources which leads to an increased productivity and cheaper products. Fixed costs are transformed into variable costs which decreases the risk in turbulent markets. Also, auxiliary tasks like maintenance and storage do not need to be performed by the customer.

As the metal forming sector has a manageable size, literally everyone knows everyone. This bears the risk of intellectual property loss, especially when it comes to service providers. During the contracting period the facility is available exclusively for one customer. This requires that if facilities have multiple press lines that are contracted to different customers they must be spatially divided. Therefore the customer does not have to fear to loose knowledge to his competitors.

The press lines are available faster compared to purchasing the press lines. This can be a significant competitive advantage if the start of production is critical.

The add-on options allow the customer to individualize the press lines to his specific needs. Therefore he does not have to pay for functionality that he does not need.

The press manufacturer gets the opportunity for growth and to open a new business area in a stagnating market. The business model will help smaller companies, that are not able to finance investment intense machines like press lines, to use such machines. Furthermore, press manufacturers can get long-term data of the machines which can be used to improve the press lines.

In general it is to say that this model is expected to work better during an economic recovery as there is more potential to increase the own market share. Also, as launching a new sales strategy bears a lot of risks, it is obvious that these risks can be hedged easier if the economic situation of the company is good. Therefore it is essential to have a good timing when it comes to the decision for the market launch date.

7.1.4 Risks of the service based business model

The leasing company is dependent on the market knowledge of the press manufacturer. The tasks of the leasing company are limited to financing and organizing the contracts. Thus this company will not be familiar with marked conventions and also not have any relations with potential customers. The contact therefore can only be made by the press manufacturer.

The service-based business model will compete with make to order manufacturers. These make to order manufacturers are customers of the press manufacturer. The latter would compete with the former bearing the risk of losing customers.

Also the contract manufacturers have the knowledge and experience edge when it comes to the production of small batch sizes. It will take a while until this edge can be compensated by the other companies.

The performance provider has to make sure that the assets are utilized in a profitable way. It is his risk if the facility stands idle. On the other hand the performance provider has to assure the availability of presses according to the customers demand. If customer demand is bigger than the available press lines it is a lost opportunity for the service provider. Especially when this channel of distribution is launched it will be difficult to determine the capacity that needs to be provided.

The profitability of the service-based business model for the customer depends on the contract quantity. For high volume, long-term contracts purchasing the press line or other models will be the better solution. The service-based business model can only be profitable for low volume, short-term contracts. Thus the decision whether to choose the service-based business model or another strategy depends on forecasts. The advantage of the service-based business model in that concern is that the due to the short contracting time the forecasts are comparable reliable.

At the moment, orders with small batch sizes or uncertain demand are typically outsourced to make to order manufacturer. These make to order manufacturers have gained a lot of knowledge and competences in dealing with volatile conditions. Therefore the customers (especially OEMs) would need to catch up with the knowledge in order to be competitive.

During the duration of the contract, the customer is bound without any cancellation clause. The utilization and maintenance fees have to be paid no matter whether the good is used or not.

7.1.5 Review of the satisfaction of the agile manufacturing definition

This section should display how and to which extend the developed business model fulfills the definition of agile manufacturing from section 2.3. It should further reveal which parts of the definition cannot be covered and would require further steps. The following paragraphs are in connection with the preceding sections the answer to the fourth research questions: How can a business model expedite the process to become an agile manufacturer?

The developed business model does not enable the company to open up completely new markets as required by Wiendahl [168]. It does however enable the company to increase the existing market and attract new customers. It also gives the manufacturing companies access to manufacturing capacity where and when they need it.

The service-based business model is dependent on the prior developed flexible and transformable production requirements. As long as they are not implemented the business model would not run economical (see also section 9.2). This is in-line with Kidd [169] who pointed out that flexibility is a necessary condition to achieve agility.

As Gunasekaran [170] pointed out; the goal in agile manufacturing is to develop solutions that are tailor made to the customers' needs. It is important to not restrict oneself to the production of products but broaden ones scope to other channels of distribution like providing a service. The service-based business model is a co-operation between the press manufacturer and his customer that is intended to increase the competitiveness of both. It crosses company borders and enhances cooperation to achieve more agility. This is exactly in-line with Gunasekarans definition.

Looking at the publication of Schurig [171] it is obvious that the facilities would have to be built in advance. Otherwise the advantage of fast availability and access would be lost. The screening of the business environment is not incorporated in the developed service-based business model. Therefore this important step would need to be undertaken separately by the companies. The purpose of the developed business model is to improve the economic

[168] c.f. Wiendahl *et al.* 2007

[169] c.f. Kidd 1994, p. 43

[170] c.f. Gunasekaran 1998

[171] c.f. Schurig *et al.* 2014

situation especially in volatile times. If this goal can be fulfilled is still to be proven and cannot be foreseen at this point. Furthermore it is important to mention that the service-based business model is not expected to have a positive impact if the markets continue to be stable. In that case the overall costs are expected to be higher compared to the channels of distribution that are currently used. The service-based business model is developed to overcome volatile times and this is where it is expected to perform better than other models.
In general the developed business model fulfills the agile manufacturing definitions quite well. Nevertheless it does not cover all characterizations and requirements and would therefore need to be complemented by additional measures.

7.1.6 Classification of the business model in the white space matrix

We cast another glimpse at the white space matrix in Figure 9 that is already known from section 4.1. It is easy to see that the direct sales make up the core business of the press manufacturer. They have existing customers that are served in a traditional way. Also, as this has already been done for decades, the whole organization has adapted and perfected this business model. The problem is that the market is very mature and involves barely any development potential. Especially for industry leaders, or those who want to become industry leaders, it is important to seek for new opportunities to grow and to secure a leading market position.
The service-based business model barely fits with the current organization. The industry is not yet prepared for this sales strategy and it would take a while to build up the know-how and capabilities that are necessary. This of course bears a lot of risk that needs to be managed. Apart from that it serves the existing, but also new customers in a fundamentally new way. This opens up new opportunities for growth and for increasing the market share.
The avoidance of competition as is intended with the blue ocean strategy cannot be achieved with this business model. The business model itself is fundamentally new. Nothing can be compared to it. In industry there are other business models like pay-on production, leasing and especially contract manufacturing. The service-based business model will compete directly with these more established business models.

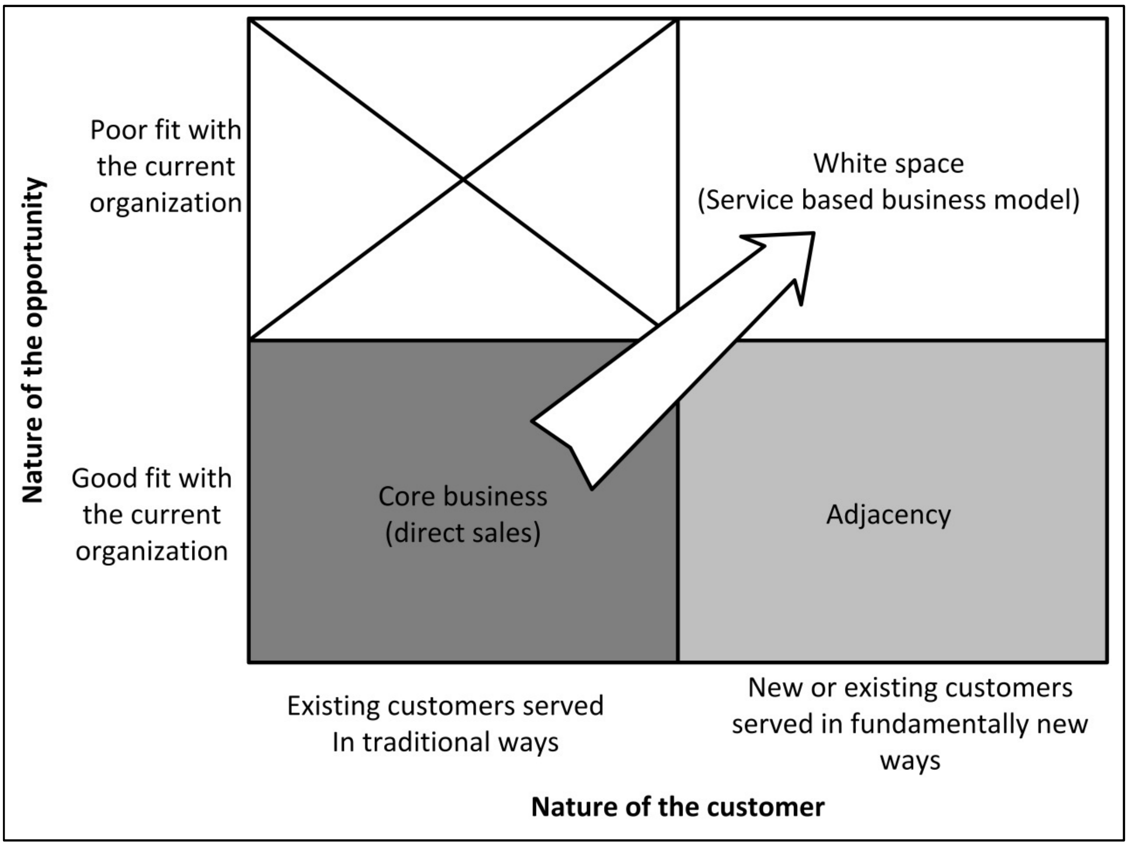

Figure 9: Defining the white space. Own representation based on Johnson [172]

7.1.7 Applicability to other industries

After developing the service-based business model and during the discussion with Prof. Haas the question emerged, if the model could be applied to other industries. Basically there is nothing that speaks against it but it has to be verified if adapting the model could improve the benefit on other sectors. This is because the service-based business model was developed especially for the metal forming industry, with all its characteristics.

Especially criteria like responsibility for maintenance and operation need to be reviewed, as the core competence might be allocated in a differently in other industries. For such an adoption it is advisable to use the morphological box as represented in Figure 5. It gives a comprehensive overview of the criteria that need to be considered and the options that are available. Also a new study would have to be applied, like it was done in this thesis, about the initial situation of the industry, the distribution of the core competences and the needs and wants of suppliers and customers.

[172] c.f. Johnson 2010

With the study as a basis and the morphological box as a framework the service-based business could be adopted to machine manufacturing plants, injection molding technology or rapid prototyping.

7.2 Pay-on production

Pay-on production is essentially an operator model that was developed to reduce costs of existing industrial productions that are within the core competences of the company. In classic manufacturer and customer business relations the former is interested in maximizing the profit by designing the machines such that they only last for the negotiated warranty time. This leads to savings in production and to further revenue through maintenance jobs for the manufacturer, however it is a disadvantage for the whole system. Therefore pay-on production is an operator model on a partnership basis where both parties are interested in increasing the profit of the production. Furthermore, in contrast to traditional outsourcing, the operation at the plant is supposed to be run by employees of the user, so he still has influence on quality, costs and the generated benefit of productivity. [173] [174]

<table>
<tr><td></td><td></td><td colspan="12">Options</td></tr>
<tr><td rowspan="8">Criteria</td><td>Performance provider</td><td colspan="6">Independent service provider</td><td colspan="6">Machinery or equipment manufacturer</td></tr>
<tr><td>Ownership during contract period</td><td colspan="6">Leasing company</td><td colspan="6">Special purpose vehicle (SPV)</td></tr>
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<tr><td>Responsibility for operation</td><td colspan="4">Independent service provider</td><td colspan="4">Machinery or equipment manufacturer</td><td colspan="4">Customer</td></tr>
<tr><td>Payment model</td><td colspan="3">Pay-on-Availability</td><td colspan="3">Pay-per-Unit</td><td colspan="3">Pay-per-Use</td><td colspan="3">Pay-on-Customer´s Economic Results</td></tr>
<tr><td>Location of operation</td><td colspan="4">Performance provider´s in-house</td><td colspan="4">Fence-to-fence</td><td colspan="4">Customer´s in-house</td></tr>
<tr><td>Exclusiveness of operation</td><td colspan="6">Single Customer</td><td colspan="6">Multiple customers</td></tr>
</table>

Figure 10 Illustration of the pay-on production Model with the morphological box. Own representation based on Hypko et al. [175]

[173] c.f. Meier 2013, pp. 16–20

[174] c.f. Decker and Paesler 2004

[175] c.f. Hypko *et al.* 2010

Figure 10 classifies the pay-on production model in the morphological box by Hypko et al. and Lay et al. Figure 11 illustrates a possible constellation of a pay-on production model.

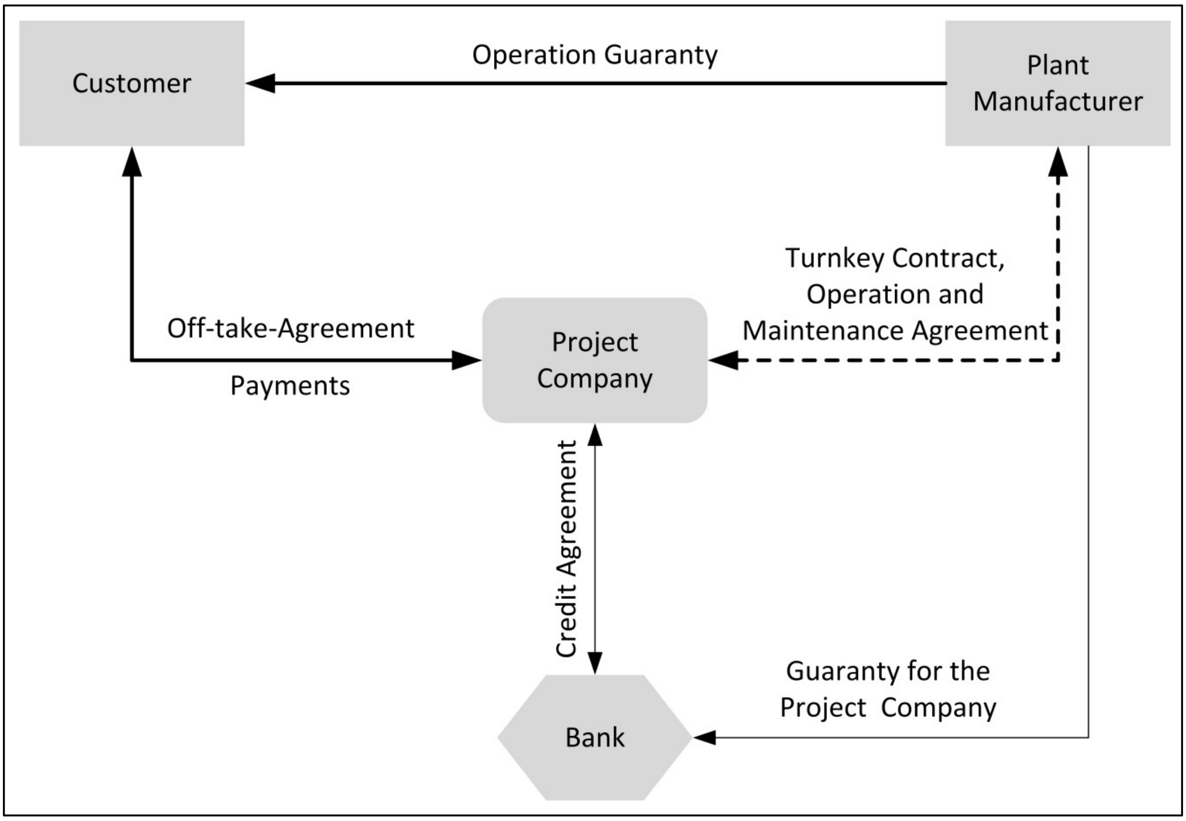

Figure 11: Constellation of a pay-on production model. Own representation based on Meier [176], Decker and Paesler [177] and Wildemann [178]

The essential characteristics are: [179] [180]

- The performance is provided by the machinery or equipment manufacturer who has the technological competence.
- The project company owning the facilities during and after the contract period is a special purpose vehicle that is purely established to run the production
- The plant is operated and maintained by the project company, but the plant manufacturer as a performance provider guarantees the customer provision of these tasks by the project company

[176] c.f. Meier 2013

[177] c.f. Decker and Paesler 2004

[178] c.f. Wildemann 2011

[179] c.f. Meier 2013

[180] c.f. Decker and Paesler 2004

- The customer pays the project company per produced unit
- The plant manufacturer has contracts with the project company and guarantees the bank for the project company
- The operation is located at the customer's company
- The whole operation is done exclusively for one customer
- The bank's duty is to arrange a bankable project financing by providing the required loan amount, setting up a bank consortia by means of inviting other banks to participate, as well as holding a share in the project loan
- The legal form of the subsidiaries of the sponsor depend on the legal requirements and the favorable tax systems

The main criterion was to achieve off-rating according to US GAAP (United States Generally Accepted Accounting Principles), which results in the following requirements: [181]

- Risk sharing – sharing of the entrepreneurial risk amongst all investment partners
- No guaranteed quantity will be purchased – no production, no payment
- No fixed contract duration
- Only payment of a fixed amount per produced entity
- Termination at call with 12 months-period without any financial commitment of the user – the "Sponsor" (plant manufacturer) bears the risk of the not yet satisfied amount of investment.
- The maintenance is done by the "Sponsor" for a fix price and will be charged for any hardware error induced down time

7.2.1 Opportunities

The user gets new and efficient plants and equipment without restrictions due to a lack of resources which leads to an increased productivity and cheaper products. Fixed costs are transformed into variable costs which decreases the risks in turbulent markets. Auxiliary tasks like maintenance and storage do not need to be performed by the user.

The sponsor gets the opportunity of growth and of opening a new business area in a stagnating market. He gets the chance to establish long-term

[181] c.f. Meier 2013

twinning and to increase his competitiveness. Furthermore, he can get long-term data of his machines which he can use to improve the design. [182]

7.2.2 Risks

It is essential for the user to choose the right partner as the competences and credit are essential for the success of the cooperation. If the partner supplies unreliable machines or runs bankrupt the project is doomed to fail. [183] The cancelation period of 12 months might seem quite flexible at first sight compared to owning the facility. As managers tend to understate or underestimate emerging market changes and wait until the very last moment to counteract the 12 month period is possibly still too long-term (compare also Wildemann in 2011 [184] who defines variable costs as influenceable within 6 months). Another criterion limiting the ability of pay-on production to deal with turbulent markets is the absence of a mechanism that enables the user to reenter the cooperation when stability and recovery return to the markets.

The sponsor does not have any influence on the design or the sales of the product, thus the success of the cooperation is fully dependent on the user. Apart from the maintenance agreement the sponsor only gets paid when he produces products or in other words, when the user is able to sell them. If the user cancels the contract the sponsor has to find another usage or partner for the facilities. If the sponsor is not able to produce he has to pay compensations to the user. [185]

Furthermore the sponsor has to take over further contractual obligations for additional contributions over a longer period of time. Finally he has to build-up specialized knowledge in the functional areas planning, valuation, financing and management as well as controlling of projects. [186]

7.3 Capital or property leasing

Leasing is a transfer of use of the property. The leasing company redeems the investment with the installments of the customer or lessee. The lease (the

[182] c.f. Meier 2013

[183] c.f. Meier 2013

[184] c.f. Wildemann 2011, p. 3

[185] c.f. Meier 2013

[186] c.f. Decker and Paesler 2004

actual good) is provided to the customer by the leasing company for use in return for payment. The leasing company buys the lease from the manufacturer but typically never gets the good which is directly delivered to the user. The job of the bank is basically to ensure the project financing together with the leasing company. These relationships are illustrated in Figure 12. [187]

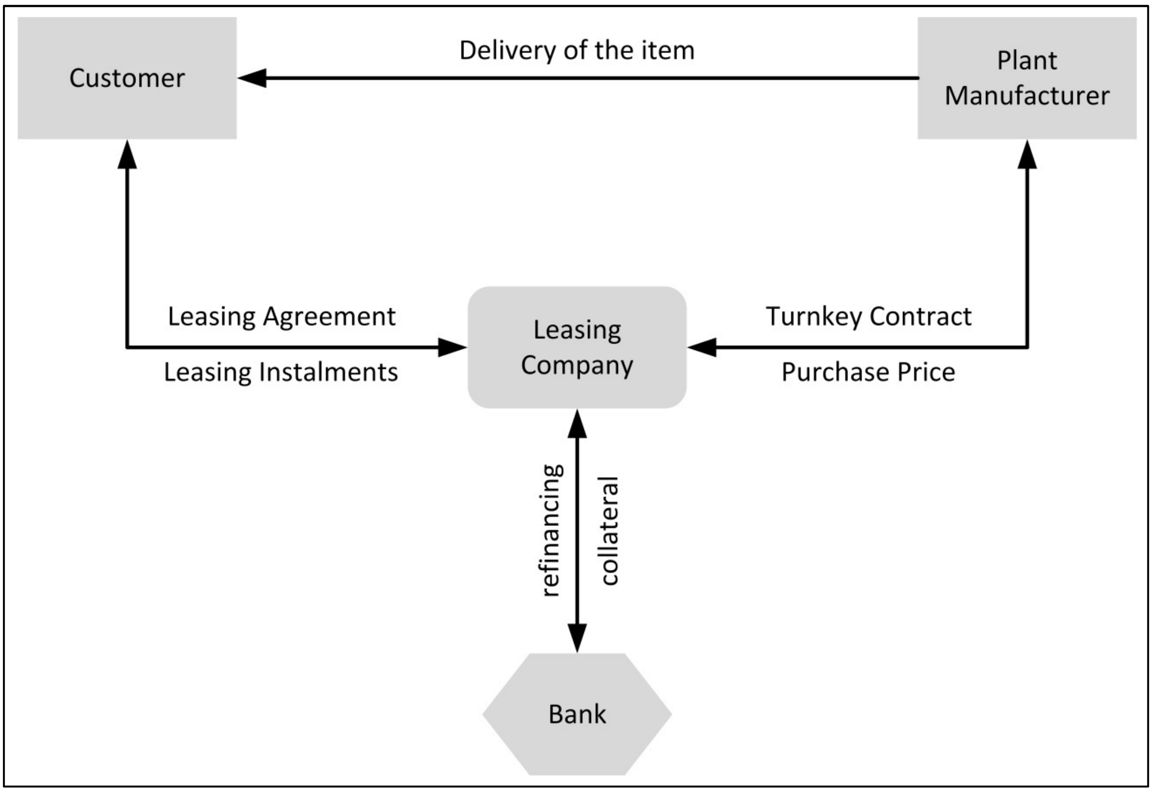

Figure 12: generic contractual relationship of leasing. Own representation based on Wildemann [188]

Figure 13 classifies capital or property leasing with the morphological box. The main characteristics are:

- The performance provider cannot be determined within the scope of the morphological box as it is a cooperation between the leasing company providing the financing and the manufacturer providing the actual good.
- During the contract period the property is owned by the leasing company.
- After the contract period the property is passed on to the customer.

[187] c.f. Grundmann 2013, p. 3

[188] c.f. Wildemann 2011

- The maintenance is done by the customer as long as no additional contracts are made.
- The operation of the machines is done by the customer. The property is held available exclusively for the customer during the contract property. After the contract period the property passes on to the customer.

Criteria	Options			
Performance provider	Independent service provider		Machinery or equipment manufacturer	
Ownership during contract period	Leasing company		Special purpose vehicle (SPV)	
Ownership after contract period	Leasing company	Special purpose vehicle	Customer	
Responsibility for maintenance	Independent service provider	Machinery or equipment manufacturer	Special purpose vehicle	
Responsibility for operation	Independent service provider	Machinery or equipment manufacturer	Customer	
Payment model	Pay-on-Availability	Pay-per-Unit	Pay-per-Use	Pay-on-Customer´s Economic Results
Location of operation	Performance provider´s in-house	Fence-to-fence	Customer´s in-house	
Exclusiveness of operation	Single Customer		Multiple customers	

Figure 13 Illustration of capital or property leasing with the morphological box.

7.3.1 Opportunities

The user is able to reduce the fixed costs which allows for more liquid funds and increases the flexibility as he does not have to use any equity funds. Only the reduction in value has to be paid.

As the leasing company takes over some of the administration tasks it can also decrease the administrative costs of the user.

Furthermore, the user always gets the newest technology and the regular lease payments allow for a better and safer planning process.

The sponsor gets the opportunity for growth and for opening a new business area in a stagnating market. [189]

[189] c.f. Grundmann 2013, p. 4

7.3.1 Risks

The user does not own the lease and therefore does not have the right to sell the good if it is not used anymore.
The aggregated costs of leasing are generally higher (about 20 – 40%) compared to other borrowing forms, as the leasing company takes parts of the credit risk and also wants to make profit.
During the duration of the contract the lessee is bonded without any cancellation clause. The leasing instalments have to be paid whether the good is used or not. The duration of a property leasing contract needs to be between 40% - 90% of the operating life which typically results in at least five years. [190] [191]
The leasing company can cancel the contract without notice as soon as the user has default. Furthermore, he can claim damages. [192]

7.4 Contract manufacturing

One of the biggest trends of the last few years regarding the decreasing product life cycle and the increasing number of products is contract manufacturing. In contract manufacturing a company transfers one or multiple tiers of its own manufacturing to another company. This can involve components, modules or the assembly of the product. Contract manufacturing benefited in the last few years from the trend towards outsourcing. They can use their infrastructure and production lines for multiple customers and convert this into a cost benefit. If the demand for one product goes down, they can accept another order. The OEMs focus on their core competences like R&D, design and marketing. Additionally they can reduce their fixed costs and spare the effort of building up production capacity for a new product. [193]
Classifying contract manufacturing in the morphological box it is easy to see that the performance is provided by an independent service provider (see Figure 14). The ownership during and after the contract period cannot be classified within the scope of the morphological box as the independent

[190] c.f. Hupfauer 1997

[191] c.f. Grundmann 2013, p. 4

[192] c.f. Grundmann 2013, pp. 4, 15

[193] c.f. Zentes 2004, pp. 281–282

service provider (the contract manufacturer) owns the facilities and production lines. Also the responsibility for maintenance and operation rests with the contract manufacturer. It is easy to see that it is a simple outsourcing strategy where the responsibility for the whole production is transferred to another company. The payment model is pay-per unit where typically a minimum quantity is contracted. The operation is located in-house at the contract manufacturer and, as mentioned before, multiple customers are served.

<table>
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</table>

Figure 14: Illustration of contract manufacturing with the morphological box.

7.4.1 Opportunities

The OEMs do not have to hire professionals or build up production capacity. Therefore the OEM does not have to invest any money into production. If the existing production network of the contract manufacturer is used, the overall time-to-market can be reduced significantly. If the contract manufacturer is in a low cost country it can reduce costs a lot. Even if the aggregated costs cannot be reduced contract manufacturing at least allows for a fix cost reduction. [194]

OEMs that do not have sufficient know-how or competences for the production of a specific product can outsource to a contract manufacturer who are capable of doing that. This increases the quality of the product and efficiency of production. Contract manufacturing allows the companies to focus on their core competences and therefore add additional value to the

[194] c.f. Zentes 2004, p. 282

products. On top of that, they can further develop these competences and increase their know-how and efficiency. As contract manufacturers have multiple customers and therefore a higher production quantity they can benefit from the economies of scale. [195]

7.4.2 Risks

The OEM has to be careful about choosing the contract manufacturer. A partner who is not capable of delivering can increase the costs dramatically. Another risk is the lack of control. The OEM cannot influence what was not contracted at the beginning of the partnership. This is especially important for quality. The quality standards need to be stated at the beginning and verified during the whole contract period. Therefore the relationship between OEM and contract manufacturer is essential for the success of both. If the contract with the company is not important to the contract manufacturer he might consider other companies as more important and favor them. In general, the lack of control results in a loss of flexibility and responsiveness, especially if the OEM is not powerful and important enough to the contract manufacturer. [196]

The OEM has to be careful about what to outsource to the contract manufacturer. It is very important to keep the core competences within the company in order to avoid intellectual property loss.

Outsourcing to low cost countries bears a lot of risks that need to be balanced with the cost advantage. [197]

The language barriers and cultural differences can lead to poor communication and misunderstandings. One crucial disadvantage is the long lead time and the slow responsiveness.

7.5 Direct sales

The direct sales strategy is quite simple and does not need a lot of explanation. Goods and products are sold directly to the customer. The ownership is transferred to the customer and in the basic version supplier and customer do not have any contractual connections afterwards. It should

[195] c.f. Adminer 2014

[196] c.f. Zentes 2004, p. 282

[197] c.f. Arrunda and Vazquez 2006

be mentioned here that in the metal forming industry it is quite common to have maintenance contracts with the press manufacturer.
As this business model does not offer any services but actual goods it is not useful to illustrate it in the morphological box describe above. Nevertheless the individual criteria are described as far as possible in the following. The description refers to direct sales as it is done in the metal forming industry.
The performance, from the point of few of the customer, is performed by the machinery and equipment manufacturer. The performance in this context has to be seen as developing and producing the machines which is not what was the intention of the morphological box.
The press lines are owned by the customer. In direct sales there is no such thing as during and after the contracting period in the sense of the morphological box (it refers to a service contract rather than to a sales contract).
The responsibility of maintenance is typically split between customer and press manufacturer. Everyday maintenance tasks are typically performed by the customer themselves. The customers additionally have maintenance contracts with the press manufacturers who are responsible for substantial maintenance and repairs.
The machines are operated by the customer with some exceptions. For the first few months the press manufacturer might provide operators in order to ensure a smooth and trouble-free ramp up of the press line.
The press line is paid by the customer all at once. Financing by the press manufacturer is possible but not common. If financing is necessary it is typically done by the house bank of the customer.
The operation is obviously located at the customers in-house and a machine is sold to one customer only.

7.5.1 Opportunities

This model is the way business in the metal forming is done since decades and is well established. It does not need complicated contractual relations or a complex structure. Probably the major advantage is its simplicity.
The press manufacturers have a lot of knowledge of the market and a customer base that they can rely on. The competitors are all known and the risk of unexpected developments, from within the market, are quite low.
The aggregated costs are quite low, as the press manufacturer offer only the presses and maintenance but does not have to bear any risks.

The machines are, with the exception of the start-up phase, exclusively operated by the customer. Thus the intellectual property is quite safe, especially compared to service models. Furthermore the customers get a machine that is tailor made to their specific needs.

7.5.2 Risks

Presses and press lines are quite cost intense. The customers are therefore limited to big companies and groups as only they can raise the capital. Also those companies that are able to finance such machines will be better off with less fixed costs, in economical difficult times.
The depreciation period of such machines is quite long. The owner is stuck with the machines for many years but the technology will be outdated quite fast. The customers have to perform a lot of auxiliary tasks like basic maintenance and small repair task that are not value adding.
The development and installation of a press line takes between eight months and two years. The ramp up of a new product on a new press lines has to be planned well in advance and does not allow for any unforeseen events.
It does not make sense to purchase new press lines for contracts with small batch sizes. If no capacity is available on existing machines, the contract cannot be fulfilled with this strategy in an economic way.

8 Comparative study of the business models

In order to determine the applicability of the developed business model to deal with volatile markets, a comparative study with established business models has been carried out. The service-based business model was compared to business models competing with it and business model that are quite similar.

8.1 Criteria

In order to compare the four different business models seven criteria have been selected. They should enable an assessment of the business models with respect to the ability to help the industry to survive and prosper in a volatile or turbulent market. Other criteria asses the suitability of the business models for the metal forming industry in particular. The criteria where rated objectively by quantifiable means if possible, but also out of the experience gained through the process of interviewing.
Further on, the criteria are listed and explained. The criteria are evaluated with a scale from 1 (does not fulfill the criterion) to 5 (fully fulfills the criterion).

8.1.1 Capability of fix cost reduction

Especially in a volatile market the capability of fix cost reduction is an important criterion in order to survive in the short-term. If the market can change unexpected and fast, as it is with turbulent markets, it is important to not be stuck with fixed capital that can potentially become obsolete before it is written of.
The rating is 1 for a direct sales model of facilities or machines. The highest rating of 5 is awarded if costs are only related to a service provision and no capital invest is necessary. As the models are either a direct sales or a service-based model and no intermediate stages are known, consequently also no partial grading is awarded.
Pay-on production was rated with 5, as the costs actually only occur when a product is produced. The service-based business model was rated with a 5 as well as the facilities are only rented when they are actually needed and the contracts are all short-term. Also with contract manufacturers no capital incest is necessary and the costs are also related to the production as a service. Therefore contract manufacturing is rated with a 5. A leasing

contract has quite long-dated terms. The costs though, only occur monthly for the service of making the capital (machines or facilities) available. Therefore it is rated a 5 as well. The only model that has a different rating for this criterion is direct sales. The costs occur all at once as fixed costs. Therefore the rating is 1.

8.1.2 Aggregated costs

The aggregated costs still have an important influence on the usability of a business model. Agile Manufacturing is expected to cost more compared to other principles and so is the developed service-based business model. If the aggregated costs exceed the alternatives by too much, this will thwart the other advantages and no one will apply it.
The benchmark here is the direct sales strategy which would be a 5 as it is expected to be the cheapest of all considered models. The costs for leasing are about 20 - 40% higher compared to direct sales. [198] Therefore it is rated a 3. For the service-based business model no data is yet available as the model has yet not been implemented. This is unfortunately also true for the pay-on production model. As the financing structure is similar to leasing the costs are expected to be about the same and rated a 3. For contract manufacturing it is a tad trickier. The actual costs depend a lot on the specific contract and on the circumstances. Some claim to have cost benefits of 15% compared to in-house production and direct sales. [199] For the purpose of this thesis the cost are assumed to be the same and is therefore rated a 5.

8.1.3 Potential for growth

The metal forming market is saturated. Therefore it is important for the new business model to have novel strategies in place to enable the company to grow. The rating consists of the novelty of the model (1 point) the degree to which it extends the market (1 point) and the avoiding of competition (2 points). The final rating consists of the sum of these three sub criteria which are added to the base value of 1.
The service-based business model is completely new to the market (1 point). It does open up new markets but serves the customer in a novel way. This business model therefore has the ability to extend the market (1 point). It

[198] c.f. Grundmann 2013, p. 4

[199] c.f. Jackson *et al.* 2001

does not avoid competition at all. Moreover it competes directly with the contract manufacturers (0 points). In total the potential for growth is 3 points.
Contract manufacturers have been known for decades (0 points). The business has changed the market and the way the companies interact with each other (1 point). It furthermore competes with the OEMs and the other business models described here (0 points). The total rating is the base rate of 2.
The pay-on production model is new and has just started to be noticed by the industry (1 point). Similar to the service-based business model it serves the customer in a completely new way (1 point). As all the other business models it directly competes with them (0 points). The total rating is 3 points.
Leasing is a well-established concept (0 points). It is in the end only a financing method that does not change the market substantially (0 points). The companies that make use of leasing are the same companies that compete in the market for decades (0 points). The overall rate is therefore the base rate of 1.
Direct sale is well established in the industry in the by far most common used sales strategy. Consequently it does not get a rating for novelty. The metal forming market is quite saturated. The customers of the direct sales model are all known and due to its immense investment costs it is not able to address any new customers. The model does therefore not get a rating for extending the market. This model is not new and is stuck with the same competitors it always had. It does also not get a rating for avoiding of competition. The overall rating in potential of growth is thus 1.

8.1.4 Responsiveness

Responsiveness or the ability to react quickly is a core necessity to adapt to volatile or turbulent markets.
The rating of 5 is only reached when the contracts can be influenced within 6 months. This is also in-line with Wildemann who defines variable costs as influenceable within 6 months. [200] If the contract can be influenced within one year the rating is 4. Models with contracts that can be influenced within two years get a rating of 3 and models with contracts that are influenceable within four years get a rating of 2. Everything above four years gets a rating of 1.

[200] c.f. Wildemann 2011

The service-based business model is especially made for short-term and short period contracts. Once the contract is signed the customer cannot cancel it. As the typical contract period is intended to be between half a year and one year the rating is 4.
For contract manufacturers the contracting period is typically a couple of years. As there is no rule about the length of such a contract and no statistical data is available the average contracting length is presumed to be three years. Therefore the business model gets a rating of 2.
The pay-on production contracts have a cancelation period of 12 months. Therefore the rating for this business model is 3.
For property or capital leasing contract periods are at least five years (see also section 7.3.1) and cannot be cancelled during the contract is active. Thus the rating for leasing is 1.
The depreciation period of a press line is according to Hupfauer [201] typically about 10 years. For this criterion it does not matter that press lines are in most cases used way longer than that, as the rating is 1 anyway.

8.1.5 Efficiency – focus on the core competences

Efficiency describes how suitable a business model is for a certain business. A business model that works perfectly well in one industry might completely fail in another. This is due to the distribution of core competences within an industry. If a certain competence belongs to the customer in one industry, it might belong to the service provider in another industry or the other way around. Therefore the efficiency for each business model for the metal forming industry is evaluated here.
The base rating is again 1. If the business model takes the competences of the customer into consideration, 2 points are added. If the business model takes the competences of the service provider into consideration another 2 points are added.
The service-based business model takes into consideration that the customers are the experts in tool manufacturing and operating the machines (2 points). It also take into consideration that the press manufacturers have the most knowledge and competences regarding the machines and maintenance (2 points). The total score is 5.

[201] c.f. Hupfauer 1997, p. 27

Contract manufacturers operate the machine themselves and also manufacture the tools themselves (2 points). The maintenance is also done mostly by the contract manufacturers which is not one of their core competences (0 points). The total score is 3 points.
If the pay-on production model was applied to the metal forming industry, the operation and also tool manufacturing would have to be done by the press manufacturer which is not a core competence (0 points). The maintenance, which is a core competence of the press manufacturer, would also be done by them (2 points). The total score is consequently 3 points.
Leasing could be done by OEMs or by contract manufacturers. Therefore the rating for efficiency is the same for contract manufacturers. The operation of the machines is done by the contracts manufacturers or OEMs as well as the tool manufacturing (2 points). The maintenance would also be done mostly by the contract manufacturers or OEMs which is not one of their core competences (0 points). The total score is therefore 3 points.
The operation of the machines if they are sold directly to the customers is, of course, done by the customers themselves. Thus 2 points are added to the rating. The maintenance responsibility without any additional contracts lies with the customer. In practice it is quite common that maintenance contract between customer and press manufacturers are made. 2 more points are added to the rating. The overall rating of the direct sales model is therefore 5.

8.1.6 Prevention of intellectual property loss

One of the major concerns of the metal forming industry when it comes to cooperation or service-based models is the risk of intellectual property loss. Therefore one of the criteria to assess the applicability of the business model is the prevention of intellectual property loss. The base value for the rating in this case is five. If the facilities and machines are not owned by the customer one point is subtracted. Another point is subtracted if the business model includes multiple customers. If the model does include the cooperation with independent service providers that are not direct competitors but are in the same industry, one point is subtracted. If the business model, on top of that, does include the cooperation or the use of the same facilities at the same time with a competitor, another point is subtracted.
For the service-based business model the machines are not owned by the customer but the tools that incorporate the intellectual property are. Also the business model includes multiple customers and a cooperation with an

service provider. Therefore the rating for prevention of intellectual property loss is 3.
For contract manufacturing the facilities and machines are not owned by the customer and the model includes cooperation’s with multiple customers. For that model a cooperation with an independent service provider is necessary, so the rating is 2.
For the pay-on production business model the machines are owned by an independent service provider. Only one customer is designated but it includes cooperation with an independent service provider. Therefore the rating is 3.
The machines with leasing are owned by the customer. It includes only one customer and no cooperation with any other companies within the industry.
Therefore the rating is 5.
Basically the same account for the direct sale model as well. The machines are owned by the customer. The press lines are only used by one customer who is also the owner. The model does not include any cooperation with other players. Thus the rating for prevention of intellectual property loss is 5.

8.1.7 Prevention of underutilization of machines

In many service-based business models the risk of idle times where no order is available is fairly high. This is due to the relatively short contract periods. The shorter the contracted period the more often new contracts have to be drawn up. Every time this happens there is a risk that no order is available. Therefor the rating for the prevention of underutilization of machines is exactly the opposite of the responsiveness criterion.
The rating of 1 is only reached when new contracts have a contracting period that is less than 6 months. If the contract last at least half a year the rating is 2. Models with contract periods lasting between one and two years get a rating of 3 and models with contracts lasting between two and four years get a rating of 4. Everything above four years gets a rating of 5.
The service-based business model is especially made for short-term and short period contracts. If the contract is signed the customer cannot cancel it. As the typical contract period is intended to be between half a year and one year the rating is 2.
For contract manufacturers the contracting period is typically a couple of years. As there is no rule about the length of such a contract and no

statistical data is available the average contracting length is presumed to be three years. Therefore the business model gets a rating of 4.
The pay-on production contracts have a cancelation period of 12 months. Therefore the rating for this business model is 3.
For property or capital leasing the rating cannot just be the opposite of the responsiveness criterion. The fact that a company is stuck with the machines for at least ten years does not mean that they are also fully utilized during that period. It is necessary to look at the contracts that the metal forming companies have with their customers. These contracts are basically the same that contract manufacturers have with their customers. Thus the business model has the same rating of 4.
The same accounts also for the direct sales model. Thus it is rated with 4 as well.

8.2 Discussion of the results

Finally the different business models are compared to each other and the strengths and weaknesses are discussed. Figure 15 is the illustration of the strength and weakness profiles. The rating from the preceding section are plotted on a grid which gives and individual profile for each of the business models.

Discussion of the service-based business model
Figure 15 illustrates that the service-based business model is distinctly strong in efficiency and the focus on the core competences of the partners. In this category it is significantly stronger than most of the other models. Also responsiveness is a strength where it is better than any of the other models. It also gained the best possible rating in the capability of fixed cost reduction but is only as good as most of the others in this category.
On the downside the service-based business model has significant weaknesses in the prevention of underutilization of the machines. It has the worst rating of all the compared models but not the worst possible rating.
The rating for the other criteria is average. The potential of growth has together with pay-on production the highest rating of the business models, even though it is on the absolute value is only average.

Discussion of contract manufacturing
Contract manufacturing has a distinct strength in aggregated costs. It is, together with direct sales, by far the cheapest model which is especially

significant as the ratings of the other models are all about the same. In prevention of underutilization of the machines it is above average and amongst the best in this category. Contract manufacturing has the best possible rating in the capability of fixed cost reduction which is only average compared to the other models.

On the downside the rating for potential of growth and responsiveness is below average but the leasing model is worse in both cases. Contract manufacturing has, together with leasing, the worst rating in prevention of intellectual property loss. In the other criteria this model has an average rating.

Discussion of pay-on production

Pay-on production only gained a top rating in capability of fix cost reduction. As already mentioned all service models have the same rating in this category which narrows the meaning of the rating.

In all the other categories the rating for pay-on production is exactly average. It is worth mentioning, that for potential of growth it has, even though the rating is just average, the highest rating compared to the other categories together with the service-based business model. In efficiency and focus on core competences on the other hand it has the lowest rating together with contract manufacturing and the leasing model.

It is important to mention that this business model does not have an outstanding weakness in any of the categories.

Discussion of leasing

One of the strengths of leasing is the prevention of intellectual property loss. It has the highest possible rating and is also rated way higher than most of the other models that are compared here. Also in prevention of underutilization of machines it got the highest awarded rating of 4 which makes it to a strength of this model.

On the downside leasing has the worst possible rating in potential of growth.

Furthermore it gained, compared to the other models, the worst rating in this category. The same is true for the responsiveness criteria. It is the only model that got the worst possible rating.

Leasing has an average rating for the other criteria even though it is important to mention that this means the worst rating in efficiency and focus on the core competences compared to the other models.

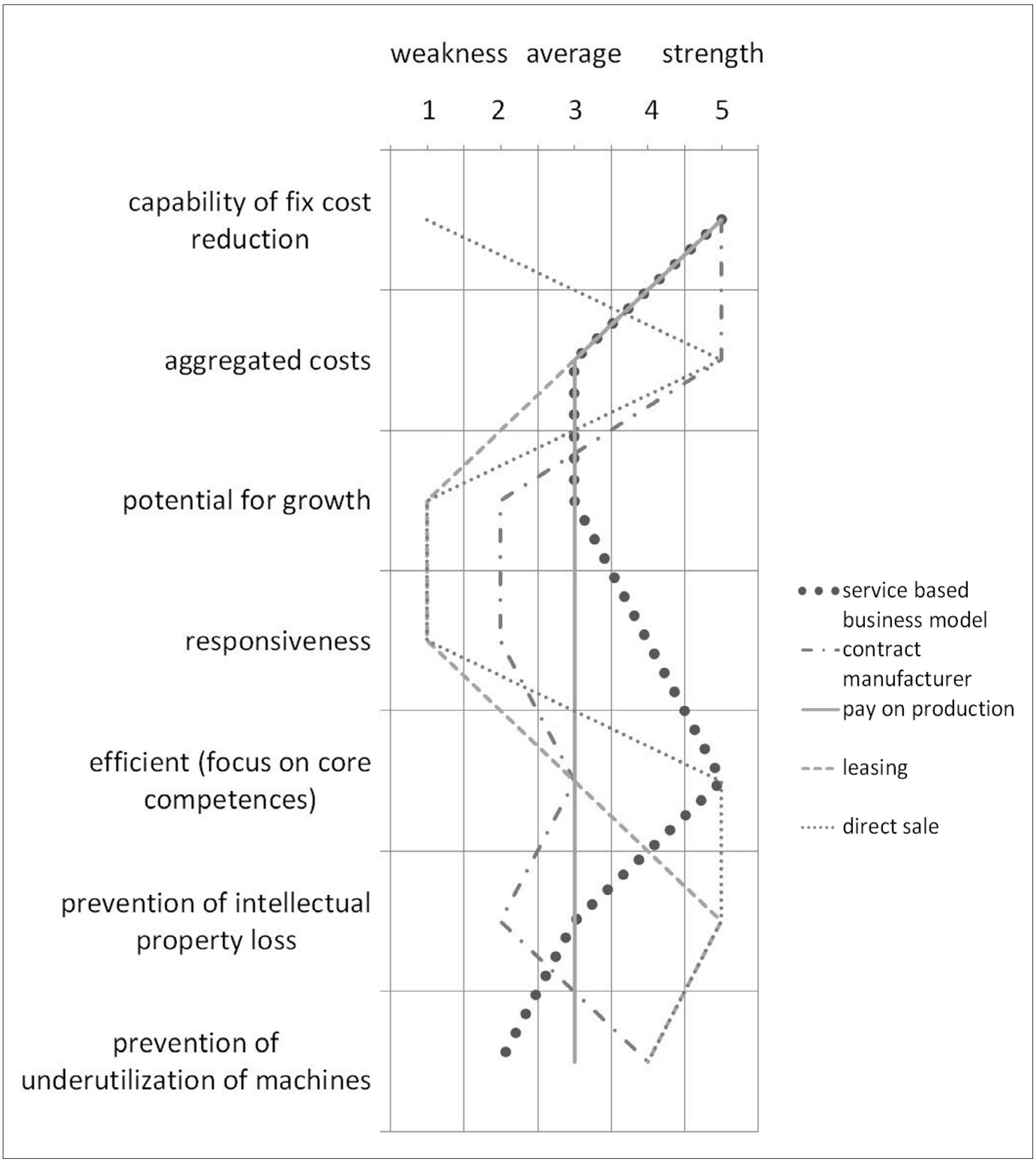

Figure 15: Strength and weakness profile of the compared business models

Discussion of direct sale

The direct sales model is particularly strong when it comes to aggregated costs. It gained the highest possible rating in this category. The model has a strong focus on the core competences which is why it got the highest possible rating in this category. Also the prevention of intellectual property loss is a remarkable strength of the direct sales mode.

In the “prevention of underutilization of machines category” the model did not get the highest possible rating. Nevertheless it is, together with contract manufacturing and leasing, amongst the best of the compared models.

On the downside this model does not allow for a fix cost reduction at all. Thus it is the only model that got the worst possible rating in this category. This is not surprising as it is the only model that does not offer a service but a product. In potential of growth and responsiveness it got the worst possible rating as well.
In general the direct sales model has the largest spread of all the models that are compared. This means it has the most distinct strengths but also weaknesses.

9 Conclusion and recommendation for action

The last paragraph should give a recommendation of how the findings of the thesis can be used to fulfill the goals that where defined in the beginning.
It is also the answer to the fifth and final research question: How and to which extend should the industry use the developed concepts (recommendations of action)?

9.1 Focus on production technology requirements

The five production requirements that were found in section 6 are the basis of the thesis. They can be used independent of the distribution channel. The production requirements support agile manufacturing no matter if a company decides to provide a service with the new business model or stay with the direct sales strategy. Moreover they are easier to implement and are expected to be accepted with less resistance by the customers compared to a new business model.
Therefore it is advisable for press manufacturers to start with the implementation of the production technology requirements in the mechanical and software design of their machines.

9.2 Production technology requirements as basis for the business model

If the production technology requirements are implemented and accepted by the customers, the next step towards agile manufacturing can be taken. It is important to wait until the production technology requirements are accepted in industry as they are enablers of the business model.
For a trouble-free and successful launch of the business model the timing is very important as well. Especially as the model intends to increase the market and to win new customers it is important to launch it during an economic upturn. Only then customers are open to such a new model and have the support of the organization to try something new.

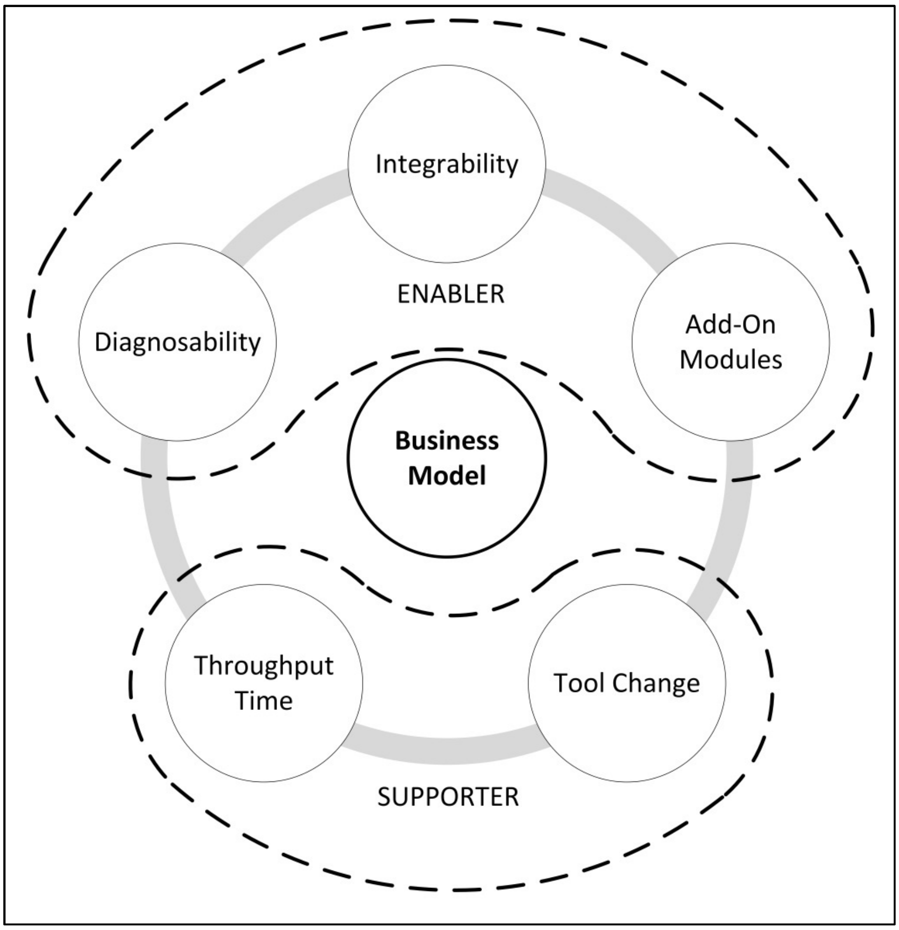

Figure 16: Production requirements as enabler of the business model

Figure 16 illustrates the relationship between the production technology requirements and the business model. Integrability, diagnosability and add-on modules are important enablers for the business model. Without them the service-based business model does not work properly and the companies would not be able to exploit its full potential. Therefore it is very important to implement these production technology requirements before the new business model in launched.

Throughput time and tool change are very important production technology requirement with respect to agile manufacturing; however they are no direct enablers of the service-based business model. Nevertheless they support the model and increase the efficiency. As the launch of a new business model will encounter resistance it is highly recommended to also master these production technology requirements before the launch of the business model.

9.2.1 Integrability

Integrability and a standard for interfaces across the industry are of capital importance to the feasibility of the business model. With the launch of the business model, shifting of the production of one product between different facilities across the production life cycle is expected to occur more often. To assure a smooth, fast and efficient shift it is essential to have the same interfaces across all facilities as the tools and the software will be reused every time.
A rework at the interfaces between tools and machine or reprogramming the software would result in time losses. Thus the business model would be inefficient and would not be accepted by the industry.

9.2.2 Diagnosability

The business model allows multiple customers and it is designated for short-term contracts. Thus the operators of the press line will change fairly fast and in fact new operators that are not familiar with the specific press line will be in charge. This is why problems with the press lines and output defects are expected to occur more frequently.
It will not be possible to avoid these problems completely. This makes it so important to detect problems and defects in real time and have a mechanism in place which traces and removes the root cause.

9.2.3 Add-on modules

The service-based business model is designed for short-term contracts with multiple customers. Consequently the requirements for the press line will change frequently. To avoid an extensive functionality the add-on modules described in section 6.3 offer an efficient way to adapt to the always new requirements.
The modules can be hired not only to customers of the service-based business model but also to direct sales customers. This would allow having a larger machinery park of add-on modules and with that increase the utilization.

9.2.4 Throughput time and tool change

The throughput time is not a direct enabler of the service-based business model. Nevertheless it is a production technology requirement with significant meaning when it comes to agile manufacturing. The shorter the production cycle of the individual contracts are the more important is the throughput time. Especially in spears part production, where batch sizes quite often have a two digit number, the throughput time becomes the critical parameter of productivity.
The same accounts also for the tool change. It is not a direct enabler of the developed business model but especially with smaller batch sizes it becomes an important production technology requirement and facilitates the business model.

9.3 Coexistence of direct sales and service-based business model

The service-based business model will not replace direct sales. Figure 15 illustrates that the direct sales model has some outstanding strengths that make it simply indispensable. Nevertheless it does also have some serious weaknesses especially when it comes to responsiveness and potential for growth. These are quite important criteria when it comes to volatile markets and dealing with them in an “agile way”. Hence the developed model should be use to complement the sales strategy in order to attract new customers and manage volatile or turbulent markets in an efficient way.
In other industries it is a common practice to award contracts, that do not deem to be profitable to small and medium sized businesses. The problem in the metal forming industry is that the investment costs for presses and press lines are immense and cannot be borne by such small and medium sized businesses. Especially for companies that are not able to raise the necessary capital to buy a press or a press line the service-based business model offers an interesting alternative.
Furthermore the business model could be used to overcome short-term capacity bottlenecks. If a metal forming company plans a new production line but is not able to fulfil the start of production, the service-based business model could be used to fill in until the new production line is finished.

The majority of the sales are nevertheless expected to be achieved with direct sales as the press manufacturers have lots of well-established business connections with companies from the metal forming industries.

9.4 Outlook and further need for research

Before the findings of this thesis can be applied to the industry further steps need to be taken and research has to be done. The production technology requirements can only be the basis of the technology development and are a guideline that defines what is necessary to become an agile manufacturer. The next step would be to define measures to fulfill the requirements and to implement these measures in the design of the press line.

Regarding the business model the financing needs to be resolved. It is important to determined, if press manufacturers are able and willing to run such a service-based business model on their own risk. Furthermore it is necessary to find out if and under which conditions external investors would enter such a business.

Another point that needs clarification is the pricing. A comparative study could give first insight on typical market prices for such services.

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List of Abbreviations

FMCG	…Fast Moving Consumer Goods
FMS	…Flexible Manufacturing Systems
DML	…Dedicated Manufacturing Line
OEM	…Original Equipment Manufacturer
PBC	…Performance-based Contracting
RMS	…Reconfigurable Manufacturing Systems
USA	…United States of America
US GAAP	…United States Generally Accepted Accounting Principles
OL	…Operator Lease

Appendix

Throughput Time

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann

Mr. Wiedenmann pointed out that the number of product variants, produced on metal forming machines, increases and, along with that, the batch size of the individual product decreases. This is an ongoing process which is expected to continue. Modern machines are designed to produce a vast variety of products from different materials and in highly diverse designs. Nevertheless blanking and metal forming machines are not made for a single unit production; consequently, completely individualized products cannot be produced in an economic way. Such products would require a different approach altogether and especially other technology. Furthermore, the technology and processes do not allow focusing on an individual work piece within the flow of material. Thus the output quantity is the determining factor for the design of a blanking machine.

Schuler AG, Lothar Gräbener

The number of models and variants especially in the automotive industry is increasing. With the platform strategy the industry tries to curb this development. The approach is to have two kinds of parts. Outer skin parts that enable the individualization of the product and are produced in a number of variants and structural parts that are used for a specific platform and therefore installed in many different models. The former require a high flexibility and many different tools. The latter demand for a high availability and sheer output quantity.

Cosma International, Dipl.Ing. Christian Juricek

The number of products, variants and derivatives increase. This leads to a reduction of the batch size of the individual product or variant. Therefore it becomes important to get the batches faster through the production process to be able to produce more different products on the same press line. The result is that the Throughput Time of machines gets more important. It is crucial to mention that, independent of this development, the output quantity is still a key indicator of a press line.

Magna Heavy Stamping, Ing. Otto Fauster

The batch size at the Magna plant in Albersdorf is highly volatile but the average batch size per press line was only slightly decreasing or even constant over the past 15 years. For spare parts which are ordered after end of series production by the OEMs the ordered batch size can even go down to seven. With smaller batch sizes the throughput time becomes a determining factor as the die change for the next product can only start when all previous produced products have fully made it through the production process.

Ramp-up

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann

A product changeover is performed by a changeover of tools. According to Mr. Wiedenmann this is more of a concern to toolmakers than to the manufacturer of the press. Their interests – in contrast - in that topic are confined to enabling a fast and efficient changeover from the machine in cooperation with the toolmakers and the operators.

Schuler AG, Lothar Gräbener

The ramp-up of a new product on a press line is mostly dependent on the tools and how they are run-in. To optimize that, toolmakers work a lot with simulation nowadays. On top of that they invest quite some money in tryout presses to assure that the tools are perfectly adjusted right before they are installed on the actual press line. Due to the huge effort that has been invested in ramp-up, the potential of this area is quite exhausted.

Due to the still increasing number of variants of outer body parts the pure tool change is still a major field of research, even though the tool changeover times decreased from multiple hours to 3 minutes within the last 5 to 10 years.

Cosma International, Dipl.Ing. Christian Juricek

Due to the increase of the number of products, ramp-ups occur more often. This tendency is expected to develop further as the number of different products is expected to increase.

Magna Heavy Stamping, Ing. Otto Fauster

Due to the fact that batch sizes are very small, the switch from one product to another is critical, to be able to handle the volatile sales. About 30 different products are produced on the same line. Each of these products is produced at least two times a week. Typical set-up times are ten minutes. With fully automated machines this can be reduces down to 3minute. The actual ramp-up of a new product on the other hand is not considered a critical requirement.

Machine Convertibility

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann
The technology used to enable an automated product changeover is ultimately dependent on the customer's wishes and the available installation area round the press line. Andritz Kaiser offers different levels of automation ranging from no automation whatsoever to quick-change systems for the tools and a complete automatic tool change without any manual operation. Furthermore, the tools that are used on their machines are oftentimes partially reusable as the base frame can be used for different tools.

Schuler AG, Lothar Gräbener
The automated tool change has been a major topic of research in the last few years. Moving bolsters are already state of the art in industry. For presses for small parts a fully automated tool change has been developed where the tools are stored in high racks, similar to a CNC processing station. This technology is not suitable for industries like automotive due to the sheer size of the tools. The industrial trucks that nowadays bring the tools from the storage area to the moving bolster, could potentially be replaced by programmable cranes in the future.

Cosma International, Dipl.Ing. Christian Juricek
The state of the art in industry is an automated tool change with moving bolsters. The transportation of tools from the tool magazine to the moving bolster is still realized with industrial fork lift trucks. A fully automated tool magazine is basically conceivable. The main reason why it has not been realized yet and why there are no specific plans is the sheer size and weight of the tools that are used in automotive industry. This topic will only become an issue as soon as the batch size goes down by so much that the charging time of the moving bolster becomes the bottleneck. So far the critical part is the downtime of the press line during the tool changeover itself. To minimize this, a fast and efficient tool changeover is the key criteria.

Magna Heavy Stamping, Ing. Otto Fauster

Magna Heavy Stamping has both, partly and fully automated press lines. For fully automated press lines not only the die change but also the changeover of the vacuum grippers is automated. This allows for an even faster switch to a different product. The trend is clearly towards more automation to allow for a faster switch between products. The tools can typically not be reused and are stored to produce spare parts after end of series production.

Configuration Convertibility

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann

The configuration of tools is convertible as long as the sequence of process steps allows for it. Some process steps (e.g. punching a whole) need to be finished before others (e.g. bending a bracket) can be taken. A production process can have serial, parallel or hybrid arrangements. Multiple parts can be produced by the same tool in parallel. This setup is, however, not flexible at all. Additional operations must be harmonized and timed with the mechanical movement curve of the press. The press movement curve and timing is set. Only in the case of a servo press the operator has the chance to adjust the speed (and thereby the timing) of the press.

Schuler AG, Lothar Gräbener

Most press lines, especially in automotive industry, are built for a special purpose or product. Even though these press lines are re-used after the product has been taken out, rearranging or reconfiguring the press line itself is not intended.

Cosma International, Dipl.Ing. Christian Juricek

Multiple parts can be produced parallel on the same press or even with the same tool. The individual parts follow a strictly serial path within the press line. Subsequently to the press line itself the parts can be further processed (e.g. forming or cutting processes) which allows for a further individualization of the parts.

Magna Heavy Stamping, Ing. Otto Fauster

It appears that some dies of a production line are used for different parts. Currently this is does not result in parallel or hybrid production lines. If for example in a production line with five forming steps the die for step two and four are identical for part A and part B, part A is produced first on the line and after a changeover of the tolls one three and five, product B is produced. This occurs very rarely.

Material-handling convertibility

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann
In most plants the material flow between machines is still processed manually either by hand or with a forklift. Concatenated systems are (in the case of Andritz Kaiser) still a major exception. The problem with manual material handling is that during peak times the throughput is too high which is solved by simply adding additional workers.

Schuler AG, Lothar Gräbener
In many cases the parts need to be realigned between two process steps. This requires flexible devices for the material handling between the individual presses.
For that reason the material handling within the press line has been a major field of research in the last few years. Robot technology, which used to be state of the art until a couple of years ago, is reasonably cheap, but has some major disadvantages concerning the cycle efficiency. The robotic arm has to move across the entire part in order to be able to grip it. In turn this means that the tool has to open relatively wide which again results in a longer cycle time. Therefore the Crossbar Feeder technology has been developed by Schuler allowing for an operation of the individual presses in waves. This new operation mode drastically increases the cycle efficiency.

Cosma International, Dipl.Ing. Christian Juricek
The material supply of the press lines can be realized either by decoiling a sheet metal coil directly at the press line, or by feeding with precut blanks. The material flow within the press line is flexible in this respect, that the material handling equipment can be adapted to the requirements of the produced parts. For example the grippers can be changed from magnetic ones to vacuum grippers if aluminum parts are produced instead of steel parts.
There is more or less no connectivity of the press line within the body or chassis production.

Magna Heavy Stamping, Ing. Otto Fauster
The material handling within the press is fully automated with robots or linear feeder for press lines and crossbar transfer for transfer presses. The material

handling at the end of line is done manually. This results from the fact that quality control is still done manually, so it does not make sense at the moment to automate material handling and not use the labor that is already there.

Customization

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann
The products produced on the machines of Andritz Kaiser are customized only to the level of business customers (e.g. OEMs). Technological limitations of blanking and metal forming processes do not allow for a customization down to the consumer level. According to Mr. Wiedenmann that would require other production technologies like laser cutting and edging.

Schuler AG, Lothar Gräbener
The technology used by Schuler in their highly automated press lines does not allow for customization. These lines are optimized for output quantity and have an overall efficiency of 70 to 80%. The need for customization is partly there but requires a different kind of technology altogether. Tool changeover would occur more often and therefore the non-productive periods of time would increase.

Cosma International, Dipl.Ing. Christian Juricek
There is a market for customization and there is a clear positive trend towards it. Nevertheless this is not the business area of Magna Cosma as they are more into high volume production. The Customization trend is relevant mostly for sports cars and special vehicles. But also in normal passenger cars variants like sunroofs, even in different sizes for one and the same car are already offered. Nevertheless a patch size on one cannot be produced economically on a forming press due to the immense tool costs.

Magna Heavy Stamping, Ing. Otto Fauster
According to Mr. Fauster a customization for the consumer is not affordable for press lines and not expected to be a possible future development. For customization other technologies are required (e.g. tinsmith for the automotive sector).

Modularity

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann
Andritz Kaiser uses a modular principle to design metal forming machines dedicated to their customer’s wishes. Nevertheless, the purpose of this modularity is not to redesign or reconfigure the machine in order to adapt to different requirements from the market. In many cases a mixture of modular principles and a partly redesign is necessary to fulfill the customers’ requirements (flexibility in engineering).

Schuler AG, Lothar Gräbener
The presses and press lines are built up by modules due to cost reasons. The ability to process different products with different requirements (e.g. steel – aluminum, structural parts – outer skin parts) is so far realized with combined plants. These plants have the basic technological requirements to do different jobs with only a few adjustments.

Cosma International, Dipl.Ing. Christian Juricek
The presses itself have no modularity. The modularity is realized with the tools. On the same press line it is possible to use a tool that produces one side panel or a tool that produces two doors or even a tool that produces three tailgates.
As a future perspective it is conceivable to have modules that allow for a fast adaption of the functionality of the presses itself according to the needs of the orders that are processed at the moment.

Magna Heavy Stamping, Ing. Otto Fauster
The design of the individual presses within the press line is basically the same, except for the lead press which is typically designed more powerful. The basic structure of the press lines is fixed and is not intended to be changed during the life time. Nevertheless modules are used as add on, to increase the functionality of the machines.

Scalability

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann
The first strategy to counteract fluctuations in sales is to operate the machines in on/off mode, i.e., the machines run on full load until the order is fulfilled and then switched off until a new order arrives. The second strategy is to simply run the machines on partial load according to the average

quantity of sales. Production plants are not prepared for a scaling strategy by the means of modifying production capacity by adding or subtracting manufacturing resources and/or changing components of the system.
In the case of metal stamping presses we have the situation, that these machines normally are customs-made. A production on stock absorbs too many resources.
This is owing to the fact that delivery times for a press range from eight months to two years and therefore do not allow for adapting the process due time. On the other hand, metal forming machines are too expensive to keep them in stock and only add them to the process when needed. Only deeper adaptions of the systems planned on a long-term basis are realized by adding production capacity. If infrastructure and space is allocated for such adaptions, depends on the customers' wishes.

Schuler AG, Lothar Gräbener

The press lines are typically purpose-built. Therefore the production quantity is already known before the press line is planned and is designed accordingly. If the sales forecast does not realize, the manufacturer is in trouble. If the facility has a certain amount of flexibility he can try to shift the production of other parts to the new press line which is not fully utilized.
The upscaling of facilities on the other hand is something that is already considered at the planning stage. This is very important as logistics and infrastructure are very crucial to be able to guarantee the output quantity.

Cosma International, Dipl.Ing. Christian Juricek

To scale a whole press line in order to adapt it to sales fluctuation is not planned. Magna Cosma deals with sales fluctuations mostly by shifting between sights of their own production network. A production on stock or operating the machines on half load is not desirable and can only be the last resort. Also the company has not provided any infrastructure in order to add new lines at existing facilities as getting all the licenses and building the infrastructure is very cost and time intense.

Magna Heavy Stamping, Ing. Otto Fauster

Magna Heavy Stamping has basically two strategies to counteract fluctuations in sales: The first one is a direct sales measure in which more orders are accepted than the plant is able to process. If some of these orders are rescinded by the OEMs the company is still able to operate the plant on full load. If on the other hand the orders remain in place, some of the orders are awarded to their competitors. The second strategy is mostly technological as the company tries to increase the functionality and flexibility of their machines (e.g. enable them to process aluminum or outer skin parts of cars). This allows Magna to accept many different orders on short call and increases the sales flexibility.

Integrability

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann
The standard used for interfaces in the metal forming business depends on the one hand on what is given by the suppliers and on the other hand on the specifications of the customer. There are generally accepted standards such as PROFINET for information interfaces but no overall industry specific standard. Even within Andritz Kaiser the interfaces often differ between the individual projects as suppliers and of course also customers may vary a lot.

Schuler AG, Lothar Gräbener
Standardization is a big topic for Schuler. In the last few years they put a lot of effort in trying to find a standard for press lines across the automotive industry. It used to be the case that interfaces and standards did not just differ between OEMs but also between plants of the same OEM. Today a general standard in automotive industry has been established.

Cosma International, Dipl.Ing. Christian Juricek
Magna Cosma has company-specific standards for their mechanical and information interfaces. In some cases they coordinate the interfaces with their customers.

Magna Heavy Stamping, Ing. Otto Fauster
The presses that are used in the automotive sector in Europe are in general compatible. Thus tools can be used on different machines of OEMs and suppliers with small or even no adaptions. This allows shifting production from OEMs to suppliers or between different suppliers as required by the current market situation.

Diagnosability

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann
The monitoring of production machines in real time can be done on different levels depending on the customer specifications. The offered systems range

from emergency systems that only switch off the machine before it gets damaged to full-fledged monitoring systems that are able to measure different forces and temperatures during the entire production process in real-time.

Schuler AG, Lothar Gräbener

The state of the art according diagnosability is that errors cannot just be detected but also traced back to their origin and also be represented in a graphic. Furthermore, the necessary spare parts and a phone number of the responsible service technician get displayed. In the more developed press lines different parameters like temperature or forces are monitored in real time. Out of the collected data the software is able to forecast the failure of components. Quality inspection is mainly still performed manually but can be complemented by technology like thermographic cameras or with light wave applications.

Cosma International, Dipl.Ing. Christian Juricek

The ability to detect defects varies from case to case. Most machines are equipped with safety devices such as sensors that ensure that no scrap is dragged along with the process and damages the tools or products. The output of such defect detection is either a defect message, a tag on the product or the automated drop out of the product.

Magna Heavy Stamping, Ing. Otto Fauster

The long-term vision is to have a control loop in place that automatically changes the parameter that is responsible for a defect that is detected at the end of line. The ability to detect and diagnose the root cause of an output defect fails so far due to problems in automating quality control. A lot of efforts have been made to detect flaws and defects fully automated but until now quality control is still made manually.

Employee emancipation

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann

Andritz Kaiser offers training courses for their customers' employees. If a customer wants to improve the skills and knowledge of his employees an experienced commissioning engineer gets on site and teaches the workers on their own machines.

Schuler AG, Lothar Gräbener

Schuler offers different levels of education to the employees of their customers. A basic enrollment lasting one to two weeks is within the scope of supply. For Greenfield facilities Schuler additionally offers basic education in metal forming and maintenance. Furthermore Schuler has an academy where employees of customers can participate in classes covering everything from basics to in-depth maintenance operations.

Cosma International, Dipl.Ing. Christian Juricek

The employees participate regularly in advanced training programs of the press manufacturer. These trainings are carried out on their own press lines as well as in academies of the press manufacturer.

The running-in of the system is executed by professionals and the tool change is executed by specialists. Apart from that the machines run unmanned.

Magna Heavy Stamping, Ing. Otto Fauster

The operation of the press lines is exclusively done by technicians. Unskilled labor is only used for auxiliary activities (e.g. for material handling activities).

General note

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann

Generally, it is to say that the production requirements and, along with that, the design of metal forming machines are heavily dependent on the customers' specifications.

Schuler AG, Lothar Gräbener

Schuller sells about 80% of their machines and equipment to the automotive sector but tries to expand into other industries.

The lifespan of a Press line is in general pretty much predictable. The structure of such facilities is designed fatigue resistant. Some components might still break. This is dependent on the rigor of maintenance and does therefore not allow for a prediction on an exact monthly basis.

The interconnectedness of press lines with the entire production process depends on the industry. For white goods the interconnectedness is quite advanced, in the automotive industry on the other hand it is still underdeveloped, mostly due to the buffers that are required.

The production requirements heavily depend on the customer. Specific groups of customers with similar requirements can be identified. German premium manufacturers for example have quite high standards and tend to buy the most advanced technology. U.S. and Japanese manufacturers are less demanding and make-to-order manufacturers tend to purchase smaller and more flexible facilities.

Cosma International, Dipl.Ing. Christian Juricek
The requirements for the production in the sheet metal industry are heavily dependent on the specific tasks that are performed. There might be universal requirements for specific areas like car body manufacturing or chassis manufacturing.
The durability of a press line is in general quite predictable, except for collateral damages like the breakdown of the eccentric shaft.
The operation of a press line together with a competitor is due to the tense competitive relationships not desirable. It is more conceivable to cooperate closer with customers of suppliers.

Magna Heavy Stamping, Ing. Otto Fauster
Magna has several press plants in Europe and America. Therefore shifting of orders within their own enterprise is possible if necessary and cooperation's with other companies or even competitors are not intended. This is also due to the fear of losing know-how to their competitors and expected problems with who is going to take responsibility in the cooperation.

Profit formula

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann
The portfolio of Andritz Kaiser includes planning and production of metal forming machines and plants, maintenance, service and overhaul of machines. About ¾ of revenue is generated by planning and production and ¼ by maintenance, service and overhaul of machines.

Schuler AG, Lothar Gräbener
The lion's share of machines and equipment is still sold directly to the customer. The financing in that case is done by the customer in cooperation with his house bank as they get good conditions there. Schuler also offers leasing and pay-on Production in cooperation with GE Capital and Deutsche Leasing, but these models are way less popular due to the higher aggregated costs. For a Chinese customer Schuler also offered an operator model, but that was done as a showcase to enter a new market.

Cosma International, Dipl.Ing. Christian Juricek

The company makes its money by developing and manufacturing components and full car bodies and chassis including the paint job. Currently the focus is on manufacturing, but customers expect that the manufacturing know-how is included in the product development which will eventually lead to a shift towards offering the whole process from engineering to finished product in growing numbers.

Magna Heavy Stamping, Ing. Otto Fauster

The core business of Magna Heavy Stamping is car body manufacturing. As a necessary auxiliary operation of this the company is also an expert in tool making for their own press lines.

Key resources/processes

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann

Mr. Wiedenmann identified their unique modular design principle, the commissioning and the engineer as the key resources of Andritz Kaiser. Furthermore, he identified their R&D, the assembly and commissioning and sales as their core competences.

Schuler AG, Lothar Gräbener

Schuler is the technology leader; this reflects technology and their development and innovation processes as their key processes. They are achieved by their employees and due to their manufacturing engineering which can be identified as their key resources.

Cosma International, Dipl.Ing. Christian Juricek

The key processes of Magna Cosma are the ability to understand the customer specifications and quality requirements and transform them into solutions that are globally available. These processes are realized by their key resource: the employees.

Magna Heavy Stamping, Ing. Otto Fauster

Mr. Fauster identified the plant and equipment as their key resources as well as the knowledge and skills of their employees. The key processes are the production of sheet metal parts and the design and manufacturing of the tools as well as sales and marketing which enable a smooth adaption of market variations.

Customer value preposition

Andritz Kaiser, Dipl. Ing. Wolfgang Wiedenmann

The limiting factor for Andritz Kaiser's customers is insufficient wealth which is mostly a consequence of the high investment costs of such machines. This is closely followed by time: for many customers of Andritz Kaiser the start of production is an important prerequisite to get contracts with their own customers. So, if Andritz Kaiser is not able to deliver a fully functional machine by the planned SOP their customers will lose orders, market share…

Schuler AG, Lothar Gräbener

The main thing that customers expect from Schuler is, to reduce costs. Another big topic is to reduce the time from the order to the start of production. As press lines typically get ordered for a specific purpose, the start of production is already scheduled before the press line gets ordered. This leads to an enormous time pressure for the press manufacturer. Another topic is consulting the customers. Schuler technology is very often the benchmark for the best solution. In fact Schuler is faced with consulting their customers who then purchase the machines at a competitor who is able to deliver for less money.

Cosma International, Dipl.Ing. Christian Juricek

The main requirements for the press manufacturers are to reduce costs and the time to set up a new press line. In addition to that a high quality, durability and availability are important values.

Magna Heavy Stamping, Ing. Otto Fauster

The most important factor when purchasing a press lines or add-ons for press lines is time. If the press line cannot be put into operation in time, Magna cannot start the production and will lose the order. A second factor are costs as all adaptions to a press line that are made to get a contract have to be economical justifiable.