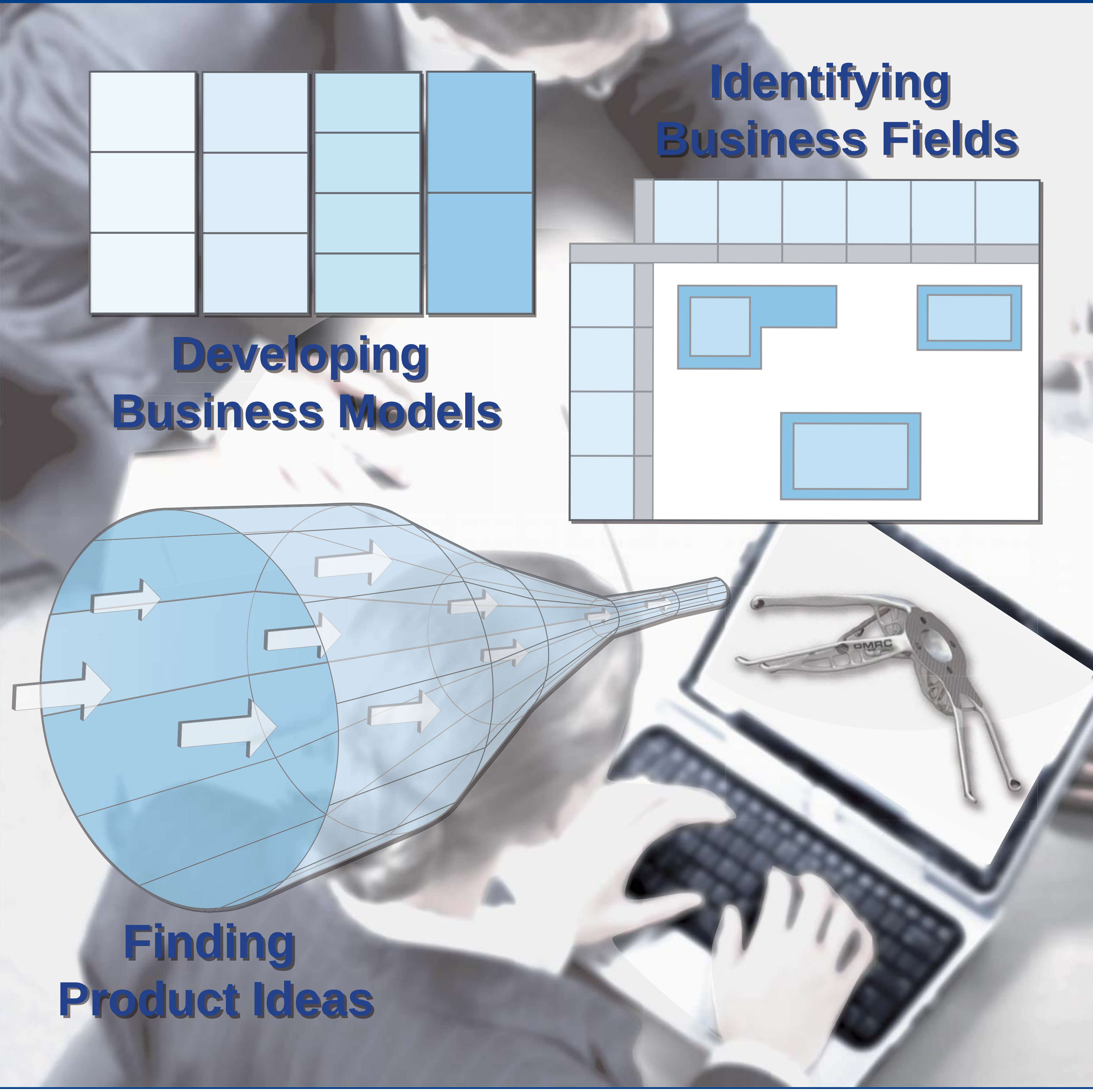
Thinking ahead the Future of Additive Manufacturing –

Seizing Opportunities for Business



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DIRECT MANUFACTURING RESEARCH CENTER

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Preface

We have recently witnessed a soaring interest in Additive Manufacturing (AM) – the reason for that being mostly the incredible opportunities for lightweight design, functional integration and rapid tooling. For years, the aerospace industry has been in the vanguard of applying AM industrially. At Boeing, the technology has turned into a reliable core technology for many of the currently operated aircraft fly with parts made via AM. There is little doubt: AM will be of pivotal importance for the aerospace industry when facing challenges such as tightening re-quirements, customization and the desire for lower cost processing.

Currently, many other industries ponder the application of the technology for similar reasons. From an aerospace standpoint, we believe the diffusion of the technology into other industries comes with benefits for everyone. Technology providers such as machine and powder manu-facturers diversify into new fields while the technology is being confronted with new require-ments which eventually leads to impetus for development.

Irrespective of whether or not AM turns out to be a suitable choice in a given application, no company should disregard checking AM for potentials. Developments such as closed-loop control, in-process validation and increased speed will boost the producibility, reliability and quality of the technologies thus making the benefits of AM available to many other players. For AM to gain ground in these industries we believe that it takes courage and a systematic analysis of the potentials for AM.

The Direct Manufacturing Research Center (DMRC) is a collaboration of technology provid-ers and users with the goal to advance AM to Direct Manufacturing. In many projects, the team from the University of Paderborn has helped us and other partners in assessing and advancing the technology. In order to strengthen their ties with their partners and pursue their strategy “Industrial Research Base”, the DMRC has carried out the project “Development of an Additive Manufacturing Potential Check System”. The goal of this project is a scalable collection of methodologies for the assessment of AM in light of the requirements of a given company.

The study at hand is the fifth sequel of the study series “Thinking ahead - the Future of Addi-tive Manufacturing”. It comprises excerpts of the project results and was supported by various companies via validation workshops. We would like to express our gratitude to the DMRC, the Heinz Nixdorf Institute and the involved companies for the excellent cooperation.

Best regards

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Introduction

Additive Manufacturing (AM) is a technology field that revolves around the layerwise production of physical objects. The term ‘AM technology’ is used in this study to simplify the represention of various complementary technologies: Different manufacturing technologies such as Fused Deposition Modeling (FDM) or Selective Laser Melting (SLM), but also complementary technologies such as Computer Aided Design (CAD), topology optimization and post-processing technologies such as milling or sandblasting. Overall, Additive Manufacturing can be applied in one of four ways (see figure 1-1).

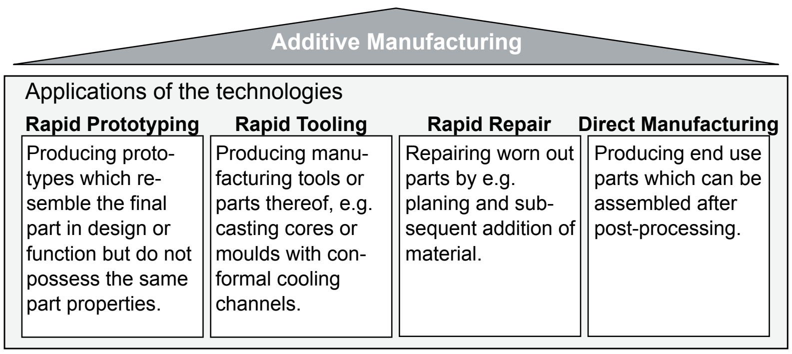

Figure 1-1: Main applications of Additive Manufacturing

Historically, the first applications of the AM technology have been **Rapid Prototyping**: the creation of parts which resemble a final product or a component of it. By this, product development processes can be shortened and made more flexible. With the emergence of metal-based processes, **Rapid Tooling** came into existence. That is the production of tools or parts thereof. The salient difference between Rapid Prototyping and Rapid Tooling are the tougher requirements imposed on Rapid Tooling components. With further technological advancement two new types of applications emerged: **Rapid Repair** and **Direct Manufacturing.** Rapid Repair describes the addition of material which has been lost by, for instance, wear or abrasion; Direct Manufacturing is the production of end use parts by layerwise production technologies [LL16].

Overall, AM has four application types.

At the moment, direct production capabilities for parts and tools have exceeded Rapid Prototyping applications in public reception, shown by most publications and use-cases. However, there is no patent remedy as to whether which application is the most promising per se. Rapid Prototyping is a viable, equally relevant application of Additive Manufacturing . Arguably, judging by the sales numbers of machines, Rapid Prototyping is still the most prevalent application of the technology as of today [Woh16].

There is no dominating application of AM.

Huge commercial and public interest

Overall, since 2013 technology management has witnessed a soaring interest in Additive Manufacturing (see figure 1-2). *Google Trends,* even though of little scientific validity, conveys a clear picture: The search requests for the term “3D printing”, often used as a synonym for “Additive Manufacturing” especially in common speech, have **increased** about **tenfold** over the last five years. Although this analysis does not differentiate between professional and consumer printing technologies, it can be safely assumed that a sizable portion of this attention is fueled by the abundance of commercial use-cases and news of large enterprises investing into the technology field (e.g. *General Electric Aviation*) [GE16-ol]: At the moment, companies worldwide are **seeking potentials** of Additive Manufacturing.

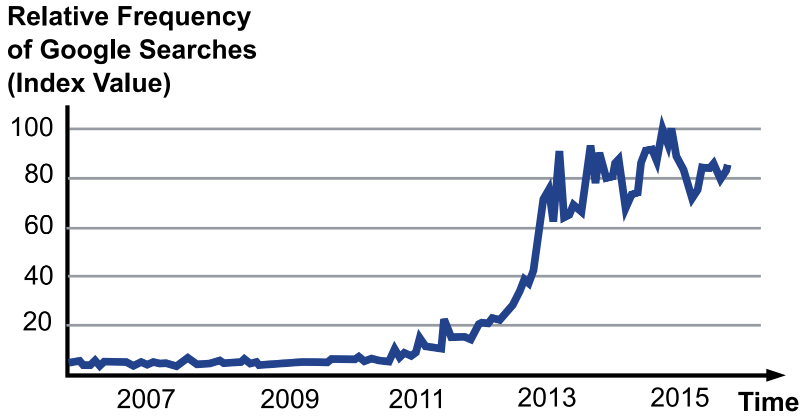

Figure 1-2: Number of Google Searches for “3D Printing”

Technology diffusion typically occurs in a five stage process

From a theoretical perspective, ROGERS has shown that innovation and technology diffusion typically occurs in a five stage process (see figure 1-3) [Rog03].

- **Knowledge:** Individuals or decision-making units in companies are exposed to a technology’s existence and gain an understanding of how it functions.
- **Persuasion:** In the persuasion phase, a deeper understanding of a technology is being developed. The result of the phase is a favorable or unfavorable attitude towards the technology.
- **Decision:** Individuals or decision-making units make a choice to adopt or reject the technology.
- **Implementation:** The technology is being put to use.
- **Confirmation:** Empirical evidence shows that particularly in the immediate aftermath of implementation, decision makers actively seek information confirming their decision.

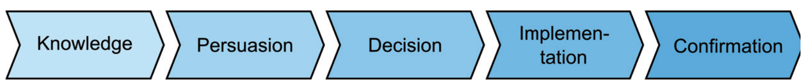

Figure 1-3: Simplified innovation diffusion process according to ROGERS [Rog03]

Due to the broad attention towards the technology field, it can further be safely assumed that ample knowledge (and initial attention) has been created around Additive Manufacturing for the diffusion process to unfold. From the DMRC's experience, currently most companies find themselves either in the **Persuasion** or in the **Decision** phase. In these two phases, the diffusion process is vastly being shaped by the development of **four factors** [Rog03]:

1) Technology development

Additive Manufacturing is constantly being developed further. However, the speed at which innovations occur cannot cope with the expectations raised by practitioners. This is vastly due to the fact that much fundamental research has yet to be conducted to understand the relationships between material, design and processes. Also the range of materials is limited to few metals and polymers at the moment [Ach16]. Naturally, the technology's performance is going to be incrementally increased, while at the same time, new technologies might be developed. An example of a recently developed new technology is CLIP (Continuous Liquid Interface Production), a further development of the more commonly known DLP technology which significantly increased the manufacturing speed for plastics parts [TSE+15]. Obviously there is no reliable prognosis as to whether the technology field is going to experience disruptive technological advances in the future. However, the possibility of these occurrences, combined with the high volatility of the technology field compels companies to a **continuous monitoring** of **technological research and development**.

New technological capabilities compel companies to continuous monitoring.

2) Requirements development

Oftentimes neglected and taken for granted: the decision in favor or against a technology depends to a large degree on whether or not a technology is capable of fulfilling the requirements imposed by customers, politics, unions, etc. However, r**equirements change over time** . Additive Manufacturing may not fulfill the needs of a market segment today, but might be able to do so in the future. The diffusion of Additive Manufacturing will depend on whether companies map the technology against **future requirements** instead of today's requirements**.**

Requirements of business fields change over time.

3) Individual adopter type

Even companies in the same branch serving identical customer segments adopt technologies at a different speed. In empirical studies, Rogers has categorized innovators by their so called adopter types. He identified five distinct adopter categories: Innovators, Early Adopters, Early Majority, Later Majority and Laggards (see figure 1-4). The adopter type is inherent to a company. Factors such as **culture, past experiences** and **operational excellence** influence the natural inclination of companies to adapt a technology [Rog03]. These 'soft' factors are not subject of DynAMiCS and therefore not detailed here.

AM's diffusion success is also dependent on courage.

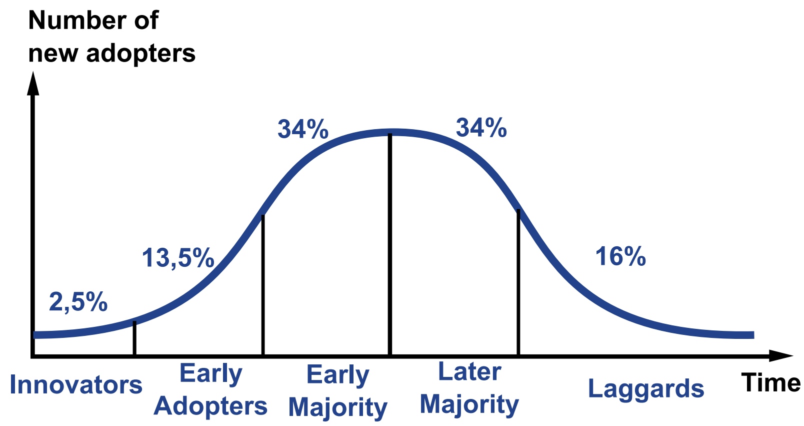

Figure 1-4: Adopter types according to Rogers [Rog03]

4) Companies capability to find potentials

Most powerful lever for the diffusion of AM is to enable companies to find potentials for AM.

The most powerful lever of technology diffusion is companies' capability to find applications for the technology during product creation. Product creation (as visualized in figure 1-5) ranges from strategic planning to integrated production management. In the first stage, **Strategic Planning and Innovation Management**, scenarios of the future are developed, products are thought ahead and business models are being developed. Engineering methodologies such as Systems Engineering help to handle the high complexity of products and production technologies and to manage the communication of different disciplines (stage **Systems Engineering & Engineering Management**). Finally, the product has to be manufactured which is organized in the stage **Integrated Production Management**. As a side-effect, this phase facilitates companies to grow their knowledge base with regard to experiences with AM in the actual work environment. In the context of Industry 4.0 manufacturing processes have to be more flexible to produce customised high complex products. **Product Use** is the last stage referring to all after-sales phases of product lifecycles. Companies gather information about the final product by usage for continuous improvements and learn for the development of new products. **Virtual Engineering** represents an enabling approach building the fundament for the other stages. Modern technologies act as an important tool for the illustration, conception and validation of modern, complex products of tomorrow. All stages create feedback and restrictions which influences other stages of the action field.

The focus of the study is on Strategic Planning and Innovation Management. The AM technology carries potential to influence new products in terms of technology push. Challenges subsume three main tasks:

- 'Potential finding' includes the perspective and the identification of segment gaps.

- ‘Product finding’ means to identify suitable products fulfilling desired requirements. It comprises classical innovation management involving creativity methods and workshops.
- ‘Business planning’ deals with the development of strategy, economic calculations and business model development.

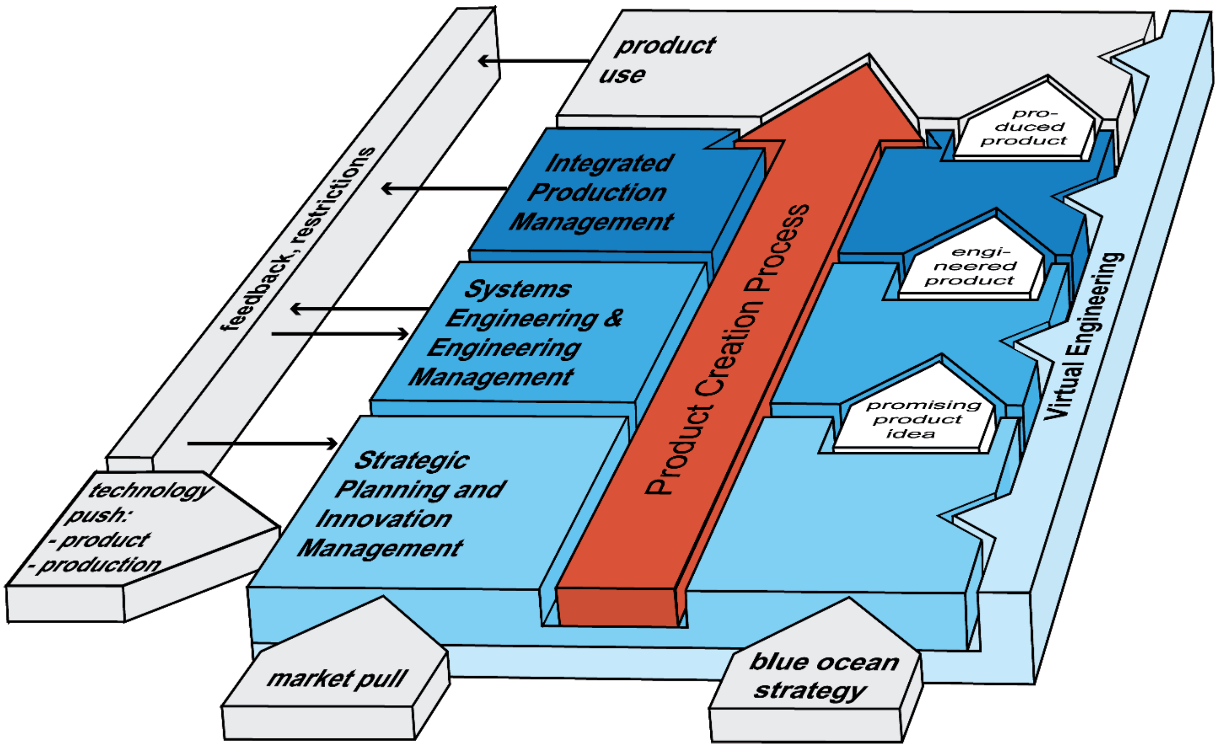

Figure 1-5: Action field of product creation

In order to determine the way in which companies proceed in their ambition to start or to increase the application of Additive Manufacturing technology, an interview series has been conducted in June 2016. Overall, **51 interviews** have been conducted; most of them on the trade fair *Rapid.Tech 2016*. The target group consisted of companies which **already apply Additive Manufacturing** or which are in the process of **finding potentials** for the technology. Since the focus of the survey lays on commercial users of the technology, neither machine manufacturers nor research institutes took part in the interview series. As figure 1-6 indicates, the interviewees stem from a broad field of branches. Without being representative, the variety of branches is in accordance with the contemporary literature about Additive Manufacturing.

An interview series about the modus operandi of AM potential identification has been conducted.

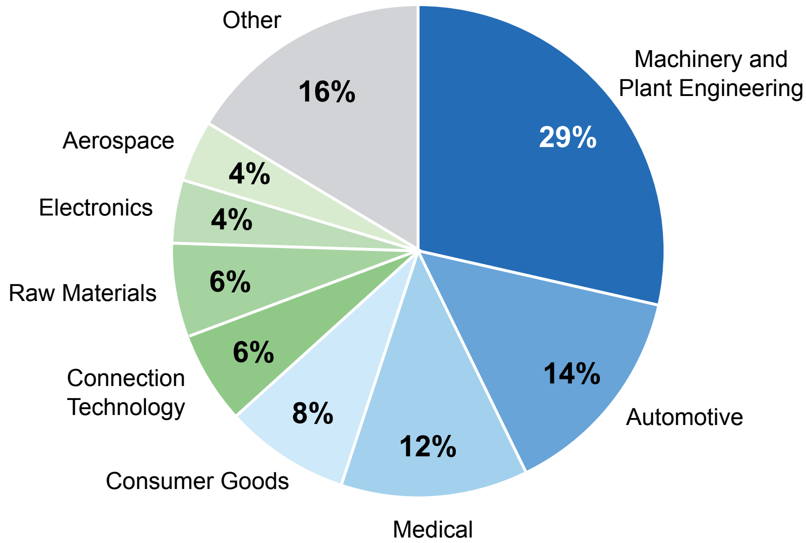

Figure 1-6: Branches of the participating companies (aggregation based on ISIC rev.4 [UN08])

For instance, the Wohlers Report 2016 indicates that Industrial/ business machines, Motor Vehicles, Aerospace, Consumer Products and Medical Industry are the leading industrial branches in Additive Manufacturing [Woh16]. Additionally, various niche branches (e.g. pharmaceuticals) showed interest in the technology during the trade fair. This also aligns well with the literature which also points towards a broad range of niche application fields for Additive Manufacturing, for instance shipbuilding, jewelry or laboratory equipment [Mil15-ol], [Kos16-ol], [KRS+12]. While first applications of Additive Manufacturing seemed to be in small range of branches, now more and more branches show interest in the technology. Currently, especially the Machinery and Plant Engineering branch seems to seek potentials: 60% of the interviewed machine and plant manufacturers have not yet applied the technology.

Coverage of usual branches as well as niche players.

There apparently is **no clear-cut branch profile** of Additive Manufacturing. This partly explains why there is no common ground in a methodology to find potentials for the technology yet, since every branch applies specific methods and tools. This is in sharp contrast to manufacturing technologies such as, for instance, Axial Forming, which are predominantly used in one branch (automotive). For these technologies, extensive tool supports for the identification of part candidates, etc. have been developed, tailored to the needs and processes of automotive OEMs.

AM has no clear-cut branch profile.

Figure 1-7 shows the size of the participating companies by workforce as indicated by the interviewees: 69% of the interviewees indicated that their companies had more than 500 employees. On the one hand, this can be explained by the fact that machines for Additive Manufacturing cost about 100,000 USD on average [Woh16]. Therefore, large investments into the technology are most likely being undertaken by sizable companies only. Also, the size distribution can be a random occurrence due to the rather small sample set.

Many large companies took part in the interview series.

A more equal size distribution along the indicator workforce could have been expected however. Especially because a vast sector of AM Service Providers has settles which reduces up front investment costs for small and medium-sized enterprises [RB13].

The goal of the interview series was to obtain an overview of the modus operandi of potential identification; with this regard, it can be assumed that the **share of structured approaches** in the sample at hand is **slightly higher than the common practice**. This is because structured approaches in technology management are more prevalent in larger companies [SK11].

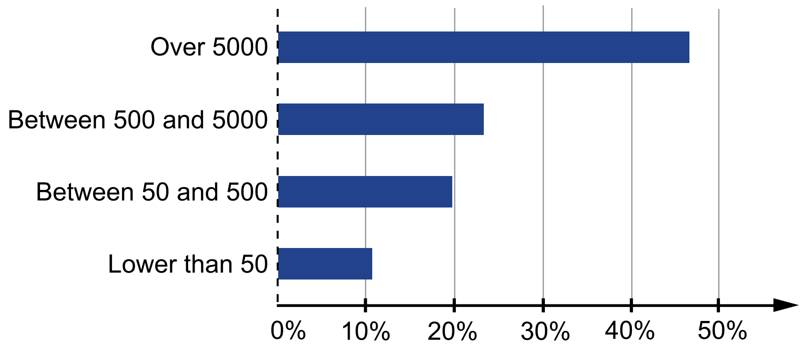

Figure 1-7: Size of participating companies by workforce as indicated by the interviewees

In the interview series companies were asked how they have been using Additive Manufacturing so far. Companies which do not yet use the technology indicated how they were planning to use AM in the future. A company is considered a user of the technology if it uses AM in-house or regularly orders parts from an AM Service Provider. For each interviewee multiple answers were possible. The results are depicted in figure 1-8. **Design Prototypes** are prototypes which are created in the product development process to illustrate, for instance, geometry, texture or color. A **Functional Prototype** illustrates the basic functionality of a part, for instance, fluid flow rate through an orifice**.** Usually, this kind of prototype category is used for later testing. **Rapid Tooling** describes the production of tools or their parts, while **Direct Manufacturing** describes the production of end use parts (see figure 1-1).

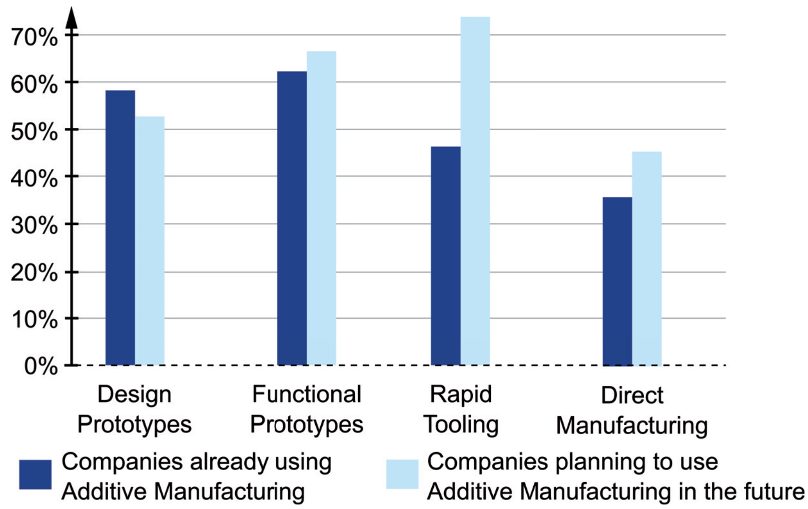

Figure 1-8: Applications of Additive Manufacturing as indicated by the participants

There is no predominant application type for AM.

From our findings, there is no clear indication which application of the technology is predominant at the moment. However, there is still an overall tendency towards the use of prototypes and Rapid Tooling. Notably, there exists a large discrepancy between the degree of current users' application of Rapid Tooling and future users' interest in this kind of application. 74% of interviewees uttered interest in Rapid Tooling in the future, yet only 48% of those who have used the technology, used it for Rapid Tooling: an indicator for the assumption that Rapid Tooling is currently experiencing the biggest attention among practitioners. The reason for this is the emergence of use cases which claim to reduce the average lead time for the fabrication of tooling by between 40% and 90% [CNC14]. Even though the production of end use parts has experienced high attention recently, applications such as Design Prototypes will certainly still play a relevant role in the future. That is why methods for the identification of potentials in companies **should allow for all applications** as possible results.

The organizational embedding of AM potential identification has been evaluated.

A point of interest for the capability of a company to identify potentials of any technology is the embedding of this task in the company's organizational structure. The organization of technology management in a company has been subject to many (empirical) studies like [SK11], [SGK10]. In this study, we do not want to argue in favor or against certain concepts of technology management. Rather we want to outline the common practice in Additive Manufacturing and derive implications for the development of methodologies.

Small and large companies use single technology experts to the same extent.

In our interview series, we asked interviewees to indicate which entity in a company bears the operational responsibility for identifying potentials of Additive Manufacturing. The results are given in figure 1-9. 46% of the respondents indicated that a single technology expert is responsible for this task. This finding does not correlate with company size. In the subset of larger companies (>500 employees), 44% of the interviewees replied that in their company, a technology expert is mainly responsible for the identification of potentials. Overall, 32% organize this potential identification in loose task forces. 16% of the approached companies allocate potential identification to central technology management departments.

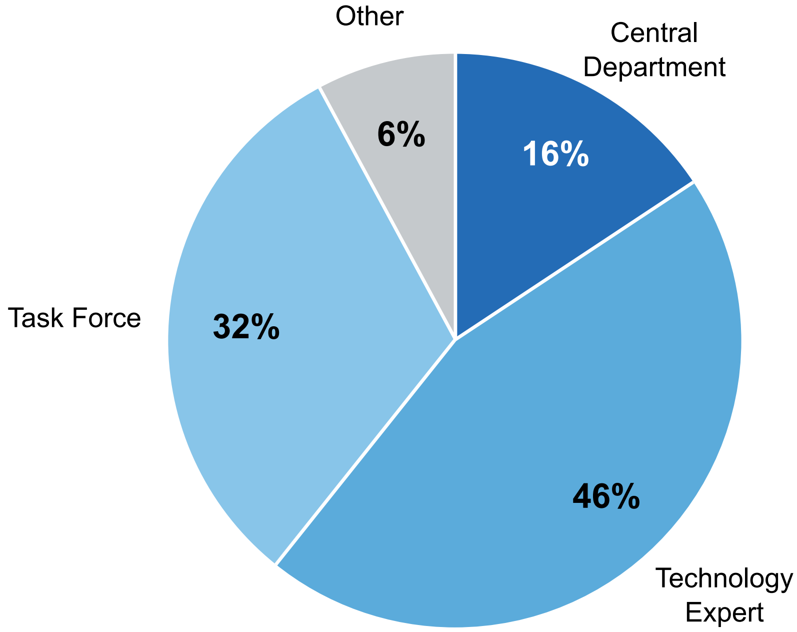

Figure 1-9: Operational responsibility of Additive Manufacturing potential identification

No relationship between organizational embedding and prior usage of AM.

Also, the organization of the AM potential identification does not correlate with whether or not a company has already used the technology or not: In 40% of the companies which have already used AM and in 58% of those who have not yet used AM a single technology expert bears the operational responsibility of finding the potentials of the technology.

A follow-up question revolved around the way in which companies pursue the potentials of Additive Manufacturing. Interviewees could choose between five options, multiple answers were possible. A **Structured** proceeding means that the interviewees can discern a concrete plan of action for the identification of potentials. **Heuristic** means that a company does not have a masterplan of action for the rollout of Additive Manufacturing, but defines pilot projects in which the application of Additive Manufacturing is tested. The goal of these pilot projects is twofold: gaining knowledge about the technology and developing internal procedures to find potentials. Also interviewees were able to indicate whether they make use of consulting services: **Know-how Consulting** by technology experts or **Methodological Consulting**.

Usually, companies follow a heuristic, trial-and-error approach.

The interview results (see figure 1-10) yield that a majority (58%) of companies pursue a heuristic approach towards Additive Manufacturing. 28% of the interviewed experts indicated that their company does not seem to follow a holistic plan in AM implementation, while 35% confirmed the existence of a structure. 37% of the interviewees stated that they were using know-how consulting. The use of methodological consulting seems to be of minor market relevance today; only 14% of the interviewees employ it.

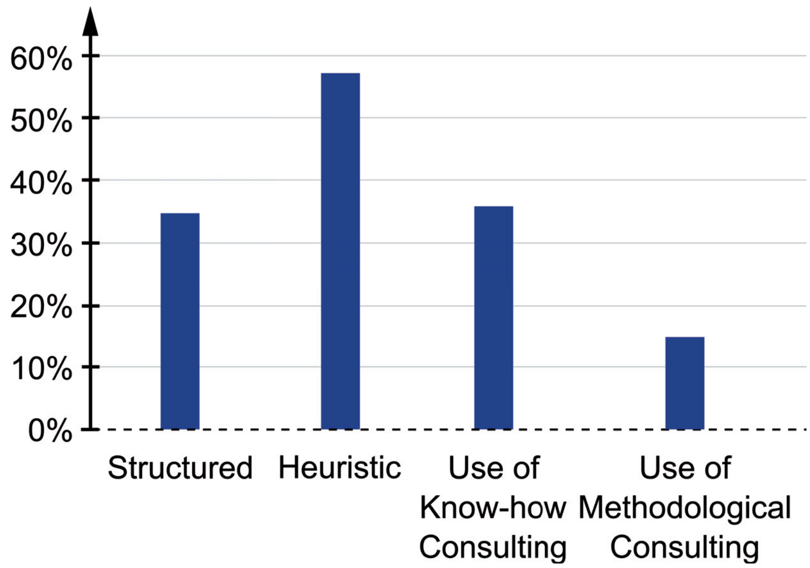

Figure 1-10: Proceeding in potential identification as indicated by the interviewees

The findings of our interview study are in line with the adoption routes of Additive Manufacturing which have been outlined by Serlegna and Montaville [SM15]. The authors point towards the existence of **three** prototypical **adoption routes**, which are prevalent in the industry:

1. **Start from design engineering:** Giving the design engineering department of a company time to experiment with the technology. This yields for a slower, but more reliable and structured learning approach.
2. **Shop floor launch:** Buying machines and using them within the existing production system framework. This approach allows for a faster implementation of AM, at the cost of inefficiencies and a suboptimal use of Additive Manufacturing since the technology is embedded in an existing production system at first.
3. **Prototyping expansion:** Using Additive Manufacturing for prototyping at first and expand to other applications later on.

Consulting services are usually know-how consulting services.

Operational responsibility and proceeding in potential identification (figure 1-9 and 1-10) unveil that a majority of companies use either loose task forces or a single technology expert to find pilot projects for Additive Manufacturing. If consulting services are utilized, these are mostly (technology) know-how consulting services . If a central department is employed to coordinate the identification of AM potentials, 87% of the interviewees stated that the department worked according to a structured plan or use a heuristic approach. Unsurprisingly, there is a relation between the use of a single technology expert and the impression of an unstructured proceeding: 75% of those who thought their pursuit of AM potentials was unstructured stated they used one technology expert.

Additionally, the approached interviewees were also asked whether or not they possess an **Additive Manufacturing strategy**. The results are given in figure 1-11. For a technology user, an Additive

Manufacturing strategy indicates 1) which applications of the technology are being used to 2) serve which business fields using which 3) competences. It is a sub-strategy of the corporate strategy [GP14]. Overall, 33% of the companies stated that they already have an AM strategy, while 63% indicated that they do not yet have an AM strategy, but would like to have one. Only 4% uttered no interest in an AM strategy. Despite the multitude of different approaches towards AM, there seems to be a longing for a structure, embodied by an AM strategy.

63% share of interviewees require for an overarching AM strategy.

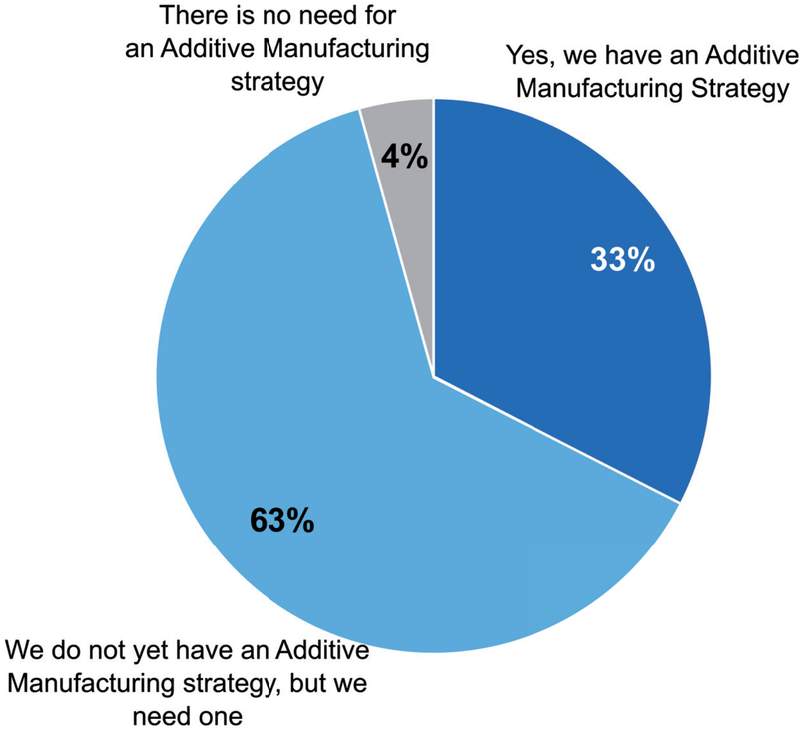

Figure 1-11: Existence of an Additive Manufacturing strategy as indicated by the interviewees

In the interview series, representatives of companies were asked about the key challenges of implementing Additive Manufacturing. The results are given in figure 1-12. The provision of multiple answers was possible. Generally, there is no consensus on the importance of finding business fields, parts or developing business models. The respective answers all lie in the range of 34% to 46%. Few interviewees stated they face other challenges as well. Notable answers were **overcoming internal resistance** and **getting to know the technology**. These findings reveal that companies clearly assign equally high relevance to the tasks of strategic planning.

Finding business fields, parts and development of business models are equally difficult for companies.

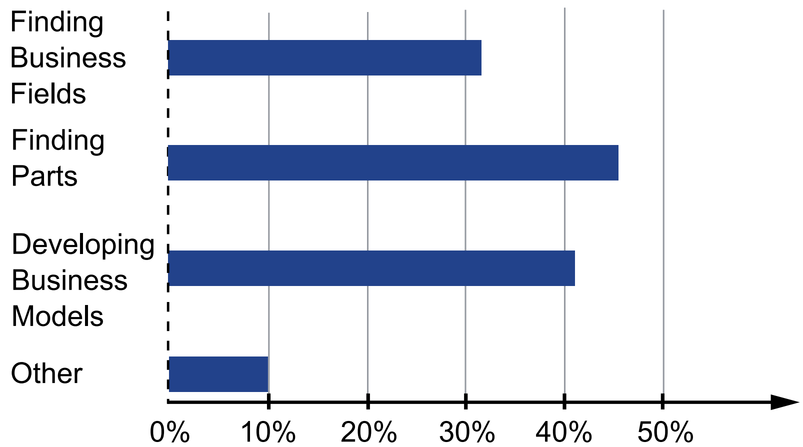

Figure 1-12: Key challenges when operationalizing Additive Manufacturing as indicated by the participants

AM is typically being discussed on the systems and processes level.

Adding to the findings of figure 1-12, much research in Additive Manufacturing has recently been focused on **systems** and **processes** level (see, for instance, [FSS+14], [Gry13], [RAE13], [GWP13]). For years, however, scholars have outlined the importance of implementing processes as a consequence of thought-out strategies, which themselves rely on a visionary draft of the future [GP14]. In the same vein, CHANDLER coined the phrase “structure follows strategy” [Cha96].

A future-oriented potential identification is necessary.

As a result of this, the endeavors being undertaken currently focus today’s deficiencies of the technology field. While being an important accelerator of technology diffusion (see four success factors) it only cures today’s teething troubles of the technology (see figure 1-13). For example, the automatization of AM-processes is vastly spurred by the existence automated process chains in comparable technology groups. To put it in a nutshell, research endeavors mimic what is known from other technologies. In the case of automation, the advantage of this development is undisputed. In the long run however, the rationale in potential identification for Additive Manufacturing should be **future-oriented**.

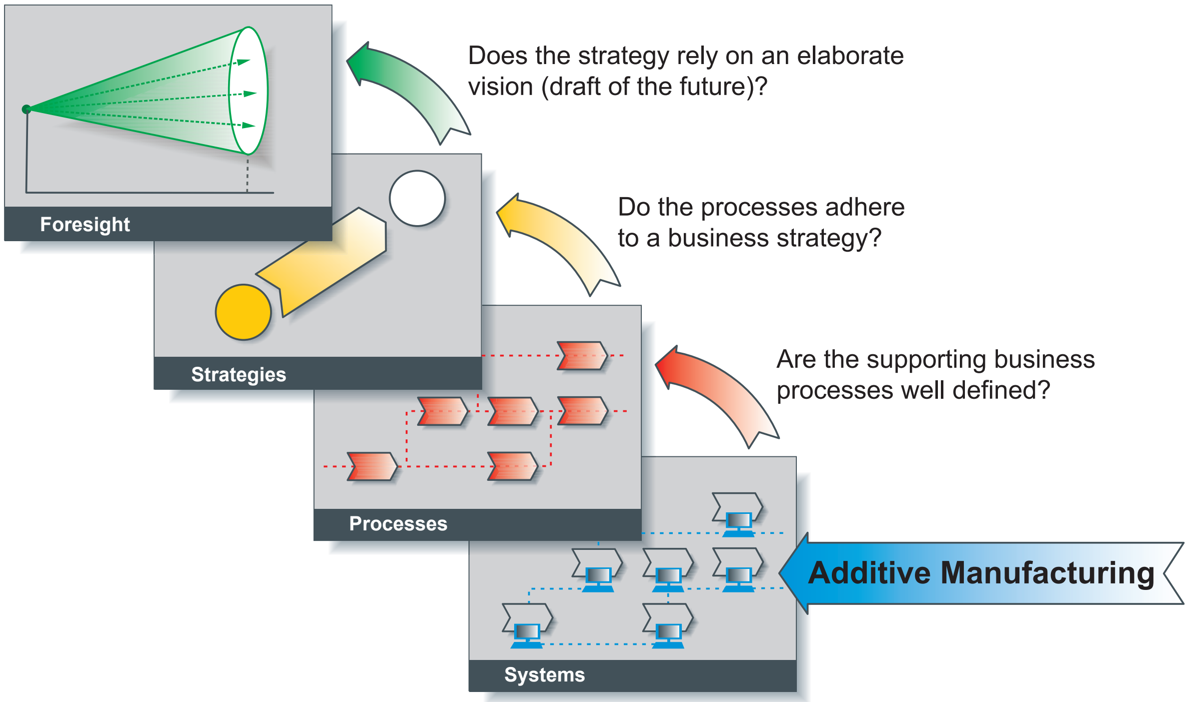

Figure 1-13: Current focus in Additive Manufacturing visualized by the four layer model of future-oriented business design (according to GAUSEMEIER and PLASS) [GP14]

Conclusion

Given the different adoption routes towards Additive Manufacturing and the findings of the survey at hand, there seems to be no patent remedy as to how to find potentials for the technology. As a conclusion it can be stated that Additive Manufacturing is a very **heterogeneous technology group** with specific chances, risks and technological requirements. The technology group is used by a **broad variety of branches** (see figure 1-6) in **various applications** (see figure 1-8)**.** Among these, Rapid Tooling and Prototyping currently seem to have a slight edge over Direct Manufacturing. It is hence understandable that there are **various approaches in finding potentials** for Additive Manufacturing which are also **embedded differently** into the organizational structure of a company. As a result of this, 63% of the interviewees would like to subordinate the pursuit of potentials to an AM strategy.

Methods and tools for the implementation of Additive Manufacturing have to adhere to the requirements posed by these findings. It is necessary to develop a toolset consisting of methods and supporting (IT) tools which allow identifying promising business fields, products and business models. In doing so they should allow for an interchangeable and modular use. The toolset should be adaptive regarding different contexts and allow for different outcomes (regarding the application). Additionally, the technological capabilities of AM technologies are going to increase in the future. That is why the concrete design of methodologies for potential identification must not be **rigid** and rather **be flexible** to the individual capabilities of the technology group. For example, SLS processes usually yield parts with a surface finish with R_z 85-200µm [SSS13]. However this limit could change in the future, making it possible to produce parts with better surface quality directly from the machine.

Project DynAMiCS – Development of an Additive Manufacturing Potential Check System

The present study contains exemplary results of the project “Development of an Additive Manufacturing Potential Check System” performed by the Direct Manufacturing Research Center (DMRC) and the Heinz Nixdorf Institute, Paderborn University, Germany.

Object of the project is the development of a methodology pool for the identification of potentials for AM.

Objective of the project is the development of methodologies to identify business opportunities for Additive Manufacturing technologies in companies. The sum of these methodologies is considered an overarching check system which has been validated in workshops with external companies and DMRC partners. The check system is based on findings from the preceding project “Research Strategies for Additive Manufacturing Technologies”.

The study at hand is complemented by results of DynAMiCS which are published in a confidential study. Both documentations present and detail the elements of the check system. The public version comprises an overview of the project results; the confidential version encompasses all results gathered in the project and is accessible for DMRC partners exclusively.

Proceeding in the Project

The present project is structured into four work packages, as indicated in figure 1-14. The study at hand is structured according to the first three work packages.

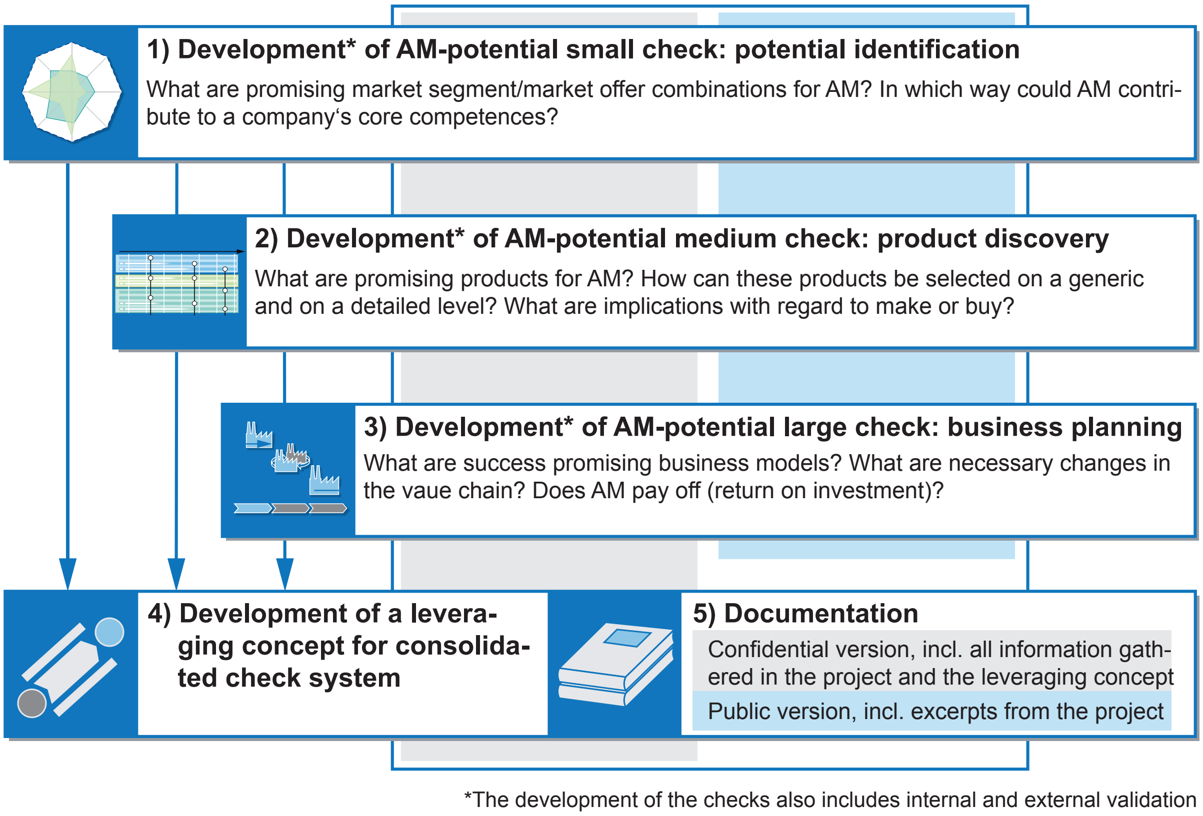

Figure 1-14: Proceeding in the project

In **work package 1**, a small check for potential identification is being devised. Potential identification addresses the following questions:

- How can promising business fields (market segment / market offer combinations) be found?
- What are the key capabilities of Additive Manufacturing to be put to use into these business fields?
- How can business fields be prioritized/ranked regarding the use of Additive Manufacturing?

To answer these questions, a suitable methodology in order to structure a company's business will be devised and extended to a business field check tool.

In **work package 2,** a medium check for product discovery will be outlined. Product discovery deals with the following questions:

- How can promising products for Additive Manufacturing be found?
- What are possible ways to select pilot products on a generic and on a detailed level?
- Does the result of product discovery justify contemplating an investment into the technology or should a Service Provider be contacted?

The known concept of the funnel of idea selection is going to be taken as a framework to answer these questions.

Work package 3 devises methodologies for business planning. This addresses the following research questions:

- What is a suitable framework to document business models?
- What are tools which help us in the development of business models?
- What are possible impacts of a business model on a value network?

The result of all work packages is a concise service offer for the DMRC in order to conduct workshops and projects covering the respective tasks (see figure 1-15). Additionally, an (internal) **work package 4** will devise concrete steps for the DMRC to implement and run these service offers.

Figure 1-15: Service offers for the three main challenges in identifying Additive Manufacturing potentials

Work package 5 entails the documentation of the project. The following chapters represent the public output of WP5, presenting a detailed documentation for all research issues addressed by the DynAMiCS project.

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2

Identifying potentials for Additive Manufacturing

The benefits of Additive Manufacturing technology seem obvious: Remarkable design flexibilities facilitate to satisfy requirements like lightweight construction, reducing waste and creating formerly non-producible complex structures [Geb13]. However, companies who are trying to leverage the advantages of AM face several questions: How can AM be practically beneficial for the company? How can AM be integrated into existing production systems? Can existing production processes be substituted by Additive Manufacturing?

Identification of potentials for the introduction of AM.

Considering AM as an additional manufacturing technology for parts, the generic suitability of AM for a company or even for a business case has to be determined. In other words, business fields, which are described by the combination between market segments and product groups (MSPG) [GPW09] and implementation potentials of AM have to be identified.

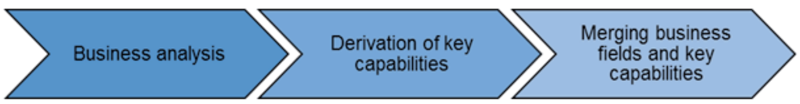


Figure 2-1: *Methodology for identifying potentials for AM*

In the following sections a methodology for potential identification is proposed. The objective is to determine the, presumably, attractive MSPG of implementation of AM. Additionally, a tool was developed at the DMRC to support the methodology. Section 2.1 devises a methodology for business analysis. Section 2.2 shows the derivation of key capabilities of AM, which are summarized by DMRC experts. In section 2.3 a methodology to allocate key capabilities to business fields is provided. Subsequently, the application of business analysis is demonstrated by a case study at Parker Hannifin GmbH (section 2.4).

2.1 Business analysis

Using market segmentation for deriving main business fields.

Business analysis is the initial step required to structure a company's products and services. It is usually necessary for small and medium-sized enterprises (SMEs), which do not maintain a clear and explicitly documented business structure. Market segmentation is a generic management tool to identify and construct precise business activities. It aims primarily at the identification of the main **business fields**. It provides the fundament for the selection and configuration of business analysis methods and tools in this study. The following paragraphs outline the proposed methodology for this step including relevant background knowledge.

For business analysis the "Market Segment / Product Group Matrix" (MSPG) is selected which divides a market into several subordinate units. It is a well-established tool. The columns of the matrix are defined by the respective market segments, while the product groups are added successively in rows. Based on PORTER, framing market segments can be conducted according to three features [Por99]: types of customers, distribution channels and geographical location of markets. A hierarchical structure of products or services can be recommended by company experts and completed in MSPG. The occupied areas in the matrix describe the business fields which can be characterized by standard Key Performance Indicators (KPIs) turnover, turnover growth and earnings before taxes (EBT) [GPW09].

Figure 2-2 shows an example of the traditional MSPG applied for an automotive manufacturer. The product groups are couplings, gears, motors, gas turbines, steam turbines and generators. The market has been divided into the segments: China, Europe, Australia, Northern America, Central America, Southern America and Africa (geographical segmentation). The turnover in million Euros is placed in the upper left corner of each business field. The bottom right corner is filled with turnover growth. The colors indicate the respective EBT.

Objective of this matrix is identifying the main business fields. Three criteria constitute main business fields:

1) A main business field is independent from other business fields.
2) A main business field contributes a significant profit for a company.
3) The success factors for all business activities are identical within a main business field.

MSPG serves as tool for business analysis.

Figure 2-2 shows a well-structured and comprehensible demonstration of the present business of the automotive manufacturer. The main business fields which satisfy the requirements mentioned above are indicated by black frames. Besides, the MSPG supports the identification of segmentation gaps (grey squares) to identify potential markets. Based on identified segmentation gaps appropriate measures can be derived.

Product Groups	Market Segments: China	Europe	Australia	Northern America	Central America	Southern America	Africa
Couplings	3.6 1	9.1 0	0 0	0.6 0	4.3 3	3.5 0	0 0
Gears	5.2 3	0.5 2	11.4 3	6.7 3	26.4 1	24.3 1	21.4 3
Motors	7.6 1	6.2 3	0.8 1	4.2 3	1.7 3	6.7 1	5.2 3
Gas Turbines	6.5 3	14.5 1	0.5 0	1.6 2	0 0	4.3 3	6.7 3
Steam Turbines	0.5 3	8.8 3	2.1 1	0.9 3	0.6 2	0.6 3	0.3 3
Generators	0 0	46.5 1	0.9 0	0.4 3	2.5 0	2.5 3	0 0

EBT
- segmentation gap
- 1%>=EBT
- 5%>=EBT>1%
- 10%>=EBT>5%
- EBT>10%

Turnover
7 million Euro

Turnover growth
0 Losing market shares
1 Growing with market
2 Growing stronger than the market
3 Growing stronger than the market (>1%)

Turnover: 24.3; EBT; Turnover growth: 1

Figure 2-2: Traditional MSPG with evaluated data of an automotive manufacturer

Using conventional manufacturing technologies, many products and parts are produced by taking pieces of raw material and cutting away sections to create the desired parts or by injecting material into a casting mold. AM adds material layer by layer to create objects. Compared with traditional manufacturing technologies AM opens up new opportunities for a broader spectrum of products. However, to enable the technology and to identify the main business fields of AM, key characteristics of AM should be devised and considered in the MSPG. Therefore it is necessary to match business fields for AM in the MSPG matrix regarding the specific requirements of the manufacturing technology of AM. Economic KPIs are replaced by technological criteria. Analyzing and evaluating the MSPG of AM, the following criteria are filled in the specific cells of the matrix:

AM enables manufacturing complete new products.

1) AM development trend in the company (increasing, constant, decreasing): The use of AM has increased significantly in previous years. However, additively manufactured products currently represent only a tiny fraction of worldwide production [DS14]. AM development trend depicts the outlook of AM in respective business fields in companies. Three arrow directions (upwards, rightwards and downwards) are used to indicate the development trends of AM referring to the requirements of products and

markets, which are determined by company experts. They represent the decision of undertaking AM activities in a company.

2) Suitability of company's material requirements and corresponding AM capabilities: AM materials, systems and process parameters should perfectly match each other to achieve the targeted property profiles for products and specific customer requirements. As a consequence, AM currently covers a small material range. Products, based on metal and plastic, are assigned to the "suitable" group with a cross. In the contract, unsuitable materials such as wood and resin are indicated by a minus. The material solutions are a major driver for this AM technology. In view of this point, the material suitability is taken into account in the specific MSPG for AM.

3) Conformity of requirements of AM (see section 2.2) with the requirements of products or markets various requirements of products, which AM often cannot satisfy, can impede and slow down the adoption of AM. For example, the production costs of AM are significantly higher than traditional manufacturing technologies [DS14]. Thus, the second criterion ensures that the key capabilities, derived from section 2.2, are meeting the requirements of products and markets. The "requirements conformity" is divided into three ranks high, medium and low, which are labeled by the numbers 3, 2 and 1 in the MSPG.

4) Production quantity in relation to the technology of AM: Although AM allows manufacturing customized and increasingly complex parts, the slow print speed of AM limits its use for mass production. Therefore, the production quantity is a crucial factor of using this technology. Three grades of quantity (high, middle and low) are indicated by colors (red, yellow and green) in each business field.

5) Visualizing the market situation from a financial perspective through analyzing the position of economic efficiency of companies and comparing with competitors: The last criterion is the current market situation, which can be measured by e.g. turnover, turnover growth or EBT from traditional MSPG. In conclusion, the specified MSPG matrix focuses more on AM specific requirements, but less on precise values.

Technological criteria play a more decisive role than financial criteria in choosing AM.

Obviously, the underlying evaluation criteria differ from the traditional MSPG. The decision in favor or against AM is determined more by technological criteria than financial criteria (figure 2-3). Besides the last criterion, all the others refer to the technology of AM, which covers the technical potential and the index of production technology. The technical potential is comprised of "AM development trend" and "requirements conformity", which address the relationship between market and technology. The criteria of "quantity" and "material" are collected to indicate the production technology, that the basic conditions of AM are reviewed. Combining the traditional MSPG with the particular features of AM, the adapted MSPG is evaluated for a pump manufacturer. This exemplary MSPG matrix is shown in figure 2-3.

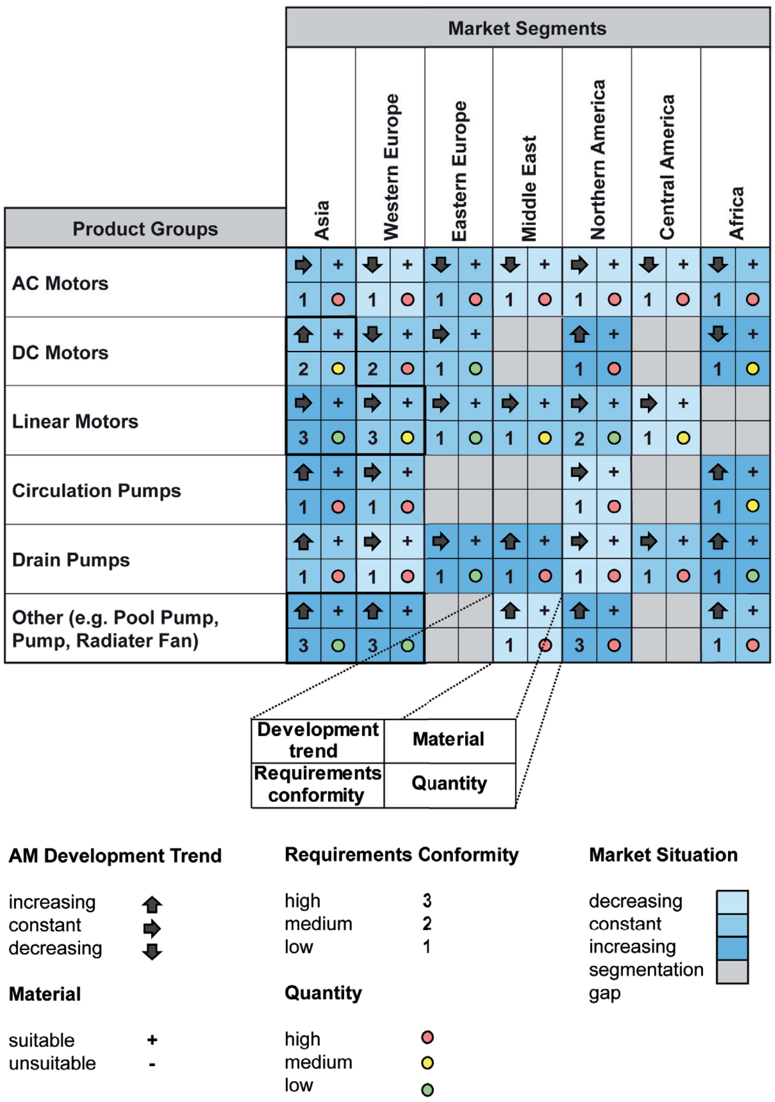


Figure 2-3: Exemplary MSPG Matrix with evaluated data for AM

The AM specific MSPG which was evaluated by experts of the pump manufacturer divides the market into five segments: Asia, Western Europe, Eastern, Middle Europe, Northern America, Central America and Africa. According to the product category of the manufacturer, AC motors, DC motors, linear motors, drain pumps and related applications are listed as product groups in the MSPG.

AC motors are mass products with low production costs which are most attractive for emerging countries in Asia. Because of the producing complexity of DC motors, main market sectors are located in developed countries which mostly belong to Western Europe and Northern America. In the business field of HealthCare costly linear motors are produced in a small lot size. These conditions of linear motors meet the requirements of AM. The high demands of circulation and drain pumps do not suit an implementation of AM. Other applications such as pool pumps require a high level of customization. The grey fields indicate the market gaps of the pump manufacturer.

MSPG shows easy comprehensible main business fields.

Based on the above analysis and the aforementioned criteria, the main business fields for this pump manufacturer are identified and indicated with black frames: DC motors in Asia, linear motors in Asia and Western Europe, other in Asia and Western Europe. These business fields will be analyzed in section 2.4 to identify the potentials of AM.

2.2 Key capabilities of Additive Manufacturing

The specific advantages of Additive Manufacturing allow to derive key capabilities which are defined in terms of distinctive technological features or a unique selling proposition – a benefit provided by the technology which is not exhibited by other technologies. In doing this, the focus is shifted to economical and practical key capabilities. Using a text mining approach to extract relevant keywords from more than 3000 documents, collected from professional journal articles and publications about the topic, 200 preliminary key advantages are discerned.

Using a DSM to identify selected key capabilities.

Identifying key capabilities allows companies to assign key capabilities to certain business fields. However, 200 terms are still overmuch for the desired quantity of key capabilities. Therefore, the preliminary results are clustered in a Design Structure Matrix (DSM). Generally, a DSM allows to cluster objects or to arrange them in a logical sequence. In order to filter advantages of the aforementioned purpose, the DSM shown in figure 2-4 is created and used. Thereby, redundancies can be eliminated. An example: producing spare parts on demand also enables producing products on demand as well as a shortening lead time.

1) Which advantages of Additive Manufacturing necessitate each other?

2) Which advantages of Additive Manufacturing can be tapped at the same time?

Advantages of AM	Shorter lead time	Decentral manufacturing	Repairing parts	Spare parts on demand	Reduction of storage	Products on demand
Shorter lead time				X		X
Decentral manufacturing					X	
Repairing parts						
Spare parts on demand	X					X
Reduction of storage		X				
Products on demand	X			X		

Figure 2-4: DSM to analyze the relationships of advantages of AM

Using this DSM, 33 clusters of advantages are identified and visualized in a tag cloud (figure 2-5).

Figure 2-5: Clusters of advantages tag cloud

One of the driving forces for the DMRC is to facilitate an effective and efficient use of Additive Manufacturing technology. Based on this objective, DMRC experts derived 13 key capabilities from the 33 clusters of advantages. The resulting 'key capabilities' are shown in the following table with individual description and picturesque instances from DMRC.

2.3 Merging business fields and key capabilities for potential analysis

The key challenge for the identification of potentials is merging identified relevant business fields (section 2.1) and key capabilities of Additive Manufacturing (section 2.2). The merging process is presented schematically in figure 2-6. This process is supported by a tool which was developed based on Microsoft Excel.

The merging is elaborated by associative requirements and features.

The evaluated business fields are linked with the key capabilities by associative requirements and features which can be reached through AM. While key capabilities are generic and independent from specific companies, requirements and features are related to actual or planned products of a company checking the potential of AM. In DMRC a workshop-capable catalogue of questions is developed to support finding out the correct requirements and features. Subsequently, these requirements and features are evaluated with MSPG and key capabilities of AM. Finally, besides providing the results of suitability between corresponding business fields and key capabilities, a potential ranking of key capabilities and a MSPG ranking of business fields, which are identified in section 2.1, are concluded.

Questions were developed in DMRC-workshops.

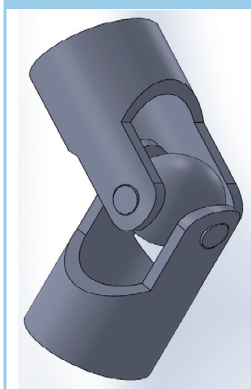
1. Complex (Bionic) Structures

Description:
The main advantage of AM is its ability to produce parts with complex structures. As compared to subtractive manufacturing methods such as lathing, milling or forging, AM faciliates the production of parts with undercuts and holes. Conventional downstream manufacturing steps are often rendered needless.
To harness the potential of complex structures, design engineers more and more draw on numerical optimization methods such as topology optimization to minimize material in parts. The results of these optimizations oftentimes resemble principles known from biology, hence the name of bionic structures.

Example:
With the use of complex bionic structures, a part of a satellite from the European Space Agency (ESA) is optimized. A reduction of waste, costs and time could be realized through a weight reduction of 60% from 1114g to 456g.

Source: Thomas Reiher, [DMRC15]

2. Functional Integration

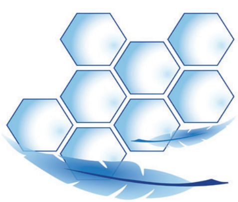


Description:
With AM it is possible to pursue Functional Integration during the manufacturing process. Functional Integration means building in one part, what normaly has to be built as separate parts, including functional components like springs, hinged joints or even pneumatic actuators. Thereby, downstream assembly steps can be significantly eliminated if not reduced. Potentials can naturally be sought in complex manufacturing lines with many assembly steps.

Example:
The function of product piracy prevention should be considered in early stages of the product development process and contribute preventively to the protection of products by including additional brandings or QR codes, which prove the authencity of the product and require AM technology and knowhow in production.

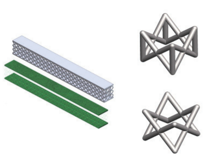
Source: [DMRC15], [HN16]

3. Lightweight Design



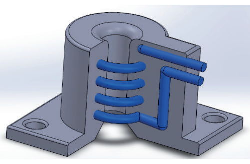
Description:
Lightweight Design is one of the core advantages of AM parts. Due to its capability to produce complete new structures, material can be cut where unnecessary. The technology has already proven to be a viable production technology in the aerospace industry. With regard to functional performance and strength, AM parts are on par with their substractive counterparts. While they are usually more expensive to manufacture, they yield high potential to reduce costs during operation (total cost of ownership). Potentials can naturally be sought in moving parts with many load cycles.

Example:
In order to meet the demand of optimized light-weight parts, the development of load adapted structures using AM has begun to play a key role in today's research. The figure shows sandwich structures with face-centered base cell with additional struts in loading direction (stretch-dominated) and face-centered base cell (bending-dominated).



Source: Alexander Taube, [DMRC15]

4. Conformal Cooling



Description:
Conformal Cooling describes the integration of cooling channels into areas which had formerly been inaccessible for e.g. drills. Thereby, heat can be transferred faster, also the heatflow can be controlled better. Benefits are significant especially for Rapid Tooling. They can be used in shorter cycles and the quality of the end product can be increased. For instance, injection molds made by AM allow a higher quality of the polymer part and also increase productivity. Estimates for the improvement of cycle times alone range form 20 to 40%.

Example:
Using AM makes it possible to integrate optimised, conformal cooling channels into the moulding form during the production process. This ensures faster and more evenheat dissipation to reduce thermal stress in the mould.

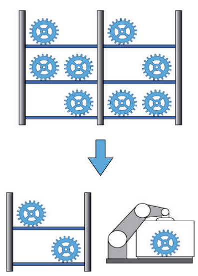
5. Waste Reduction

Description:
During conventional machining processes parts are stripped off unnecessary material, thereby creating the final geometry. Naturally this results in waste of build material and lubricants. Additionally, tools are susceptible to abrasion leading to downtimes and increased costs. Using AM, parts can be produced almost without waste. Potentials can naturally be sought in larger, complex parts which are machined from a single block of material.

Example:
A wheel carrier of 515g for a formula student team was formerly milled from a 16kg block of material. Via FEA optimization and AM, the part could be reduced to 305g, requiring 720g of powder. This material and waste reduction of over 95% was achieved in a project at DMRC.

Source: Thomas Reiher, [DMRC15]

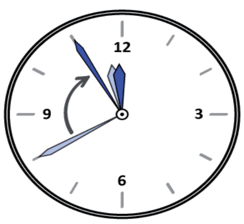
6. Spare Parts on Demand



Description:
Printing spare parts on demand is a promising future application field for AM. At the very bottom, the core idea is reducing stock inventory for parts that have to be kept in storage for long periods. Via AM, the company is able to store the digital models of the part and print them when necessary. Thus, AM is attractive for companies or business fields with huge product portfolios, volatile spare part demand a long product life cycles. A credible implementation of this potential has yet to be realized.

Example:
In 2015 Boeing has filed a patent for printing non-metallic aerospace spare parts via AM. The company is already using approx. 20,000 parts in 10 aircrafts production lines. The figure shows the first-sized T25 housing for a compressor inlet temperature sensor, which was fabricated by GE Aviation, for over 400 GE90-94B jet engines on Boeing 777 aircrafts.

7. Realization of Last Minute Changes



Description:
Since AM is a throughout digital manufacturing process right until the start of the build-job, it is possible to realize last minute changes in the design of a product. Because there is no need of producing manufacturing tools beforehand, changes in a parts geometry can be realized rather quickly. This potential is especially auspicious in cases of volatile customer requirements. Some companies have already taken advantage of this capability and offer software solutions which allow for quick changes during the design stage.

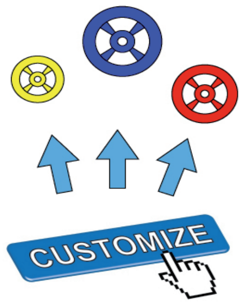
Example:
Volvo Trucks is now producing more than 30 tools using AM. It enables the equipment design team to be far more responsive and avoids possible waste in the event of last-minute design changes before tools are made (according to a interview of a technical manager in Volvo Trucks).

8. Decentral Manufacturing

Description:
Decentral Manufacturing describes distributing the production to local production facilities as compared to centralized production facilities. Each small production facility is supplied with the material necessary to produce the required parts, as compared to distributing final parts. The material can be supplied in larger batches reducing emissions and local manufacturing units can specialize on e.g. regional product variants. Once large production capacities are required, an intelligent platform distributes build jobs according to a multiobjective optimization.

Example:
Nowadays, 3D printing services are becoming more and more popular. Trinckle for example offers a cloud-based customization engine which allows rapid adjustments of the product design during the development process. Thereby the consumer is able to customize shape and appearing of products.

9. Individualization

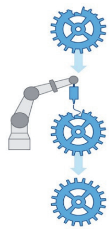


Description:
AM allows for the production of smaller batches, up to lot size 1 (assuming the quality of each product can be verified). Customer requirements can be met more specifically (e.g. regional requirements). Products can be adapted for the demands of a single customer. Here, the medical industry is in the vanguard: custom protheses are reality today. For the manufacturing industry, potentials can be sought in products with many variants and in products which are directly sold to the consumer.

Example:
AM enables the inclusion of consumers into design and manufacturing processes. With an online cloud, consumers can design and order traditional toys and furnitures and place orders for their own product.

Source: eppm.com, [DMRC]

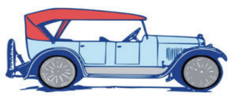
10. Repairing Parts

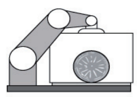


Description:
Abrasion due to mechanical load or temperature cycles oftentimes forces the replacement of whole parts or groups of parts. Deemed "unrepairable", old parts are often scrapped directly. Here, AM bears the potential of adding material onto worn out surfaces via e.g. Laser Cladding or Laser Melting technology. Hybrid AM machines already show the possibility of straightening the fracture plane of worn out parts and then successively building up onto the plane.

Example:
Maintaining and repairing aircrafts in a cost efficient way can be realized by AM. AM technologies create the possibility to repair damaged parts just in time and thereby safe material and money.

11. Rebuild older Parts

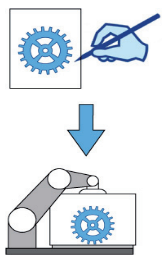




Description:
One application field of AM is the replication of older parts respectively the retrofit of older products. Machine parks in small and medium sized companies are oftentimes characterized by older machines. Manufacturing equipment which is not supplied anymore can easily be replaced by AM. As long as there is a digital mockup of the part, the part can oftentimes be printed. Potentials can be sought in older machine parks and aircrafts in late phases of their product life cycle of about 50 years.

Example:
Jay Leno is a former tv-host, who is collecting many old cars. To replace obsolete parts, he uses his own direct manufacturing 3D printer by simply scanning the old part and reprinting it.

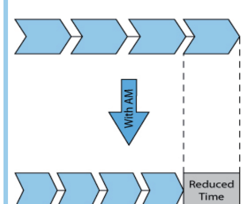
12. Rapid Prototyping



Description:
Rapid Prototyping describes the production of design or functional prototypes via layer wise manufacturing. In doing so, it is possible to include the customer into the design process and realize faster feedback loops. Some technologies are able to print from a large set of colors. New, high strength materials are able to create functional prototypes in order to verify requirements in the early phases of the development process.
Potentials can be sought in complex product development projects, volatile customer demands and daring projects which require fast feedback loops.

Example:
One of the many successful applications of Rapid Prototyping is the Skil-Bosch Power Tools Corp. The company produces functional protptypes of tools via Fused Deposition Modeling.

13. Reduce Time to Market



Description:
Due to shortening product life cycles, time to market has to be reduced. AM has proven to be a viable option in order to shorten development cycles.
1) Rapid Prototyping technologies allow faster design feedbacks and functional testing and
2) Direct Manufacturing technologies make the production of tools unnecessary, therefore enable a production directly from CAD file.

Example:
A.O. Smith, a manufacturer of water heating equipment managed to reduce their time to market by weeks using 3D printers for prototyping. A.O. Smith can print multiple prototypes reflecting a range of design alternatives in a few hours at a significant cost reduction. The conventional manufacturing of prototypes has taken at least six weeks before.

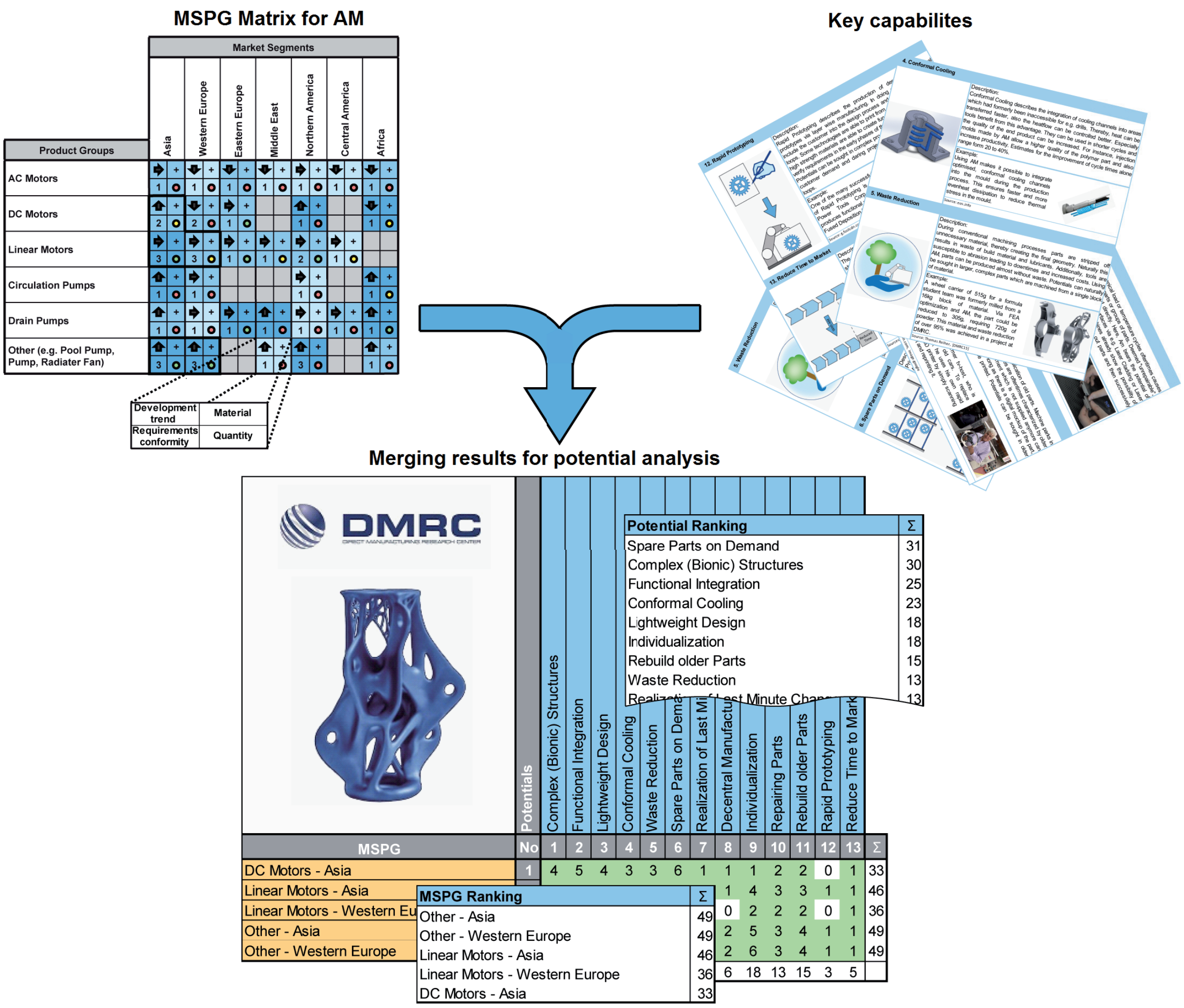


Figure 2-6: Merging Business Field and key capabilites for potential analysis

Referring to the example of the pump manufacturer (see figure 2-3), the critical requirements and corresponding descriptions are requested and listed in the table below (see figure 2-7). For example producing smaller motors is represented by the requirement "small or limited build space".

Nr.	Requirements and features	Description
1	Small or limited build space	Smaller motors
2	Complex force load	complex build
3	Reduction of assembly steps or time	improving assembly process
4	Dynamic loads (damping needed)	installation of additional damping
5	Reduction of parts	reducing complexity
6	Reduction of life cycle costs	production of spare parts
7	Many moving parts	reduction
8	Complex cavities	complex cooling
9	Volatile demand of spare parts	especially for new markets like india
10	Long product life cycle	spare parts
11	Large product portfolio	analyse portfolio
12	Customer as part of the design process	individual customer demands
13	Regional different product variants	e.g. different voltages
14	Small lot size (up to only one part)	installation minimum lot size
15	Very old parts and tools (possibly no supplier)	long life cycle

Figure 2-7: Extract of requirements and features referring to the pump manufacturing

Evaluation of main business fields.

After listing requirements and features, the main business fields are evaluated. The evaluation of the relationship between MSPG and derived requirements and features is extracted in the following figure 2-8. Two types of requirements and features with positive or negative effect for the implementation of AM in business fields are filled in light and dark blue background. In the evaluating process, crucial requirements for assigned business fields should be noted by '1' or '-1'. The other slight combinations are not taken into account. For instance, the business field of 'DC motors in Asia' requires lightweight design. However, a hollow structure is irrelevant for the production of DC Motors. Furthermore, DC motors in Asia have a medium lot size, which favors conventional manufacturing technologies instead of AM. Evaluating the key capabilities is similar to this procedure.

Evaluating business fields through requirements.

DMRC
New MSPG
Evaluation
Key
1 = MSPG meets the requirement

Requirements and Features		Small or limited build space	Lightweight design	Elaborate structures	Hollow structures	Complex force load	Many interfaces	Flow optimization	Reduction of assembly steps or time	Dynamic loads (damping needed)	Highly expensive parts	Very old parts and tools (possibly no supplier)	Short product life cycles	Simple geometries	Cheap parts which are easy to replace	Large lot sizes (>1000 p.a.)	No moving parts	Standard parts	High requirements for surface finishing	Homogenous demand (same parts)	Local competitors	Certification effort	Part design irrelevant for customer and consumer
MSPG	No	1	2	3	4	5	6	7	8	9	30	31	32	33	34	35	36	37	38	39	40	41	42
DC Motors - Asia	1	1	1			1			1	1	1					-1		-1		-1		-1	-1
Linear Motors - Asia	2	1	1	1	1	1			1	1	1							-1				-1	
Linear Motors - Western Europe	4	1	1	1	1	1			1	1	1					-1		-1			-1	-1	
Other - Asia	5	1	1	1		1	1	1	1		1								-1			-1	
Other - Western Europe	6	1	1	1		1	1	1	1		1								-1		-1		

Figure 2-8: Extract of evaluation of the main business fields

Results of the identification of potentials are presented in figure 2-9. The value of a potential, or rather a key capability, increases by 1 whenever a requirement is met. For example, the combination between DC motors in Asia and 'Functional Integration' adresses five common requirements, while linear motors in Western Europe do not meet the requirement "Decentral Manufacturing".

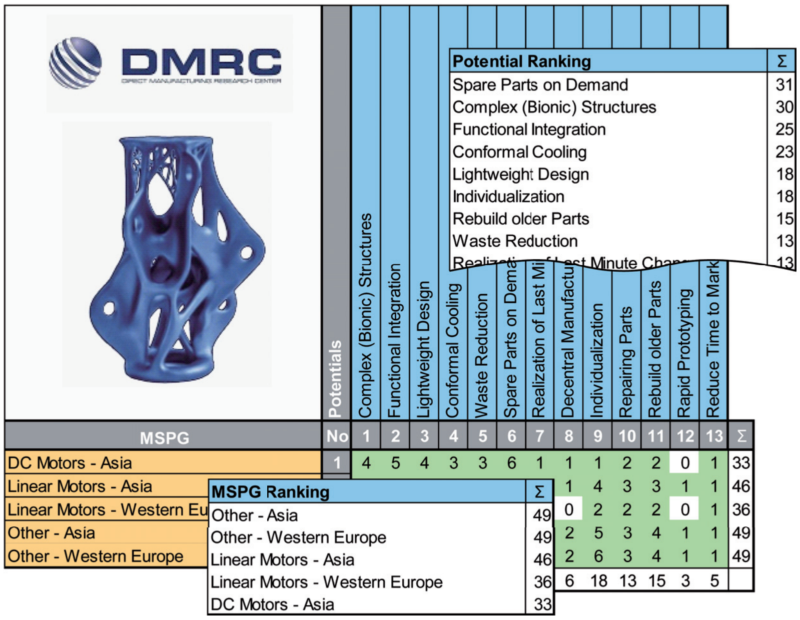


Figure 2-9: results of the potential analysis

In this example for a potential ranking, 'Spare Parts on Demand' is the most important potential of the business fields with 31, whereas, for instance, 'Conformal Cooling' is less important with an assessment of 23.

On the other side, 'MSPG Ranking' shows that 'Other' in Asia and Western Europe have the highest potential for the implementation of AM with the values of 49. In contrast, DC motors in Asia and linear motors in Western Europe show a worse prospect to implement AM technology with the analyzing value of 33 and 36.

2.4 Case Study: Parker Hannifin GmbH

Practical application at Parker Hannifin.

Parker Hannifin is the world's leading diversified manufacturer of motion and control technologies and systems. With approximately 55,000 employees in 50 countries, Parker provides precision-engineered solutions for a wide variety of mobile, industrial and aerospace markets. Parker´s products cover most areas of mechanical engineering and therefore serve as a prime example for showing the potentials of implementing AM. The wide range of products includes individualized products, which need to be developed in close collaboration with the customer, and mass products with completely different characteristics.

As mentioned in section 2.1 the first step of the AM potential identification is an analysis of the current business situation in a company. This analysis includes the determination of technological potentials of implementing AM and an identification of market growth potentials. Both were determined by expert surveys through workshops at Parker Hannifin. As a result an adjusted MSPG matrix for the identification of AM market potentials and main business fields were created. An exemplarily derived MSPG matrix is extracted and shown in the following figure 2-10. Values are modified to ensure confidentiality of actual data.

Figure 2-10: Extract of MSPG at Parker (modified values)

The MSPG is divided by customer segments and different types of products. Because of different requirements of small and big producing companies, an additional division was made. Parker has a wide range of product groups (more than 20). The MSPG shows the current situation of each business field regarding AM. For example, the market situation in the business field ‘Ship & Ship Repair’ for small and big producers is constantly increasing. It results on the progress of ocean technology in the last decades. Other business fields, like the manufacturing of ‘Robots’ also offer high potentials of AM due to a good market situation and meeting prerequisites. Besides, with the increasing implementation of clean energy, the product group ‘Wind Power’, which is not shown in this extract, possesses also an attractive AM market at Parker, especially for ‘small producers’ and ‘governments’.

The technological requirements conformity is mostly determined by AM-related product and production features. Lightweight design, complex structures, a high demand of individualization, different materials and susceptibility to repairs are indicators for a product-wise high beneficial AM implementation. Production-wise small lot sizes and a minor influence of production costs on total costs are requirements. The black frames in the extracted MSPG indicate high potentials for an application of AM. Many business fields pair a fulfilment of prerequisite with an increasing market situation for AM. Besides an individual implementation of AM in each business field, Parker Hannifin could benefit from a company-wide AM implementation due to improvements in prototyping and repair.

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3

Product discovery

The chapter **Product Discovery** deals with different approaches of product idea generation. Several questions have to be answered such as: Which products could gain the most benefits from Additive Manufacturing? What are possible ways to select products on a generic and on a detailed level? Does the result of product discovery justify contemplating an investment into the technology or should a Service Provider be contacted?

The project DynAMiCS followed a twofold approach: From a methodological and scientific perspective, the full potential can be utilized best by integrating it from early stages of product engineering. From a pragmatic perspective, companies often need to experience the benefits of AM at first. Therefore, approaches, methods and tools are developed and used to identify suitable products. Suitability means that, for a given product, there is a significant likelihood that many resp. sufficient key capabilities of AM have a positive impact.

Companies chose mostly a heuristic way to integrate AM technology.

The first section describes the creative and deductive approach to find products, representing the two aforementioned perspectives. The methodological one is emphasized by useful creativity techniques with an excursion to Design Thinking. Necessary stages and methods for idea creation are incorporated in the funnel of idea creation process illustrated in the third section of this chapter. After that, several methods and tools are described which are necessary to structure and condense product ideas. For a better understanding of methods and tools in this chapter a fictive example is given. The last section includes a real industrial case study, conducted in cooperation with the companies **Krause DiMaTec** and **Krause Biagosch**.

Methods and tools support the structured way to find product ideas.

3.1 General Modes of Product Discovery Approaches

Finding suitable products for AM is a difficult task for companies all over the world. The survey presented in chapter 1 has confirmed the finding of parts as the main challenge when operationalizing Additive Manufacturing as indicated by the participants. 46% of the interviewees have depicted this point as the main challenge. Evidence from interviews shows that companies mostly do it in an unstructured way. To change the way of product idea generation the DMRC has used two structured ways supported by several tools in the project “DynAMiCS”.

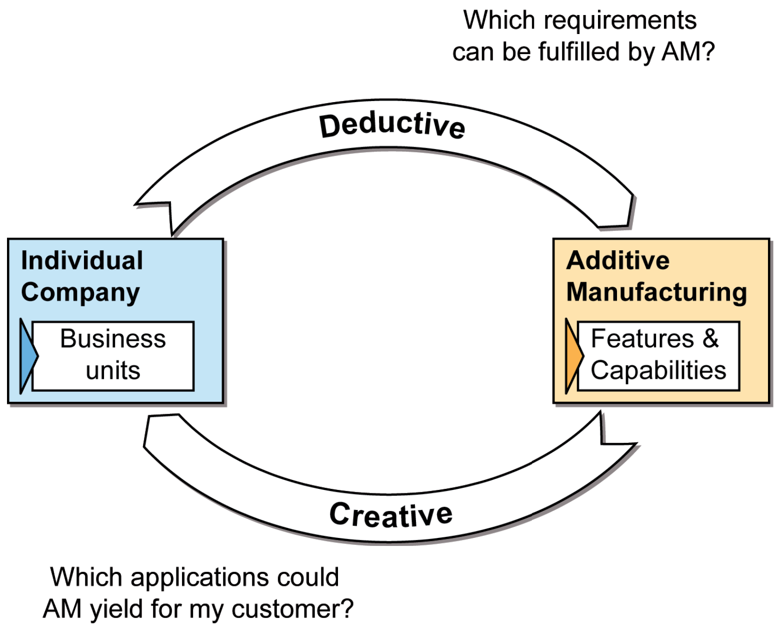


Figure 3-1: General modes of product discovery approaches

AM provides a new possibility of manufacturing.

AM can be regarded as a substitution technology. It extends the options to change manufacturing processes of the actual product portfolio and to design new products. Product idea generation for additively manufactured products can be divided in two different ways being illustrated in figure 3-1.

Interdisciplinary teams of companies are important to implement company specific information.

One possibility is scanning an existing portfolio. Questions like "Which requirements can be fulfilled by AM?" or "How can I reduce unsuitable product possibilities of my portfolio for AM?" are important for a deductive analysis. In this case, the product idea generation process can be based on existing products with specific properties and information. One advantage of the deductive way is the high dimension of concrete data and information. Product information has to be available to carry out the deductive way. Another important point is the local availability of employees to implement company´s internal know-how. It has to be noticed that the deductive approach prioritizes those key capabilities regarding physical part characteristics in contrast to service related characteristics.

The other possibility is generating products and services for AM. All features and capabilities of AM are incorporated by this approach. In facilitated workshops new products and services are found using Additive Manufacturing. In these workshops, dedicated facilitation tools are implemented to structure product ideas (Chapter 3.2).

3.2 Creative Approach

The creative approach requires specific methods being used in facilitated workshops for generating AM product possibilities. Classical methods such as brainstorming or mindmapping can assist, but are not enough goal-orientated to generate successful or even disruptive ideas. For the development of AM products and services a suitable mindset including use cases, advantages and disadvantages is necessary. This mindset defines the constraints for the creative way. Within these constraints ideas can be developed in a free way of thinking. The identified AM key capabilities help to orientate within constraints.

The matrix in figure 3-2 includes a categorization of several useful creativity approaches and techniques being important for creativity workshops [Gau01]. Intuitive thinking is defined by Steiner [Mus12] as the idea of free thinking and method to investigate thinking. Schieschkoff defines discursive thinking by a structural procedure which assembles the idea of logic trains of thoughts [ScSc78].

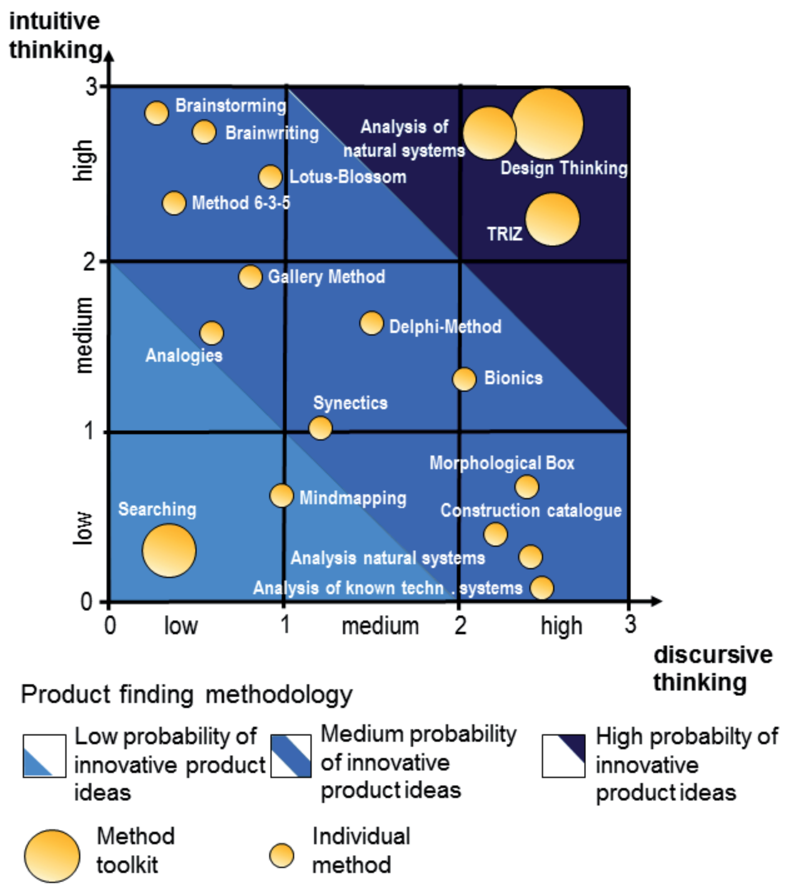


Figure 3-2: Portfolio of creativity techniques

The bubble chart shows that methods having a high degree of both categories provide a high probability for innovative product ideas. By validations of the DMRC it was determined that methods such as Brainstorming have a high degree of intuitive thinking, but not a high degree of discursive thinking. The method is not structured enough to increase the probability innovative product ideas.

The area of the portfolio with low probability of innovative ideas includes methods such as Searching and Mindmapping. These methods are not capable of creating innovative ideas. In the area with medium probability of innovative ideas methods such as Brainstorming, Method 6-3-5, Morphological Box and Construction

Catalogues are placed. These methods differ by the inclusion of intuitive and discursive thinking. For instance, Brainstorming and Method 6-3-5 have a high rate of individual free thinking, whereas the Morphological Box and Construction catalogues provide a high rate of structural ideas. The most promising methods are included in the area of high probability of innovative ideas. Methodologies such as TRIZ and Design Thinking include intuitive and discursive thinking by combining methodological procedure and a high rate of free thinking by participants. Because of these conclusions, it is logical to choose creativity methods with a high grade of intuitive and discursive thinking. In this context especially the Design Thinking approach delivers high quality and quantity of AM products in workshops with several companies. It is suitable to generate product ideas in the creative approach.

Excursion: Design Thinking

Design Thinking is an innovative approach to solve complex problems.

Design Thinking is suitable to create new ideas, but also to solve specific problems. Figure 3-3 visualizes the approach of Design Thinking. One important element is a multidisciplinary team. A Design Thinking team should include up to six people. Not only team members of technical disciplines like mechanical engineering are important. Employees of human resources, management and other disciplines and domains have other points of view on problems. For a holistic view on the creation of AM use cases all workshop members include several different perspectives. The second important element is the work space for the procedure. [PMW09]

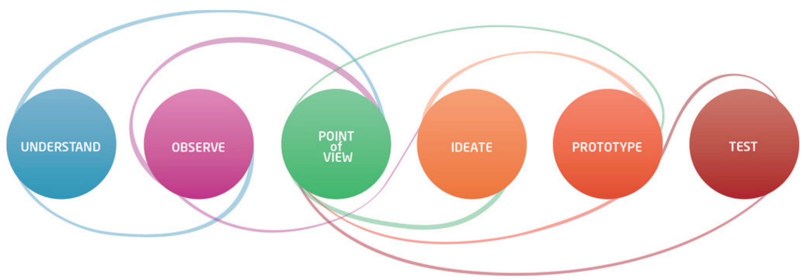


Figure 3-3: Design Thinking process according to [PMW09]

For generating innovative ideas, use cases, products and services, it is important to create a suitable atmosphere. There are alternatives such as moveable and flexible furniture or space for whiteboards. Another important point is the supply of prototyping material. The material can differ by different types and time of prototypes. An innovative way to produce complex prototypes is Additive Manufacturing. Another possibility is a paper based prototype in the first runs of the iterative process. By parallel working of Design Thinking groups the creativity can be increased. [PMW09]

The third element is an iterative micro process which is repeated by the team several times. The process consists of six steps. The step **Understand** describes the problem space. The **Observe** step has the task to analyze users and stakeholders. After that, in **Point of view** the team defines the point of view to solve the problem. Workshops at DMRC confirmed that especially interdisciplinary teams are necessary to identify all users and stakeholders. In the

Ideation several solutions and use cases are generated which are produced as prototypes in the following step. The produced solutions are validated and tested in the last step. The Design Thinking approach has proven to be very useful because the combination of generating ideas and creating prototypes of ideas guarantees fast results. The DMRC has determined that the usage of AM prototypes in workshops increases the imagination of participants which leads to higher creativity. New ideas can be discussed on AM prototypes to find new use cases, products and services.

Prototyping is one of the core aspects of Design Thinking. AM expands the possibilities of prototyping.

3.3 Deductive Approach

The deductive approach describes the other possibility to identify suitable products. The experiences of the DMRC show that companies have less problems with the procedure of this approach due to already existing information on products. It has to be mentioned that the usage of this approach requires a re-design of the chosen products which can be an immense effort.

For this case, the funnel of idea creation provides a suitable option to structure the deductive process [Gau06]. Figure 3-4 shows the AM specific adjustment of the funnel of idea creation. It is suitable for the deductive approach to find product ideas. In case of the creative approach, the first task is to analyze the product portfolio to collect a selection of possibly suitable products. The funnel of idea creation is an optimal process to reduce the wide range of possible product ideas (up to 1000 product ideas). The process includes seven steps from **Collection or Creation** to **Cost Analysis**. The **Collection or Creation** deals with generating product ideas. This can be handled in several ways, for example the creation of product ideas in workshops. The **Exclusion Criteria Analysis** includes first exclusion criteria. The use of AM is only possible with specific materials and coping with the limited build space. These Knock-Out criteria prove the product ideas in context of AM specific characteristics. But they have to be updated continuously because of the technological improvements of AM. The **Product Analysis** deals with AM, market and product specific criteria such as material, production, market and requirements to assess the product ideas. The assessed product ideas can be manufactured with AM technology and are ranked with these criteria to identify the products with the highest potential. These criteria depend on individual situations such as the specific AM process being interesting for the company. The **Re-Design** deals with the optimized product geometry for AM processes. The restrictions of AM design rules have to be integrated to exploit the full AM potential. This step is only necessary for the selection of already existing products of a company’s portfolio. New designed product ideas being collected with the creative approach do not have to change. They should possess an optimal AM geometry. The **Chances-Risks Analysis** includes methods to estimate the chances and risks. This is possible by a portfolio. **Specify** deals with the listing and documenting of the chosen product´s properties such as dimensions, measures or environment. The last step **Cost Analysis** includes relevant economic aspects. The final product ideas have to be proven in their economic feasibility. The assessment

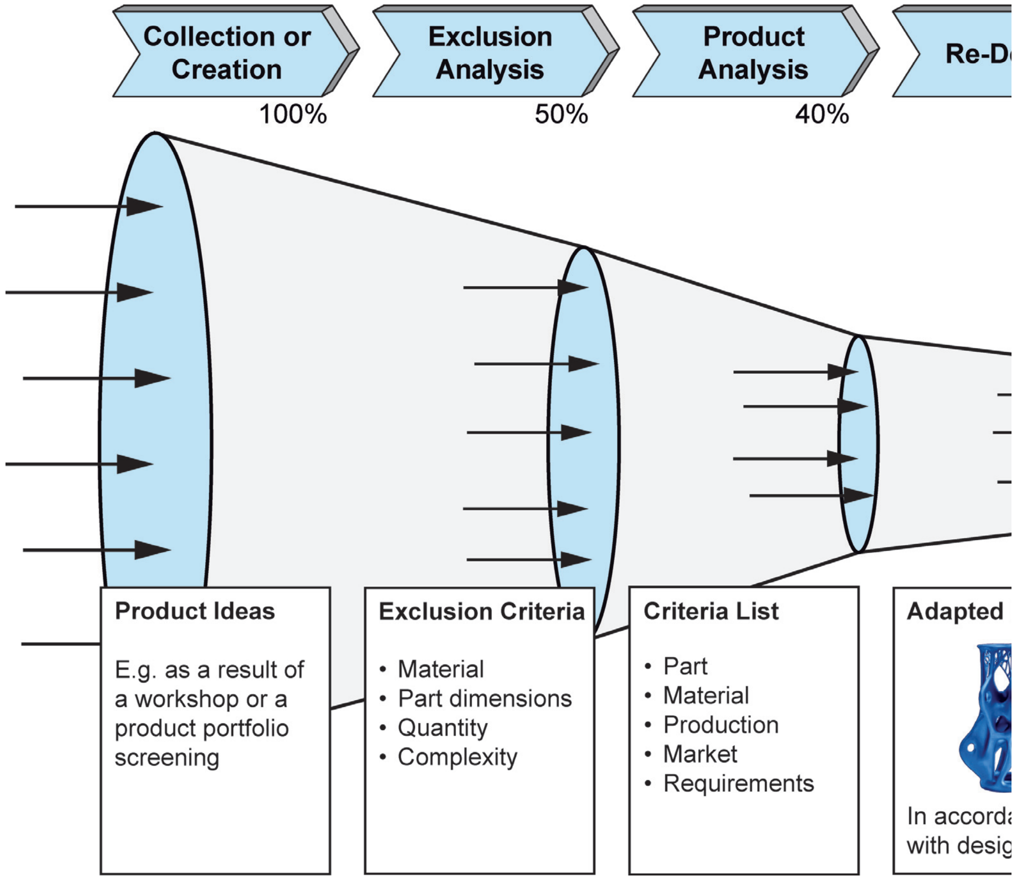


Figure 3-4: Specific AM funnel of idea creation (based on [Gau06])

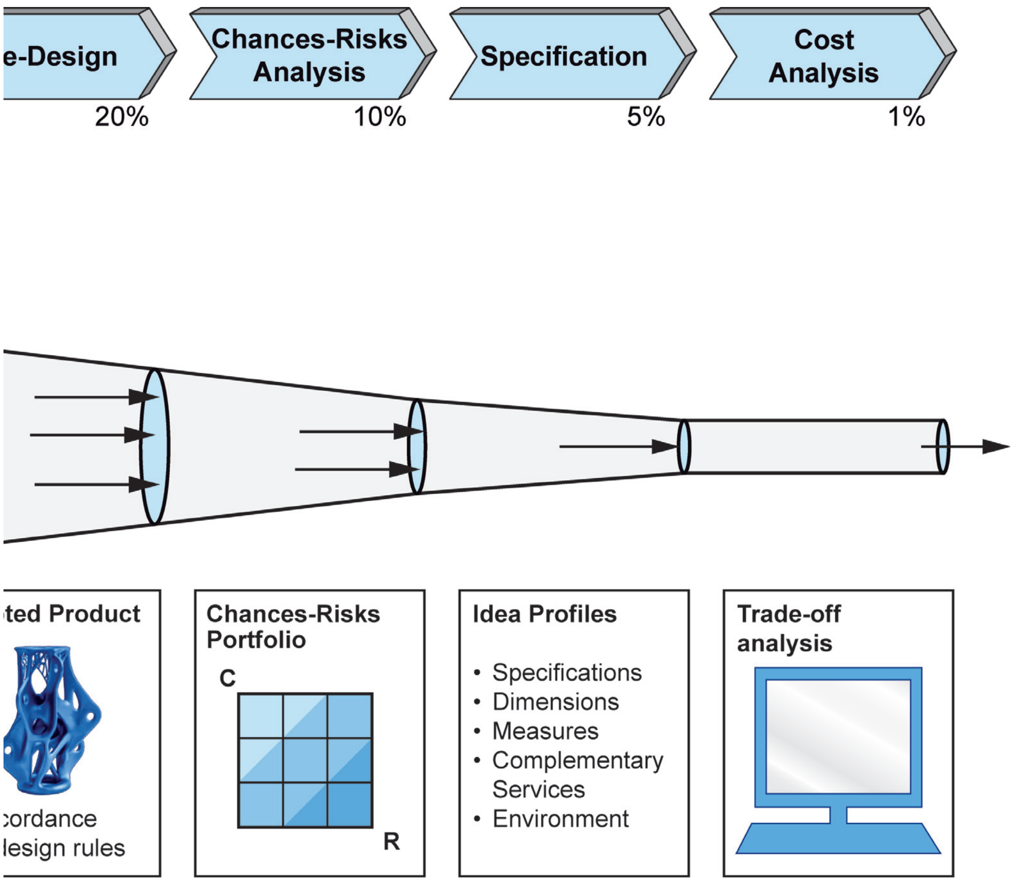
effort and the range of products are inverse to each other. During the reduction of possible product ideas the assessment effort increases [LRJDK15].

Lightweight design plays an important role for aircraft and aerospace industries.

To demonstrate the procedure with the funnel of idea creation, a specific example is chosen: Company A is an automotive, mechanical engineering and aircraft and aerospace supplier. Company A has over 5000 employees all over the world and a turnover of 2 Billion Euro a year. The portfolio of company A includes several product fields. Technology specialists are already concerned with AM technology. They have chosen the product portfolio mechanical connection technology which includes products such as bearing flanges, torque shafts and other components for . Company A wants to prove the potential of AM technology for this product portfolio. The previous investigations of AM technology were unstructured. They want to execute the deductive approach to find suitable Am products.

1) Collection and Creation

Key elements initializing the approach are enlisted in the **Collection or Creation** phase: A set of candidate product ideas and/or existing product designs. Product ideas can be generated by creativity workshops with an interdisciplinary team of the company and AM experts. Chapter 3.2 describes creativity methods being important for the creation of product ideas. Methodologies such as Design



Thinking and TRIZ especially are suitable for these tasks. The other possibility is scanning the chosen product portfolio. Employees have to make a pre- selection.

For the specific example of company A, the DMRC organized creativity workshops using Design Thinking to create product ideas with an interdisciplinary team of the company. In this case, the workshops took place in a creativity focused environment. As a key element for the study, a portable AM system was used to create prototypes for the generation of ideas. Manufactured prototypes increase the imagination and enable creativity processes. It helps interdisciplinary teams to improve already existing product ideas and create new ones. In addition to creativity workshops, employees have scanned the product portfolio of mechanical connection technology. Combining both ways, the company created and collected a wide range of product ideas. Five products were identified of the product portfolio mechanical connection technology: Torque shaft, joint shaft, bearing flange, linear ball bearing and shaft holder.

2) Exclusion Criteria Analysis

The candidate listing is based on various perspectives and an open approach. Thus **Exclusion Criteria Analysis** are applied to sort out those candidates that are not suitable (for instance, due to size restrictions, applicable materials or intellectual properties). The collection and creation phase ensures that several properties and pieces of information of already existing products are available for this analysis. To enhance efficiency and traceability, a decision making tool has been created. A short overview of the developed exclusion Criteria Tool is illustrated in figure 3-5.

As an example, applicable material can disqualify the possible product idea. Today only few materials are suitable for AM. Focusing the Selective Laser Melting process, Aluminium, Cobalt, Steel, Nickel and Titan alloys are possible material. In context of Fused Deposition Modeling and Laser Sintering processes, several polymers such as Polylactide and Polyamid are suitable. Products which consists of other materials such as glass are not manufacturable with AM technology. Another criterion is the dimension of the product ideas. The build space of AM systems is limited. One example is the part dimension which is limited to the build space of Additive Manufacturing machines. Machines such as SLM500HL with a build space of 500 x 280 x 365 mm³ or EOSINT P 800 with 700 x 380 x 560 mm³ constitute a limitation for the creation of parts. But this build space limitation is an actual hurdle which will be overcome by future machine generations. Products exceeding the dimensions of the build space are not manufacturable by AM. Another criterion is the cross-sectional area of material accumulation which should not be greater than 20 x 20 mm with a low wall thickness. All three criteria are exclusion criteria which are clearly implied by the state of the art of the technology. Product quantity is another criterion which is based either economic assessments or assumptions regarding the ability to draw conclusions from a pilot study. Products being manufactured 1000 times a year are hardly suitable for AM. Higher lot sizes should be manufactured with conventional processes such as lathing and milling.

Back to the example of company A, the five identified product ideas are investigated with the exclusion criteria illustrated in figure 3-5. The assessment by exclusion criteria identifies that the product’s torque shaft and shaft holder are unsuitable for AM. Both products can be manufactured in a more efficient way with conventional manufacturing technologies. The torque shaft does not possess a high geometry complexity. The product can be manufactured with a lathing process. The shaft holder is a similar example. The geometry is not complex enough and can be manufactured simply by milling processes. A second criterion which leads to the rejection of the torque shaft is the dimension of the product which exceeds the dimensions of the available AM machine. Only changing product geometry or purchasing a new machine could change the assessment. But these changings lead to high costs. The second exclusion criterion for the shaft holder is the product quantity. The product is manufactured more than 1000 times a year. After the assessment with the exclusion criteria the company determined that only the joint shaft, bearing flange and linear ball bearing are suitable to be manufactured with AM.

			Materials					Dimension	
		Component can be produced with conv. technologies?	Tool steel	Stainless steel	Aluminium	Polymers	Other materials	Smaller than 250mm x 280mm	Bigger than 250mm x 280mm
Nr.	**Part/Product**								
1	Torque Shaft	X		X					X
2	Joint Shaft		X					X	
3	Bearing Flange		X					X	
4	Linear Ball Bearings			X		X		X	
5	Shaft Holder	X	X					X	

Figure 3-5: Exclusion-Criteria Tool for AM product finding

3) Product Analysis

After the efficient reduction of the candidate list, the **Product Analysis** helps to identify product ideas with lower suitability. The evaluation criteria in this stage of the funnel of idea creation differ from the exclusion criteria. The evaluation criteria depend on the situation of the company. Product ideas are investigated using a criteria list which concretizes the properties of product ideas. Several specific questions such as: “Does the product possess undercuts, cavities, etc.?” or “Is the product geometry simply designed because of the given manufacturing conditions?” help to assess the suitability of the product ideas. Also, material and manufacturing specific properties influence the selection process. One example is the possibility, dependent on product geometry, to manufacture more than one product at the same time in the build space of the AM machine. The usage of conventional manufacturing processes is also regarded: for example, the current buy-to-fly ratio in context of milling and lathing processes and the number of tools which are necessary for conventional manufacturing processes. Additional criteria are material properties and required or collected load cases.

DMRC experts help to assess parts of an existing product portfolio.

The assessment of the criteria has to be carried out by AM experts and experts for the product portfolio together for a realistic result. The assessment can be realized by a numerical system. The criteria are weighted with values from 1 to 5 (i.e., from low to exact fulfillment of the criterion). The results for product properties, material and manufacturing criteria are summed up separately and integrated in the portfolio of figure 3-6. In case of company A in figure 3-5 and 3-6, the bearing flange has the best suitability for AM. The results of the material and product properties are illustrated on the axes of the portfolio. The assessment of the manufacturing criteria are described by the diameter of the product bubbles. The portfolio shows that the bearing flange fulfills the most criteria with high values. The joint shaft and linear ball bearing are also suitable for AM processes but are less suitable. This indicates that the bearing flange is the most suitable product and is predestined to be manufactured with AM. It is chosen for the next stage of the funnel of idea creation.

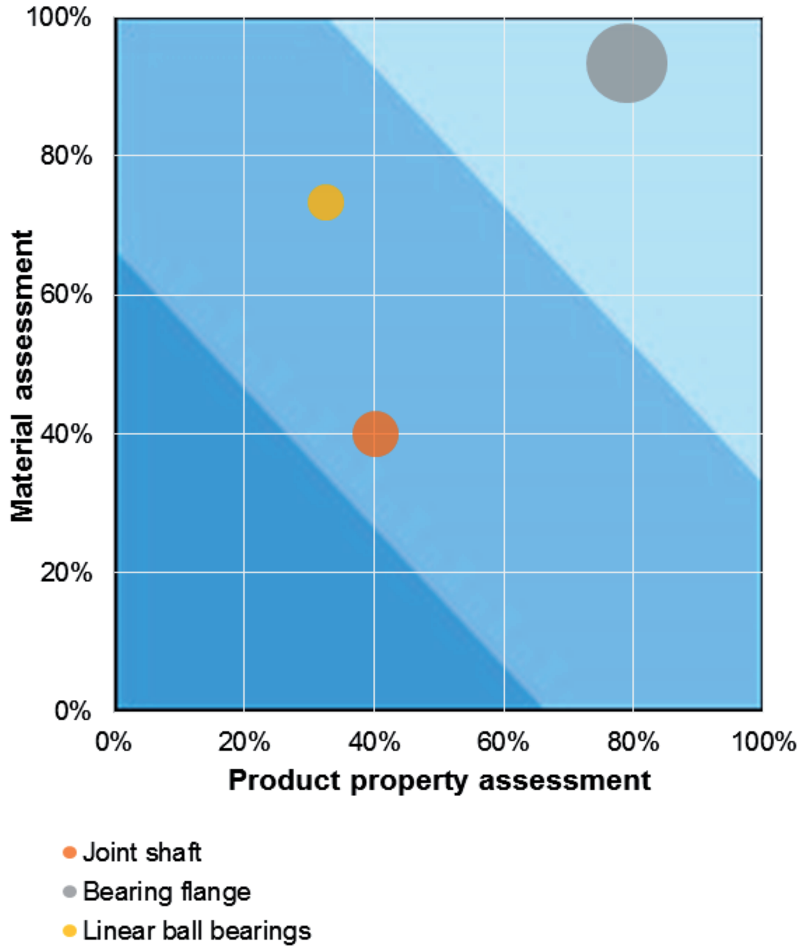


Figure 3-6: Assessment portfolio of possible product ideas

4) Re-Design

The next stage is to adapt the product ideas and to create a **Re-design**. A reasonable pilot study is defined by using key capabilities of AM such as lightweight design or complex (bionic) structures and being manufacturable with AM. Both characteristics imply that the original design of selected products or product ideas has to be adapted. The DMRC has investigated specific AM design rules which are summarized in the Design Rules Catalogue [Ada15]. It aims at a successful manufacturing process without failure and accounts for the differences of several AM processes such as Selective Laser Melting, Selective Laser Sintering and Fused Deposition Modeling. In combination with the topology optimization process a new suitable AM design which uses AM key capabilities can be created [ReKo15].

Topology optimization is one possibility to create an optimized product design. Usually the resulting designs are lightweight and include key capabilities of AM such as functional integration (cooling canals) or individualization. The first step for topology optimization is the identification of defined build space. After that, the model is transformed in a FE-model with meshes and specific loads which have influences on the investigated part. A defined design variable which controls the density distribution for every finite element is an important element of the model. A parallel task is the definition of part regions such as interfaces or contact surfaces untouched by topology optimization. In the last step, the optimization goal and possible constraints are being determined. Topology optimization is followed by smoothing and removing details (see figure 3-7). The next step is the intersection with design space and combination of non-Design. Finally a structural check is necessary to investigate the needed properties of the part. If failures occur, the model has to be adjusted.

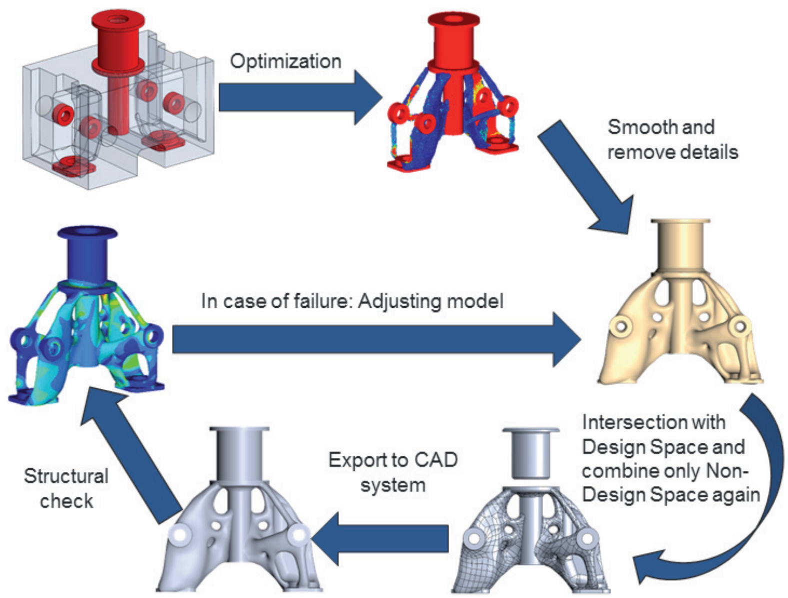


Figure 3-7: Topology optimization process

Topology optimization leads to a high reduction of material. The re-designed bearing flange possesses a force optimized structure and fulfills AM design rules. The investigation with FE simulations proves the fulfillment of necessary properties by the re-design. The re-designed product is validated based on the same load cases as the initial product being manufactured with conventional manufacturing processes.

The usage of topology optimization leads to an ideal lightweight design of parts.

To document the results of the previous product selection and the re-design, product profiles are used (figure 3-8). For a characterization of the product ideas the DMRC uses a workshop tool to structure the information of product ideas. The paper-based product profile document includes necessary information to analyze the product idea in context of criteria being important for AM usage. Another possibility to use the product profile is the documentation of product ideas created in workshops to collect already existing information. The uniform structure of the document allows a comparison and evaluation of product ideas. The product profile includes general information such as name of idea and idea number. A detailed description and current technical solution is important for a correct characterization of product ideas. The most important categories are advantages & benefits and disadvantages & risks. In these categories key capabilities and specific product information are combined. Disadvantages and risks can be used to inform the

Key capabilities of AM were identified in 2: Identifying potentials for Additive Manufacturing.

product finding process. The contemplation of both categories provides a possibility to assess the suitability of AM product ideas in a much more detailed way. For example, bearing flanges or joint shafts can be identified by employees in a workshop as possible product ideas (figure 3-8). In this case, advantages and benefits are lightweight potentials and material reductions. The AM product is only profitable in low unit numbers which is a disadvantage.

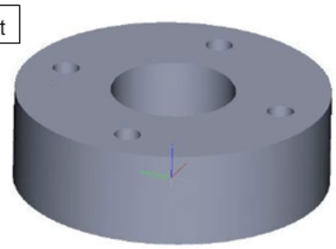
Idea No.	Name of the Idea
1	**Bearing flange**

Description

The bearing flange is used as a connection component. It is linked with shafts. In the case of our company it is integrated in a swashplate of a helicopter. Because of this integration the bearing flange has to fulfill specific requirements such as the functional translation of linear motion to rotation motion. The whole swashplate is a safety relevant product. The bearing flange has to be durable to guarantee the safety of the whole product.

Draft

Conventional part



Advantages & Benefits

- Lightweight potential
- Material reduction
- Cost reduction by lightweight design
- Implementation of AM as a possible manufacturing technology

Disadvantages & Risks

- Only in low lot sizes profitable
- Safety relevant component

Current Technical Solution

The part is actual produced with several steps of conventional manufacturing processes. With a topology optimization a high reduction of material will be generated. This is a high advantage in the area of aerospace industries.

Type of Idea

☐ Product update ☒ Adaption ☐ Innovation

Figure 3-8: Product idea profile for the topology optimized flange

The description documents are used in workshops by different employees of several departments. This gives the possibility to create product ideas of different viewpoints. Another benefit is the assessment which can be created by an interdisciplinary team.

For company A, the bearing flange is described with the product profile document. The product is a component which is used in the aircraft and aerospace industries. One special application of the bearing flange is the integration in a swashplate of a helicopter. Companies of aircraft and aerospace industries have specific requirements. It is a safety relevant product. The central function of the bearing flange is the translation of linear motion to rotation motion. To fulfill this function the product has to absorb high forces continually. Additionally in aircraft and aerospace industries waste reduction and lightweight design play an important role. It is also documented that the bearing flanges is only profitable for AM with a re-designed geometry and low lot sizes.

5) Chances-Risks Analysis

After the re-design the market chances and risks have to be identified for the product in the **Chances-Risk Analysis**. One possibility to analyze these aspects is the Chances-Risks-Portfolio [Gau1]. Chances and risks are depended on specific application scenarios and the specific environment of a company such as branch of industry or the share of market. The chances and risks can be assessed by influences of the company and probability of occurrence being illustrated by x- and y- axis of the portfolio. This step of the funnel of idea creation does not need adaptions of existing methodologies to fulfill the task for Am products.

6) Specify

The second last stage of the funnel of idea creation is the stage **Specify** including a detailed description of the part. No matter which approach (creative or deductive) a detailed description of the chosen part is necessary. The DMRC uses a document which is an extension of the already presented product profile document (figure 3-9). By several categories such as market performance, requirements and competition different viewpoints on the product ideas can be verified. For these detailed investigations of product ideas an advanced document is used (figure 3-9). The elaboration of an interdisciplinary team helps to create a holistic illustration of the product idea. Aspects such as product design, key features or product variants can be determined by engineers. But the integration of the middle management or designer gives the option to include hidden arguments.

Different perspectives are important to choose the most suitable parts.

In the context of company A, a detailed product profile document for the bearing flange was used. It concretizes the already existing description of the short product profile document which is used after re-designing the bearing flange. The detailed product profile document includes several aspects such as market performance, requirements, competition, research approaches, abilities of AM technologies, assessment of the product, reference to other products and a conclusion.

With regard to the bearing flange, the part is integrated in a swashplate in a helicopter. It is a safety- relevant component which needs a high durability and a low weight. Lightweight design is a very important topic for aircraft and aerospace industries because a reduction of the weight leads to fuel savings. Lightweight design and waste reduction are requirements which do not have to be fulfilled only by the bearing flange, but also from the whole end product swashplate. There are several requirements which have to be fulfilled by the product. The first point is the elementary function to translate linear motion in a rotation motion. The main requirement of the bearing flange itself is the mount for the swashplate. In this case, the bearing flange has to guarantee fatigue strength larger than the average of 30 years. To regard the competition it has to be documented how the part is actually manufactured with conventional processes. In the company example, the bearing flange is produced in several manufacturing steps. The bearing flange is manufactured with a heat bending process followed by welding, milling and lathing processes. Finally the part is heat treated. A description of the actual manufacturing process shows many subsequent steps are necessary to create the part. The integration of the comparison between actual and AM specific production costs in combination with added values of AM processes helps to make a decision for the suitability of AM usage.

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No.	1	Name of the idea	Bearing Flange

Market Performance	
Brief description • Position in the value chain • Unique selling points	The bearing flange is a part of the swashplate integrated in a helicopter. The bearing flange is a safety- relevant part which connects elements of the swashplate. The bearing flange provides a high durability by a low weight.
Product concept, draft • Product design • Key features • Possible variants • Substantial performance data (specification)	The design of the bearing flange is lightweight suitable. The geometry of the part meets the Additive Manufacturing design rules. Additionally the bearing flange is processed with topology optimization and possess a bionic structure which guarantees the lightweight design. Key features are the implemented key capabilities of AM such as waste reduction, lightweight design and high fatigue strength.
Unique selling points • Value add • Value proposition	High safety relevant part, Lightweight design, high durability
Requirements	
Requirements on the product	Mount of the swashplate, translation of input to motion, lightweight design
Requirements on the material	Guarantee of a fatigue strength larger than the average of 30 years
Competition	
Conventional manufacturing technologies • What manufacturing technologies are used so far? • Can the prod...	The actual manufacturing process consists of different manufacturing processes. To form the bearing flange a head bending process is used followed by welding and a mechanical processes such as milling and turning. Finally the parts have to be heat treated.

Figure 3-9: Detailed product profile document

In case of company A, the production costs of AM and conventional processes are assessed to be "similar". But the added values such as lightweight design and better buy-to-fly ratio are strong arguments in favor of AM. For an investigation of the technical feasibility, future requirements and the actual ability of AM technologies have to be considered. The company producing the bearing flanges has to add the fatigue strength for more than 30 years as a future requirement. To fulfill it, materials have to be identified and investigated which possess suitable requirements and are able to be manufactured by AM technologies.

Finally a decision has to be made for the product idea. There are several possibilities such as give up, put back, pursue and realize. In the company example it is decided that the product idea should be pursued. One possibility to pursue the product idea is a concretization by modeling product structure, requirements and activities to ensure that products´ requirements are fulfilled.

Especially in the context of requirements various important differing aspects are identified by employees of the products´ value chain. As a result of detailed product profile document the product architecture has to be modeled. One possibility to model complex structures of products is the usage of the modeling language SysML [Wei14]. There are several partial models in SysML. A requirements diagram determines a connection between elements of the product structure and their requirements. Figure 3-10 illustrates a requirements diagram of a swashplate including the chosen product idea.

SysML is a modeling language based on UML.

As described by the product profile document the swashplate is an important control element of a helicopter. It transfers a linear motion into rotation. It is used on the one hand to control the angle of all the main rotor blades and thus of the lift, and on the other hand, the cyclic pitch to control the lateral and longitudinal movement. General requirements of the swashplate are for example strong resistance of cyclic loadings, Fly-By-Wire approval, fatigue strength and a product life cycle of 30 years. One component of this part is a bearing flange which has been re-designed for AM. In the requirements diagram the requirements of the bearing flange are structured and connected with other components (Blue boxes) such as the flange connection. Waste reduction or lightweight are for example requirements which are valid for several elements of a product. Because of that it can be connected with several elements of a product. The aim of a requirements diagram is the reduction of complexity by a structural illustration. Figure 3-9 shows that AM is the generic term for AM specific requirements. All key capabilities of AM such as waste reduction, lightweight design or individualization are connected to the generic term AM which is connected with part elements being necessary to fulfill the AM specific requirements. The implementation of SysML modeling makes sense for complex products with a high amount or safety-relevant components.

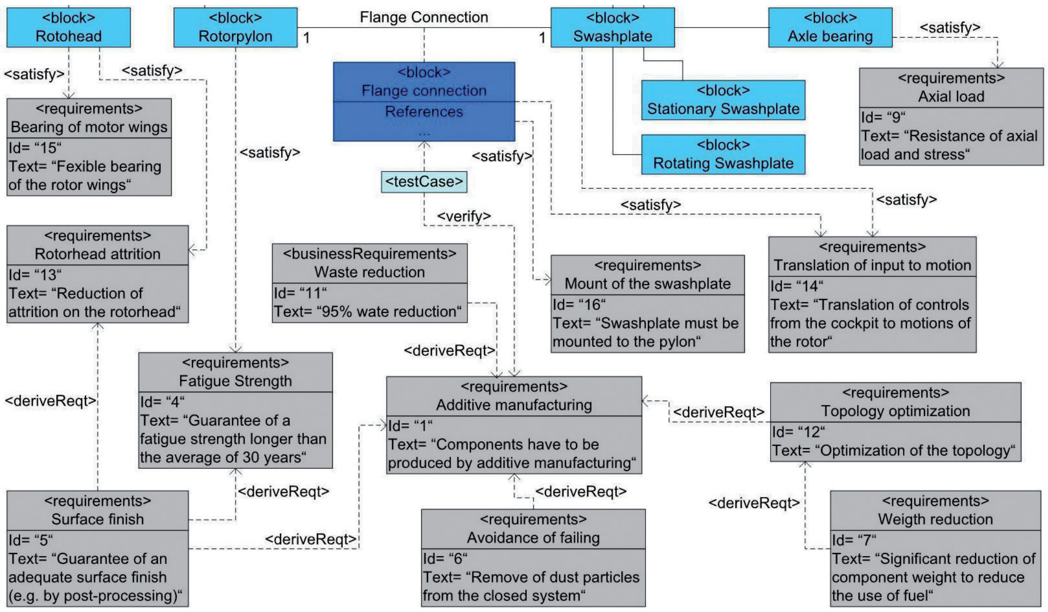

Figure 3-10: Section of a requirements diagram of a helicopter component swashplate

7) Cost Analysis

To investigate the final cost structure of the product, another established DMRC tool is used. Basically it is a multi-criteria decision support tool which is called "Trade-off Methodology Matrix" (TOM) [LJRK14]. It supports rating the suitability with regards to product/process/economic, environmental and social criteria. The TOM consists of a classification based on a traditional design and a comparison between the conventional and a possible AM design-(idea). For instance, the part definition contains basic information like a brief description of the function, typical production quantities, production costs, dimensions and mass of the part, as well as the currently used material. Once this data is entered, the user gets a first quote over the rough production costs. For an easy-to-use tool in this early phase the production costs are calculated based on certain assumptions like appreciation times and a specific demand. Detailed costs can be assessed later in the methodology. The TOM consists of different segments and sub categories which target different users. For instance, the part owner/design engineer needs to be aware of the original part characteristics while other section might be filled by AM experts.

Through a change of ratings or through an adaption of sub categories the matrix may be adapted to several applications. Taking 'possible weight savings' as one example criterion, one can see that this aspect is more important for the aerospace industry or race car applications than for medical components.

After evaluation of the part design, the comparison between the conventional and the possible AM design parts for the re-design / AM application are chosen in a final trade off. This requires very detailed information on the part and includes a detailed cost analysis to finally decide if a part should be manufactured additively or not.

3.4 Case study: Krause DiMaTec

To illustrate the proceeding in Product Discovery, one example of a validation workshop series is presented in the following.

Krause DiMaTec is a Service Provider and competent partner for Additive Manufacturing in mechanical engineering and related industries. The company supports their costumers along the entire product development and manufacturing process. Starting with technology selection, construction design and optimization for mechanical stress and weight and ending with the production of small series. The company is part of the HorstmannGroup, a family-run company group with wide diversification and a focus on mechanical engineering. Because of this, Krause DiMaTec knows the requirements and desires of the branch. Part discovery has been conducted in collaboration with Krause DiMaTec and the DMRC to find product ideas for Krause-Biagosch, an affiliated company within the HorstmannGroup. Krause-Biagosch develops and produces innovative computer-to-plate systems (CTP) for the graphical industry.

At first, a preselection of parts from an existing portfolio (drawn from the company's ERP system) has been conducted via ABC analysis. Furthermore, first exclusion criteria could be applied easily such as the exclusion of parts with a simple geometry or a low product price. We have for instance found that tubes and shafts are not suitable because the product complexity is not high enough. They can be produced with conventional manufacturing technologies for lower costs.

The selected parts were reduced with further exclusion criteria (materials, dimensions, lot size, etc.). Some of the exclusion criteria used in this process will be discussed in the following. The material type of products is a factor which influences the feasibility for AM. Product ideas which need other materials such as wood or glass are not suitable for AM. The dimension of a part is also an exclusion criterion because the build space of AM machines is limited (about 5000 mm x 3000 mm x 3000 mm). Lot size is another criterion which separates AM suitable products. Small lot sizes (about 1000 pieces per year) are typically suitable for the usage of AM technologies. An increasing of lot sizes leads to a change of efficiency which favors the choice of conventional technologies such as milling, lathing or injection molding.

After the reduction, the selected parts were assessed further and documented by brief characteristics in an Excel file. Overall, the assessment was conducted in the three dimensions material-fit, part-fit and manufacturing-fit. Each dimension is specified by about ten evaluation criteria, some of which will be discussed in the following. For instance, the material range of AM is quite limited at the moment. Already available materials for AM (AlSi10Mg, Ti64, etc.) have to be investigated for the fulfillment of the specific part requirements.The manufacturing-fit for example also encompasses whether excessive machining efforts are associated with the conventional design. Overall, the DMRC´s and DiMaTec's analysis showed that several product ideas can be manufactured by conventional manufacturing methods such as injection molding in a more profitable way, for example a feedback lever because of its low design complexity.

The resulting number of suitable product ideas is low enough to develop re-designs. The best assessed product idea (vacuum shoe) was re-designed without a topology optimization. The high design skills of the design department of Krause DiMaTec rendered computer aided re-design steps unnecessary.

In the following the re-design process is going to be outlined using the example of the vacuum shoe. The vacuum shoe has initially been manufactured by milling and sheet metal bending. The basis of the product consisted of 14 parts which had to be assembled. The product had air-channels to create a vacuum by a Laval nozzle to pull release papers. The vacuum shoe itself does not bear heavy loads.

Are-design of the vacuum shoe is necessary to guarantee producibility of the part on the one hand, but on the other hand usually provides for the opportunity to make use of the specific advantages of AM (reduce weight, etc.). In this case, the most important potential that could be put to use is the reduction of the assembly time as a result of functional integration.

Figure 3-11 shows the previous design and the re-designed vacuum shoe. These illustrations help to understand the importance of a new design for AM specific products. It is visually recognizable that the re-designed vacuum shoe has a completely different geometry. Starting from the air channels the vacuum shoe was optimized. The most important advantage is the reduction of assembly steps, the re-designed vacuum shoe consists only of one basis part. Another result of the re-design is a volume reduction of more than 50% and a weight reduction of 70%. The changed geometry leads to a cost reduction by exploiting lightweight design made possible by AM. The availability has also changed for Krause DiMaTec. The initial product was produced by a supplier and had a delivery time of up to three weeks. By the AM know-how of Krause DiMaTec the re-designed product can be manufactured internally in few days.

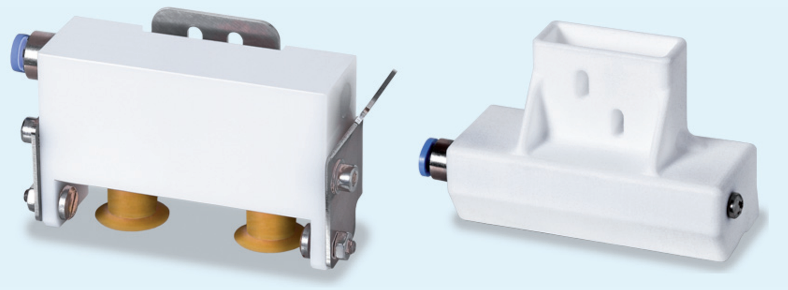

Figure 3-11: Previous design (left) and AM specific design (right) of the vacuum shoe

The last step was a final cost analysis with the re-designed product. Therefore, the determination of unit costs is one possibility. To get a realistic result specific constraints have to be regarded. For example it is important to use the complete build space of an AM system to produce the maximal number of products. Because of the low lot sizes for AM specific products, it is rational to manufacture different products in the build space. The consideration of the lot sizes alone is not adequate to gather the holistic economic point of view. Therefore a comparison of initial and re-designed product with aspects such as availability and product weight is created. The AM vacuum shoe has a lower weight and is quickly available through in-house production. These aspects lead to a massive cost reduction by 60 percent. The important information of the re-designed AM part are documented with data sheets (figure 3-12).

Idea No.	Name of the product idea
1	**Laser-sintered vacuum shoe**

Description

Vacuum shoes are parts of CTP systems and are being utilized to remove large release papers which are typically applied to separate printing plates from each other during transport. An integrated Venturi nozzle and suction cups generate a negative pressure which allows for holding the release papers and moving them to the desired position. The idea is redesigning the vacuum shoe such that it can be produced as a single SLS part. A weight reduction down to 100g is realized. The part will be produced and delivered by DiMaTec, alleviating dependence on third-party suppliers.

Draft

Advantages & Benefits

- Reduction of costs
- Shortening the supply chain and reducing its complexity
- Less dependence on third-party suppliers
- Reduction of part complexity
- Increase of performance

Disadvantages & Risks

- Technological risk
- We cannot identy disadvantages of this solution from a technical and econimic point of view

Current Technical Solution

The functions of the sheet metal part and the suction cup recordings are realized via separate parts. The therewith associated drill pattern is very complex. Ten parts are needed to create the whole part.

Type of Idea

☐ Product update ☒ Adaption ☐ Innovation

Figure 3-12: Product ideas description of Krause DiMaTec

The example of Krause DiMaTec successfully shows the strength of a structural product finding approach. In this context, Krause DiMaTec has elaborated the AM potential for Krause-Biagosch in cooperation with the DMRC. The procedure based on the funnel of idea creation is used by Krause DiMaTec. Tools such as the product ideas profile and the decision making tool have been used to support the process.

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4

Business Planning for Additive Manufacturing

The following chapter is going to devise methodological excerpts for the development of business models in the context of Additive Manufacturing. The chapter is structured according to the phases of business model development (see figure 4-1). Chapter 4-1 deals with **Value Proposition Design**: the specification of a customer segment and its specific value proposition. Chapter 4-2 covers enriching a Value Proposition to a full-grown **business model**, using tools such as business model patterns or business model variables and options. Chapter 4-3 describes the **evaluation of business models**. The implementation phase will not be subject of the present study. Instead of outlining the implementation phase of business models, chapter 4-4 is going to conclude with a brief assessment of the gathered experiences in the project. Chapter 4-5 contains a brief example from a **validation project** with one of the DMRC's partners.

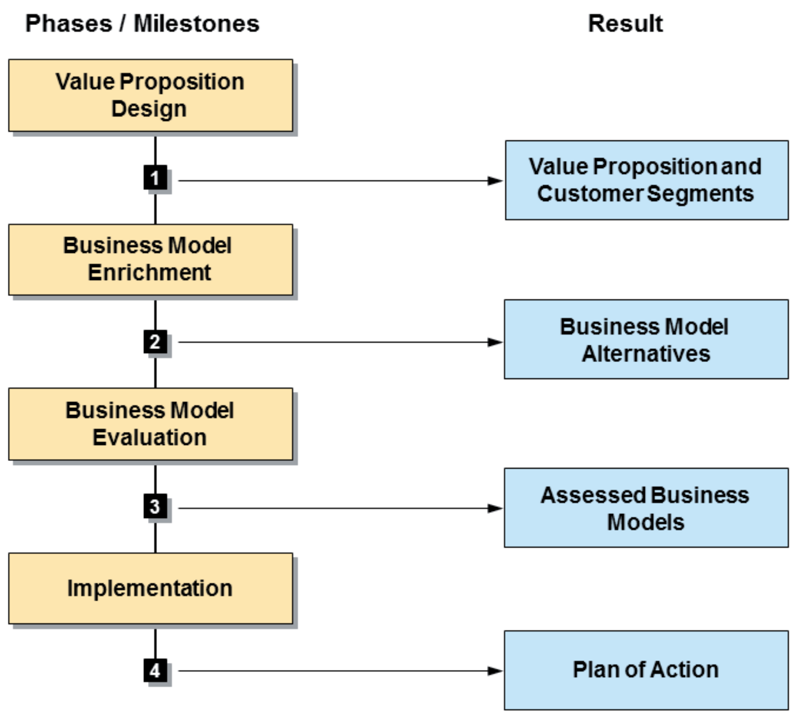


Figure 4-1: Generic Business Model Development Process (according to [Kös14])

4.1 Value Proposition Design

Example for the illustration of business model development.

In the study at hand, the process of business model development is going to be explained on the basis of a fictional example, a slightly altered result from one of the validation workshops will be devised in chapter 4-4. The example is the market entry as an intermediary between customers and AM Service Providers in the AM industry. The following role constellation in the value network illustrates the business idea (see figure 4-2):

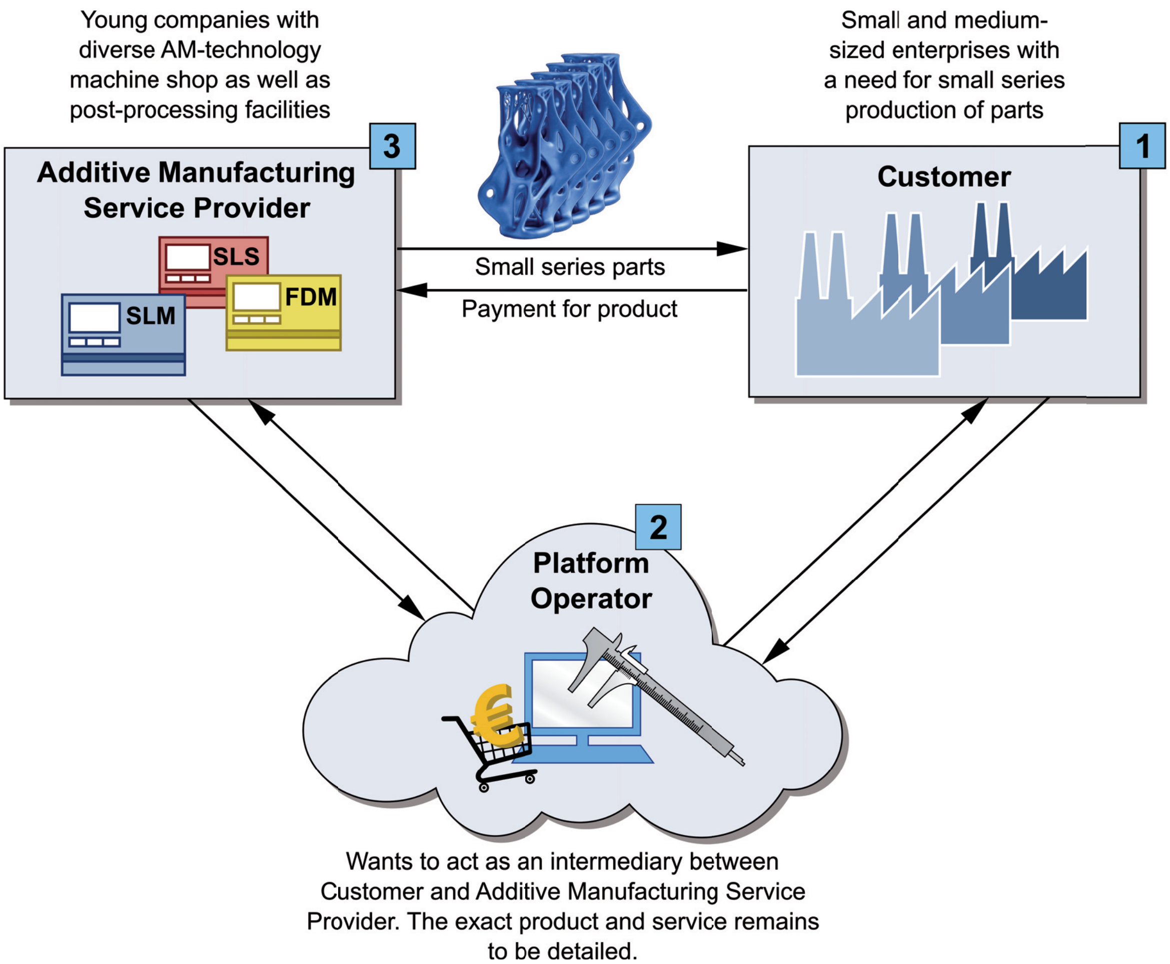


Figure 4-2: Customer intermediary for Additive Manufacturing Service Providers

1) **Customer:** The role customer describes companies and individuals purchasing products made by Additive Manufacturing. Especially addressing various small niche markets is made very easy by the technology due to the abolition of tooling costs. This concept has been popularized by the term “long tail” [And08]. Hence, the role customer can be occupied by various types of actors.

2) **Platform Operator:** The platform operator wants to act as an intermediary between customers and Additive Manufacturing Service Providers.

3) **Additive Manufacturing Service Provider:** Service providers are usually small and medium sized enterprises with a diverse machine park. On the basis of manufacturing inquiry, they offer individual quotations for each customer and deliver (small series) parts in exchange for a payment [Woh16]. They use the services of platform operators to establish or strengthen sales channels.

In the present study, the development of a sustainable business model for the role platform operator is used as an exemplary application to demonstrate the methodology. For the development of the value proposition (the core of the business model), the process draws on the value proposition canvas [OP10].

Business model development for a platform operator.

Due to the tighter interaction between stakeholders in modern business ecosystems, it is necessary to obtain a sound overview of the **relevant stakeholders** for the respective business model. Therefore, stakeholder radar is a suitable tool [Sly96]. In the present case, the two main stakeholder groups for the platform operator have already been presented: customer and Additive Manufacturing Service Provider. For simplification purposes, an additional stakeholder analysis is not going to be outlined. If the group of potentially relevant stakeholders is too large, they can be prioritized using the **Influence-Goal-Grid** [Leh14].

Stakeholder analysis.

In order to refine and check the business idea, a value proposition canvas according to Osterwalder et al. can be used [OPB+15]. The value proposition canvas addresses three elements of a business model: **Customer Segment**, **Value Proposition** and **Products and Services**. When working with the value proposition canvas it is important a) to indicate which information holds true for which stakeholder and b) to include participants from the respective stakeholder groups in the workshop. The following six step procedur e has proven to be successful for value proposition design, albeit iterations must not be allowed for (see the numbers in figure 4-3 and 4-4 for reference).

Six step procedure of value proposition design.

1) **Framing customer jobs:** Customer jobs are noted and prioritized from the perspective of the respective stakeholder. Functional, social, personal and emotional actions can be addressed. A customer job simply describes, what the respective stakeholder does or intends to do (without an evaluation). In the present example, the customer wants to quickly create parts in very small lot sizes. The Service Provider however wants to scale up his business, i.e. realize a high occupancy rate of his machines or even buy new machines. Additionally, the business relationships between Service Providers and customers are not yet well established for there are many branches entering the AM business currently (see chapter 1).

2) **Deriving pains:** Pains are nuisances which keep the customer from the successful completion of his customer actions. In the example at hand, the customer cannot quickly engage in a relationship with a Service Provider because he is possibly

afraid of sharing valuable product information online. The Service Provider cannot create quotes efficiently, because he is not acquainted with e-commerce solutions. Therefore his staff has to deal with every inquiry individually.

3) **Developing gains:** Gains are advantages or benefits each stakeholder hopes for. Gains can be structured in various ways (see e.g. [OPB+15] for further reference). In the example at hand, the Service Provider wishes for a simple interaction between the customer and him which allows the customer to specify his desired product. On the basis of this specification, the Service Provider could then deliver a quotation.

4) **Deriving pain relievers:** Pain relievers describe how pains (result of step 2) can be overcome. A certain pain reliever for the Service Provider would be an automated design checker functionality, such that designs which are not suitable for Additive Manufacturing are automatically fed back to the customer with the request to redesign them.

5) **Deriving gain creators:** Gain creators describe how gains (result of step 3) can be realized. A Gain Creator for the Service Provider would be an automatized meshing engine such that the design-input by the customer is directly enhanced towards printable data.

6) **Finalizing products & services:** This element comprises the concise products and services which should be addressed by the business model. Typically, ideas for products and services are derived during steps 1 – 5. The core product and service idea in the example at hand is the provision of an Additive Manufacturing online shopping (e-commerce) solution for AM Service Providers. Core element of this e-commerce solution is a drawing engine which allows customers to provide input about their part with respect to geometry, material and tolerances. A design checker engine checks whether the product can be printed and realizes quick quotations.

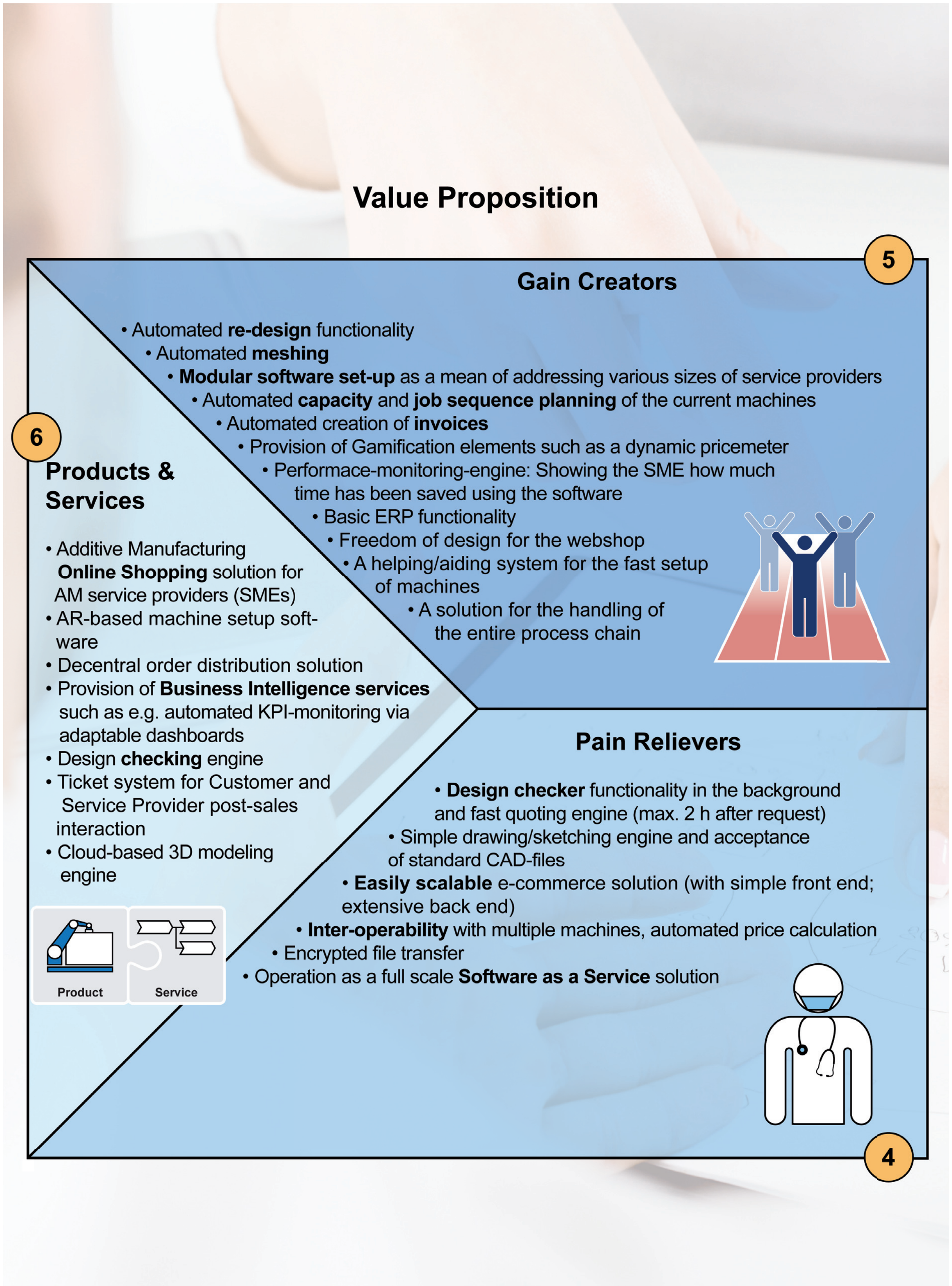


Figure 4-3: Value Proposition Canvas as a first step towards an AM Business Model (1/2)

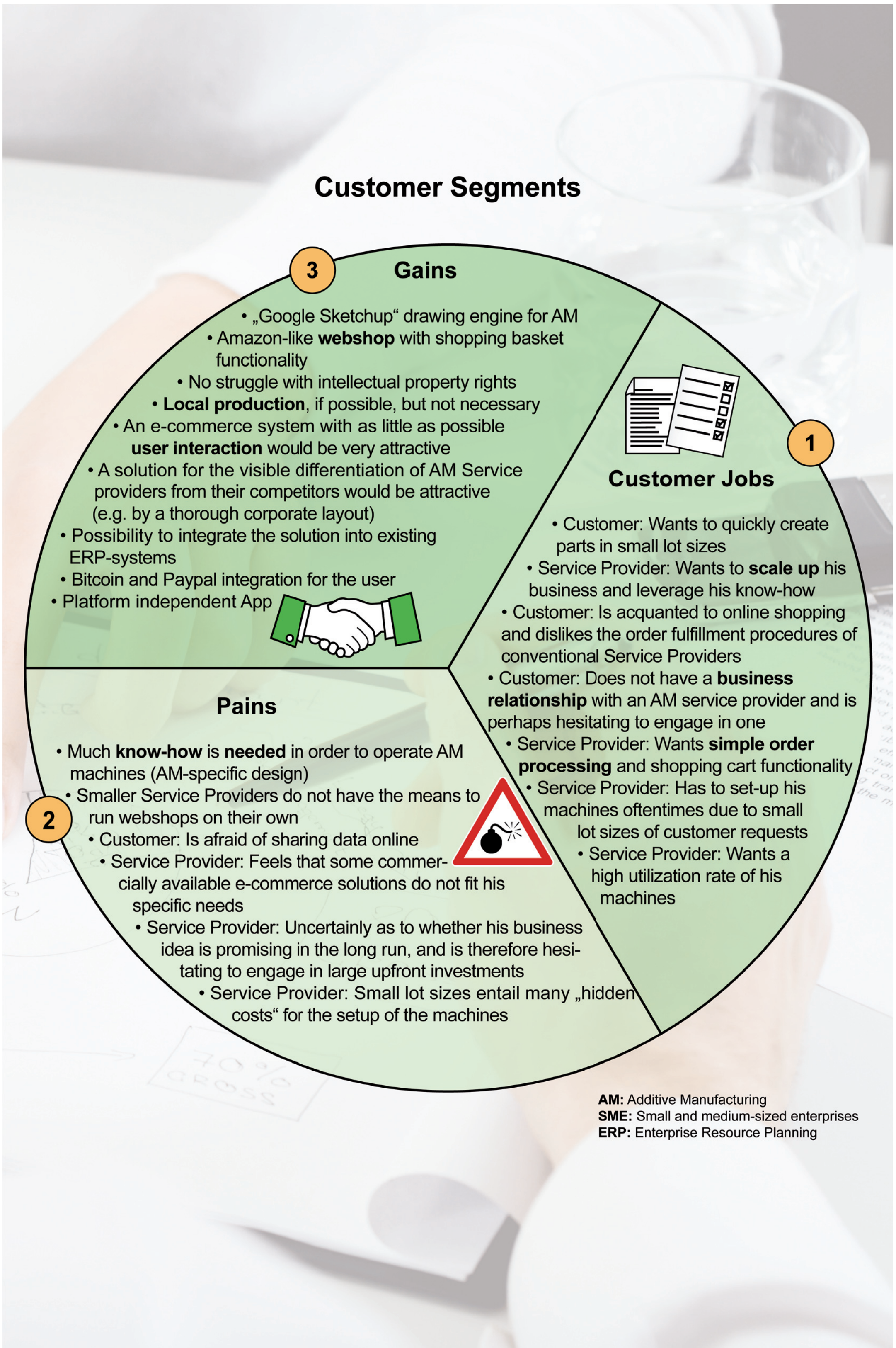


Figure 4-4: Value Proposition Canvas as a first step towards an AM Business Model (2/2)

4.2 Business Model Enrichment

The core idea of Business Model Enrichment is developing business model alternatives which can each be modeled by a business model canvas [OP10]. The literature provides numerous types of business model canvases [OP10], [Kös14]. In the context of the DynAMiCS, the business model canvas according to Köster has been further developed (see figure 4-5).

Further development of known business model canvas frameworks.

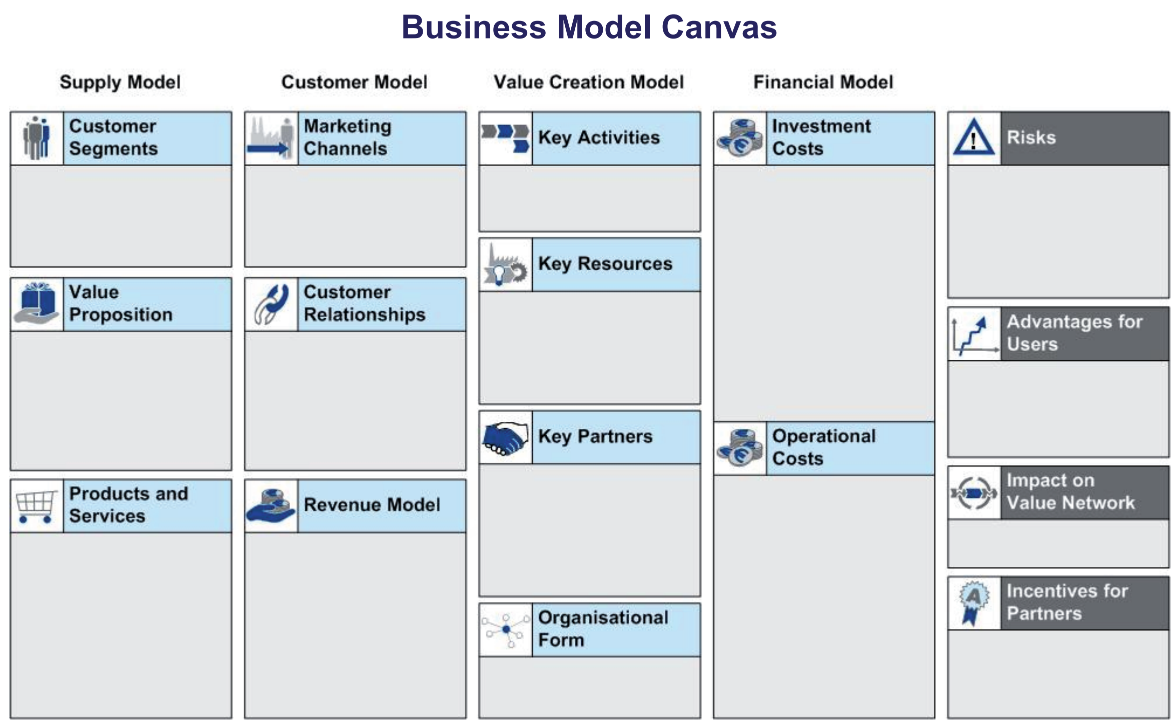


Figure 4-5: Extended Business Model Canvas (based on [Kös14])

The new elements (colored grey on the right) will be devised briefly in the following:

- **Risks:** **"**What are inherent risks in operationalizing and running the business model?" During business model development workshops organized by the DMRC, oftentimes valuable input for a risk assessment is being discussed (e.g. *Will the customer provide the data for this service?*). This is the reason for the addition of this element to the business model canvas.
- **Advantages for Users:** "Which benefits do users (i.e. operators) of a business model obtain, especially when comparing it to the business model of (potential) competitors?" As a conclusion from validation workshops, the key benefits of business models should be extracted in order to ensure management approval.
- **Impact on Value Network: "**Can possible impacts (positive or negative) on the value network already be discerned?" Oftentimes, a change in the business model automatically alters relationships to partners, or even renders them redundant. Changes

in the value network are typically more relevant in cases where existing business models are adapted than in full out startups.

- **Incentives for Partners: "**What are the benefits for the key partners in the business model and what are motivations for them to cooperate?" Sometimes neglected, partners are more likely to engage as partners in a business model, if (besides monetary compensation) there are other (weak) incentives for them to take part. Examples are, for instance, ingredient branding.

As mentioned above, the Business Model (Canvas) is connected to the value proposition canvas via the elements **customer segments, value proposition** as well as **products and services**. These three elements are framed in detail by the value proposition canvas. The objective is hence, to fill the remaining elements such that the overall business model is 1) economically viable, 2) realizable and 3) consistent [Kös14]. In the following, three different exemplary methods and tools to aid in this process are going to be devised briefly.

Configuring business models using variables and options

Business models can be developed by composition of business model options [Kös14]. In doing so, the business model elements (e.g. revenue model), are detailed further utilizing variables (e.g. pricing mechanism or revenue form) which in turn can again each be detailed by various options.

Business model development on the basis of consistent options.

There are two modes of operation when using variables and options for business model development: 1) Different options for a business model can be **checked** for **consistency** and therefore allow for the development of highly consistent business models and 2) they can be used as **creative stimulus** during workshops. In the project *Development of an Additive Manufacturing Potential Check System* a list of variables and options has been collected and described. Overall, the list contains 107 standardized variables and 490 options. The figures 4-6 and 4-7 show exemplary excerpts.

Reduction of the variable set.

If a consistency-focused approach is being favored, the list of variables has to be narrowed down to about 20 most relevant variables for the business model. In the following, the corresponding options are being checked for consistency. Depending on the number of selected variables and the associated options, this can result in more than one thousand evaluations. Combinations of options which are highly consistent are each considered alternative business model drafts. They are then clustered to bundles and prioritized. If used as creative stimulus, the variables and options list can be used in terms of a questionnaire to walk through during a workshop.

The key challenge in configuring business models using variables and options is finding relevant business model variables and options in the first place. Because a business model which is described by 107 variables and 490 options cannot be comprehended easily, it is necessary to either work through a long list of options and prioritize them first, or find suitable options by chance.

Development of business models with patterns

According to Alexander, patterns describe proven solutions for recurring problems [AIS77], [Ale79]. Alexander, an architectural theorist, formulated 253 patterns for designing towns, buildings and constructions. The basic idea of patterns is reusing solutions which are documented in an abstract way, such that they can be applied in a different context. Thereby, patterns contribute to reduce the complexity and increase effectiveness in problem-solving [BMR+96].

Patterns help in the solution of recursive problems.

Hence, working with patterns is not a new concept. Also in the context of business models, several authors have conducted groundwork: Weill et al. have defined 16 business model archetypes by analysis of 1000 US-based companies [WMU+06]. Osterwalder and Pigneur have found five business model patterns [OP10]. Gassmann et al. have compiled 55 business model patterns which vary in their degree of abstraction [GFC13]. Whether implicitly or explicitly: All business model patterns stem from the empirical analysis of successful companies and the abstract description of their core elements.

In Business Model Development, several attempts for pattern catalogues have been made.

Business Model Element	No.	Business Model Variable	Business Model Option	Description
Customer Segment	1	Selection of Customer Segments	Opportunistic Stick to the plan	Describes the way new customer groups are being chosen. Does the BM allow for the agile change of customer segments, or is the BM tailored to one specific segment?
	2	Competitive Behavior of the BM-Operator	Niche Player Aikido Mainstream	How does the BM ensure its competitive advantage over BMs from competitors who run a similar business?
	3	Purchasing Behavior of the Customer	Habitual Selective Impulsive	Describes the purchasing behavior of the BM's customer which is important to determine for there are e.g. marketing activities to be adjusted accordingly.
Value Proposition	14	Unique Selling Proposition for the Customer	Individualization Lowest TCO Lightweight Design Highest Quality Lowest Price ...	Describes which attributes of the offered product and service are outstanding at the point of sale when compared to competitors' products. What should your marketing be focused on? Remember to always check whether your Value Proposition is appreciated by the customer and he is willing to pay accordingly.
Marketing Channels	22	Level of Marketing	High-level Launch Standard Launch Low-volume Launch Selective Marketing	What kind of marketing offensive do you want to launch for your product? Do you have the necessary means to do so, or are further activities (Key Activities) necessary?
	23	Marketing Phase	Individualization Lowest TCO Lightweight Design Highest Quality Lowest Price	Describes which phase of the purchasing process the marketing is aimed at.
Customer Relationships	40	Customer involvement into the innovation process	Not at all Customer Surveys Customer Observations Consulting by Lead Customers Tendering in Open Innovation Platforms	Opening the innovation process to external sources is not new. Does your Additive Manufacturing BM entail customer interaction into the innovation process? Keep in mind that Additive Manufacturing bears the potential for you to quickly interact with the customer via e.g. design prototypes. Why not use this potential?
	41	Customer Loyalty Promoters	Increasing switching costs Customer loyalty by techn. USP ...	Describes which elements of the BM promote long-term loyalty of the targeted Customer. Loyalty can be either voluntary or compulsory.

Figure 4-6: Extract of Business Model Variable Catalogue (1/2) (according to [BV07], [FWW14], [GK16], [Joc10], [RS14])

Business Model Element	No.	Business Model Variable	Business Model Option	Description
Revenue Model	63	Revenue Form	Product Sale Leasing Flatrate Licensing Fractionalized Ownership Hidden Revenue ...	Describes the mode in which revenues are generated. Besides direct sales of the product, recently novel forms of revenue generation have begun to emerge in digital business models. Overall, we have collected eleven Revenue Forms.
	64	Price Mechanism	Catalog Price Pay per Print Pay per Volume Razor and Blade Pay What You Want For Free ...	A price mechanism describes how and on the basis of which criteria a price for a product or service is being calculated. Note that, especially in the service domain, customers usually react cautiously if they have to pay for something which used to be free in the past (e.g. pre-sales support). Overall, we have collected 16 different price mechanisms.
Key Activities	84	Research and Development	Fundamental Research Reverse Innovation Collaborative Research Open Source	Describes in which mode the research necessary to operate the business model, is going to be conducted.
Organizational Form	89	Value Network Maneuver	Focus Integrate Coordinate Comprise Expand Re-Construct	Describes the composition of the value network after operationalizing the business model at hand. The first three Options rather describe a change of vertical range of manufacture, while the lower three usually go in hand with a re-alignment of the branch value network.
Key Resources	94	Certification and Qualification	Tools Methods (Production) Systems Products Raw Materials	What are the typical key resources for the aspired business model? Make sure to always think ahead possible risks which might be associated with these resources (e.g. Sourcing Risks: Do you only have one supplier for this resource?)
Key Partners	101	Sourcing Approach	Single Sourcing Multi Sourcing Component Sourcing Modular Sourcing	Describes which sourcing approach is applied in order to balance: • Maintaining independence from suppliers • Reduce purchasing complexity • Economies of scale

Figure 4-7: Extract of Business Model Variable Catalogue (2/2) (according to [BV07], [FWW14], [GK16], [Joc10], [RS14])

Typically, business model patterns are described in **business model cards** and are complemented by at least one concrete example. Exemplary business model pattern which are frequently being discussed in the context of Additive Manufacturing are **Mass Customization** or **Razor and Blade**. Simply put, Mass Customization describes the sales of customized goods at costs of mass production. Mass Customization business models are usually the ultimate goal of Direct Manufacturing – due to the obsolescence of tools, manufacturing companies plan ahead future business models in which products are tailored to customer needs in lot size one. **Razor and Blade** is a business model pattern which involves a basic product sold at low prices and complementary goods sold at high prices. Widely known examples are consumer goods (razors and blades) but also electronics (printers and cartridges). Similarly, in the Additive Manufacturing branch there are currently companies

Pattern catalogues entail business model patterns relevant for Additive Manufacturing.

The Additive Manufacturing branch operates according to known business model patterns.

selling machines which only operate with proprietary materials. According to our observations, the Additive Manufacturing branch overall operates mostly with established business models.

At the DMRC, we have evaluated known business model patterns and evaluated them with regard to their relevance in the realm of Additive Manufacturing. Once the set of patterns has been reduced, there are two modes of working with business model patterns: **Pattern Association** and **Pattern Confrontation** [GMC13], [EAG15]. Pattern association describes the process of allocating business model patterns to a given business idea. In the context of the previous example (customer intermediary for Additive Manufacturing Service Providers), the business idea has already been developed using the value proposition canvas (see figures 4-3 and 4-4). On the contrary, pattern confrontation describes the process of handing out business model patterns to participants in business model development workshops and developing entirely novel business ideas.

Patterns can be used for association of confrontation.

In the example above the ideas developed for the example **customer intermediary for Additive Manufacturing Service Providers** (figure 4-2) can exemplarily be enriched by business model patterns: For instance, the business model pattern **Lock-in** can refine the business idea further such that the platform operator 'forces' Service Providers (either via contractual obligation or technical aspects such as file formats) to use the platform operator's software exclusively for order processing. Another idea could revolve around the business model pattern **Layer Player:** Possibly the ideas developed in the value proposition canvas can be quickly adapted to other manufacturing technologies as well.

Using business model patterns in our example.

Overall, we have found that the development and enrichment of business models using patterns is very efficient – usually many ideas can be generated in little time. Also, it takes little time for workshop participants to understand the methodology . In the vast majority of cases patterns have been used for pattern confrontation. However, in about 50% of business model workshops business model patterns yield ideas far from the intended business idea. Workshop facilitators are well-advised to incorporate this into their planning. On the negative side, business models developed by patterns are **seldomly new-to-the-world**. Arguably, this is never the case due to the principle of using patterns. Also workshops showed that only a small fraction of patterns sparks the creativity of participants in the first place (low hit rate). That is why, for each workshop, the available set of patterns has to be prioritized up front, depending on the specific case at hand.

Patterns are easy to use.

No revolutionary business models.

Developing cross-industry business models

Cross-industry business model innovation describes the direct application of business models from a foreign industry to the domestic industry [EG09], [Dür12]. Similar to pattern-based business model development and the employment of variables and options, cross-industry business models have their roots in product development. For years, companies have developed methodologies to solve development problems or transfer product ideas by solutions from other branches. A famous example is the *BMW iDrive* whose human-machine-interaction system has been borrowed from joysticks in the computer games industry [Ste09]. In that sense, cross -industry business models are similar to pattern-based approaches. The salient difference between **cross-industry business model innovation** and **pattern-based business model innovation** is that for the latter, the solutions have already been found and described in an abstract manner. Here, practitioners can draw on extensive pattern catalogues. On the contrary, cross-industry business model innovation largely relies on serendipity. There obviously is no overarching catalogue or systematization of business models yet.

Cross-industry business models are related to pattern-based approaches.

Cross-industry innovation processes usually follow a three step logic [EH10]: 1) abstraction, 2) search for analogies and 3) adaptation. In a first step, the 'problem', i.e. the business idea for which suitable business models are to be sought, has to be abstracted. We usually use known methods such as progressive abstraction or abstraction trees [Nöl10], [Ech14]. In the sample case, customer intermediary for Additive Manufacturing Service Providers, the abstraction leads to search terms such as solutions for a 'two-sided market' or for a novel 'sales system' because the AM Service Provider industry largely consists of small and medium sized enterprises which are possibly hard to reach.

Cross-industry innovation process as a three step process.

Using abstracted search terms , analogies from different branches are sought and adapted to the domestic industry. Searching for a sales system with a high penetration of the target market yields **multi-level-marketing**. Albeit sometimes confused with pyramiding schemes, multi-level-marketing has proven to be a reliable sales system which is efficient, robust and guarantees a high degree of penetration of the target market [Die10-ol]. Figure 4-8 illustrates what the adaptation of a multi-level-marketing business model would, exemplarily, look like in the domestic industry.

Abstracting the problem to search terms.

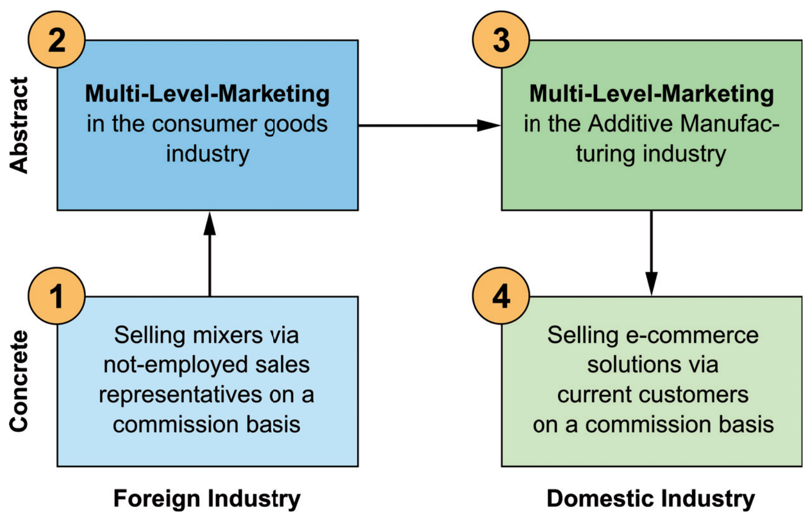


Figure 4-8: Adapting a foreign business model to the domestic industry [EH10]

Checking for success factor compliance.

The key in adapting business models from foreign industries is checking whether the important success factors which make the business model work, also hold true in the domestic industry. For example, the German household appliance manufacturer *Vorwerk* successfully operates a multi-level-marketing business model for their kitchen appliance *Thermomix.* They hire non-professional sales representatives who conduct product presentations in the homes of potential buyers and receive a commission for sold appliances. The first implementation of this business model is from *Tupperware Brands Corp.* [Gro07]. Among others, the success factors for this concrete business model are:

- It is very important for the product to be sold by credible salespersons.
- The product can be sold via emotional attachment.
- Existence of an interconnected customer base.

Setting up and testing hypotheses.

If, for instance, the product representatives do not have access to other possible customers, this distribution system would fail. One of the hypotheses of adapting this business model to the realm of Additive Manufacturing (according to figure 4-8) is therefore: The customers of an Additive Manufacturing e-commerce solution know each other and are willing to interact. Before rolling out such a business model, this hypothesis needs to be tested with a *minimal functional prototype* [Rie12].

Disadvantage: high effort.

Cross-industry business model innovation has the advantage of the discussion of concrete, existing business models. In pattern-centered workshops, practitioners usually automatically search for use-cases or examples for patterns and inadvertently discuss these. The disadvantages of cross-industry business model innovation are twofold: 1) Finding suitable business models for customers usually takes about a month of research and 2) there is a risk of rejecting business models for the wrong reasons.

Business model enrichment with the DMRC

Professional help is often needed for the value creation model.

From a methodological standpoint, there is sufficient theory and support for business model enrichment. Additive Manufacturing does not impose the necessity for new methods of business model development per se. However, due to the complex value network around Additive Manufacturing the know-how necessary to develop profound business models (especially regarding key activities, resources and partners) is spread sparsely in new incumbent companies. In our business model workshops with the DMRC (see e.g. figure 4-9) we therefore found it inevitable to bundle the methodological know-how of business model development with the technical know-how of our experienced staff.

Figure 4-9: Business Model Enrichment with the help of the DMRC

4.3 Business Model Assessment

Choosing the right business models.

The results of Business Model Enrichment are typically either entirely different business models or different variations of the same business model (e.g. differing only in revenue model). The primary goal of the third phase is therefore a (single) prioritized business model to be implemented at first. Additionally, it is worthwhile to discuss whether alternative business model drafts (developed in Business Model Enrichment) can be launched over the product life cycle [Pei14]. The study at hand however exclusively focuses the prioritization of business models and disregards the roadmapping approach.

Focus is twofold: rentability and stability of the value network.

Tool for the assessment of value network stability.

We have developed two independent analysis tools to prioritize business models according to 1) profitability and 2) stability. The stability tool will be devised briefly in the following; the profitability assessment is part of the confidential study which is available exclusively for DMRC partners. The stability of a value network describes how the current stakeholders of a given company are likely to react to an intended business model change. DynAMiCS resulted in a tool for this purpose – **BMESA (Business Model Effects and Stability Analysis).** The tool is borrowed from the established Failure Modes and Effects Analysis (FMEA) and allows for the analysis of entirely novel business models, as well as small business model changes [TDM11], [PBF+07]. The overall proceeding is illustrated in figure 4-10, the general manner of processing is from the left to the right (column).

Stakeholder analysis.

In a first step, the relevant stakeholders or stakeholder groups are being determined drawing on, for instance, stakeholder radar [FS06], [Sly96]. A stakeholder group is a role in the value network such as *MRO provider;* a corresponding stakeholder is *Lufthansa Technik*. Depending on the complexity of the value network either concrete stakeholders or stakeholder groups are considered. Using this tool, the most influential stakeholders can easily be discerned and pre-prioritized for further use. In parallel to the stakeholder analysis, the relevant **business model changes** are determined. Since business models are usually described in prose or bullet points for each element, the business model changes usually comprise short textual statements. For example, in figure 4-10 the business model to be analyzed is a decentral manufacturing order distribution platform in which production orders are distributed to several Service Providers according to availability of resources and desired lot size. The value proposition to the Service Provider is a higher utilization rate of his machines allowing for a faster Return on Invest (RoI).

In the next step, the BMESA rates the **likelihood** of the respective stakeholder (group) **to encounter** the given business model change (rated on a scale from 1 – very low; to 10 – very high). This evaluation metric goes back to Coyne and Horn, who rated the relevance of a stakeholder according to whether the stakeholder detects an action overall, whether the stakeholder is affected by the action and whether the stakeholder has a natural inclination to react towards the action [CH09].

In the fourth column, possible **effects of the business model change** are noted. In doing so, it is necessary to take the perspective of the corresponding stakeholder (group). In the given example, the Service Provider is for example most likely going to be afraid of a long-term dependence of the order distribution platform. The fifth column 'likelihood of occurrence' describes how likely the given effect is (rated on a scale from 1 – very unlikely; to 10 – much likely). The second last column indicates the reaction strength of a stakeholder to the observed business model change. The reaction can be positive or negative. For this reason, the evaluation metric ranges from -10 to +10 (excluding 0).

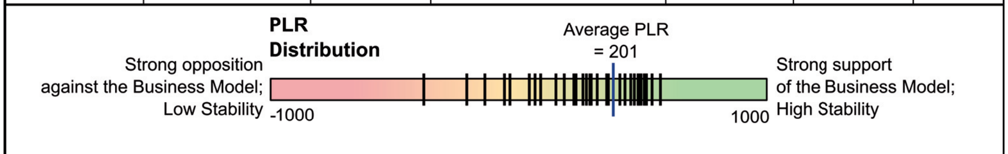
The multiplication of (p)robability of detection, (l)ikelihood of occurrence and (r)eaction strength of the stakeholder yields the **PLR value**. The PLR ranges from -1000 to 1000, negative PLRs represent possible threats to the realization of a given business model and should be accounted for during implementation. On the contrary, a high PLR represents the possibility for potential cooperation partners.

BMESA – Business Model Effects and Stability Analysis

Business Model Idea: Decentral Manufacturing Order Distribution Platform

Responsible: Adam, G.; Kage, M. **Date:** September, 20th 2016

Stakeholder Group	Business Model Change	(P)robability of Detection (1 to 10)	Effects of Business Model Change[1]	(L)ikelihood of Occurrence[1] (1 to 10)	(R)eaction Strength of Stakeholder[2] (±1 to ±10)	PLR P x L x R (-1000 to 1000)
Service Provider	Enabling Service Providers a higher utilization rate of their machines.	10	Service Providers might fear long-term dependence from Order Distribution Platform.	9	-3	-270
			A chain of successive price undercutting could unfold.	4	-2	-80
	Automatic Order Fulfillment for the Service Provider.	10	Service Providers will have to implement ERP-systems which allow for an automatic processing of manufacturing jobs.	9	4	360
Machine Manufacturers	Enabling Service Providers a higher utilization rate of their machines.	8	Increased sales of machines to Service Providers due to faster return on invest.	6	8	384
			More demand for open access ... parameters in	7	2	112
Powder Manufacturers	Enabling Service Providers a higher utilization rate of their machines.	8	More steady demand for standard powders, hence flatrate business models become attractive.	1	5	40



1) From the perspective of the stakeholder group
2) A negative number implies a conflicting reaction and vice versa

Figure 4-10: Business Model Effects and Stability Analysis (BMESA)

As mentioned before, the second dimension of business model evaluation is the financial payoff. Here, **statistical simulation** has proven to be an effective aid for the solution of complex foresight problems [Has70]. On the basis of a mathematical model, different 'pay-off' scenarios with uncertain input can be calculated. The salient feature of this methodology is that the method can be scaled up or down, depending on the level of abstraction of the business model [BBG97]. The result of the methodology is therefore not one expectation, but rather a probability distribution of the expected payoff. This is illustrated in figure 4-11: The business model profitability cannot be attributed to a single point on the x-axis. In most cases, business models typically agglomerate at certain x-values. Note that the y-axis is identical for each business model idea. The bubbles positions have been altered merely for visualization purposes. Further information on the statistical analysis can be drawn from the confidential study.

Probability distribution of business model payoff.

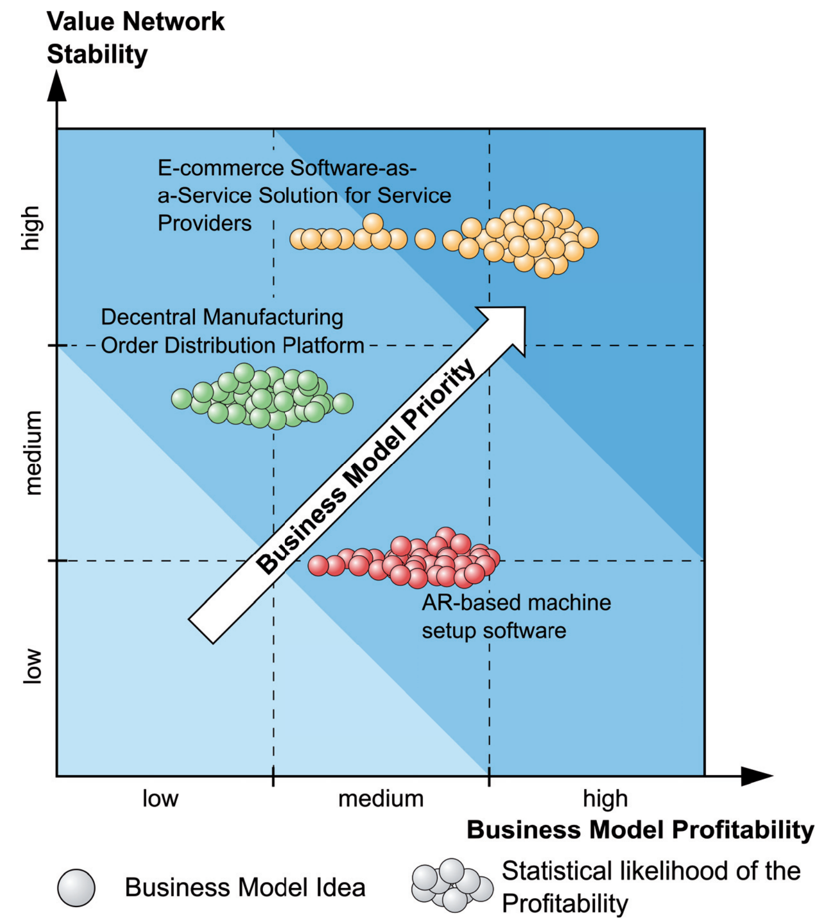


Figure 4-11: Portfolio for Business Model Assessment

Using the portfolio in figure 4-11, the three developed business model ideas which were enriched by the methods in chapter 4-2, could be evaluated. The selected business model e-commerce software-as-a-service solution for Service Providers has a decent pay-off expectation and (when compared to the other business model ideas) a rather high stability of the value network. The detailed business model can be drawn from figure 4-12 and 4-13 in which they are described in prose.

Supply Model

Customer Segments

- Small and medium-sized enterprises
- Start-ups in the AM Service Provider business
- Mostly offer print services and 3D models
- Operated by "digital natives": want to remain independent from widely available e-commerce solutions; do not want to focus on one particular technology yet (vastly plastics)
- Short staffed
- Little business sense, operated by no businessman by trade; have technical know-how though
- Customer of the Service Provider has an impulsive, irregular purchasing behavior

Value Proposition

- Enabling the Service Provider to concentrate on his core-business, by taking over *pesky* tasks such as quoting
- Customer of the webshop (Service Provider) has a familiar shopping experience, lowering the barriers of initial contact
- Increasing the value of the Service Provider`s business
- Flexibility with regard to later business expansion
- Little financial obligation due to Software-as-a-Service concept

Products & Services

- E-commerce solution for AM Service Providers
- Modular Software-as-a-Service e-commerce solution consisting of:
  1) Quoting and pricing engine
  2) Design checker and meshing engine
  3) Extensive back end for dashboard-based Business Intelligence
  4) Sketchup-like drawing engine for playful Customers
  5) Web-shop
- Training concept for the e-commerce solution
- App

Risks

- Service Provider is not aware of the capabilities of e-commerce solutions
- Dying market due to overinflated expectations
- E-commerce solution is very branch-specific, diversification to other branches is very unlikely
- Overestimating the unique selling proposition „easy to use"

Customer Model

Marketing Channels

- AM community is rather small and domestic, hence, a strong presence on trade fairs and conferences is mandatory
- Selling e-commerce solutions partly via current customers on a commission basis
- Attractive, young website for ourselves (Aventura Font style)
- Standard marketing via the established forums and Social Media
- Youtube videos
- Testimonials from lead customers
- Marketing Phase: Attention, Assessment and Purchase

Customer Relationships

- After the initial contact has been established, a service presentation is quickly being scheduled. This should be a web-based presentation from Customer and Service Provider perspective. Afterwards a free trial account (30 days) is being activated
- Rollout by ourselves, together with the customer
- Depending on the revenue model, contact is either extensive (pay per quote or job) or „leave them alone"
- A 24/7 helpdesk is necessary in order to maintain the Service Provider's business in case of emergency

Revenue Model

- Revenue model is fully scalable and depends on the Service Provider's size and requirements:
  1) Pay per quote: Initial (rather small) up front payment for the initiation of the e-commerce service, afterwards 2% of the quoting price for each transaction
  2) Fixed licensing per year
  3) Pay per traffic
  4) Pay per successful business transaction

Advantages for Users

- Theoretically: Possession of all customer data
- Guaranteed existance of a customer segment which is interested in the solution and willing to pay
- No field operations necessary
- No product liability for AM products (in GER) according to §437 HGB

Figure 4-12: Selected Business Model for the e-commerce solution provider (1/2)

Value Creation Model

Key Activities

- Development of all necessary algorithms (esp. meshing engine)
- Once successful: Publication of scientific papers about the algorithms to be used (intention: gathering feedback and eventually find more developers)
- Check for research proposals in the respective service fields

Key Resources

- Long term: Intellectual Property on service system
- Own data center
- Long term: Our new brand
- Know-how on lean order fulfillment processes

Key Partners

- Research institutes with extensive know-how regarding meshing strategies and job preparation
- Software development companies
- If possible: ERP system provider
- Machine manufacturers

Organizational Form

- Interface between Service Provider and his Customer
- Most likely: Spin-off necessary for our today‘s brand name is not known in the customer segment (possibly advertisement with parent company brand in the initial phase of business model implementation)
- Flat hierarchies and tight entanglement with our ERP development team

Inpacts on Value Network

- Possibly accelerating the market entry of further AM Service Providers
- Possibility of new content platform providers entering the AM market

Financial Model

Investment Costs

- Development costs for design checker
- Hardware infrastructure
- Initial marketing costs
- Developing a pay per X order-fulfillment solution for our own ERP-system
- Main cost type: personnel costs

Operational Costs

- IT service department (24/7 service center)
- Ongoing product upgrades necessary for
  1) Upgrading machine interfaces
  2) Further development of the service performance
- Third party services for the maintenance of our own hardware
- Main cost type: personnel costs

Incentives for Partners

- Research institutes: Working together in publicly funded projects
- Software development companies: Money and the general appeal of the technology field
- Machine Manufacturers: Increasing machine sales to Service Providers

AM: Additive Manufacturing **ERP:** Enterprise Resource Planning

Figure 4-13: Selected Business Model for the e-commerce solution provider (2/2)

4.4 Business Model Design in the context of Additive Manufacturing

In the project DynAMiCS, the developed methodologies for business planning have been tested and validated in workshops or short projects with companies willing to engage in business planning in the context of Additive Manufacturing. Various business models (resp. business model alternatives) for Additive Manufacturing users and suppliers have been developed.

In related literature, many authors have pointed towards the fact that Additive Manufacturing revolutionizes business models or significantly changes them (for instance [RS14], [RB15], [BHB16]). Judging from the experiences in the project it can be stated that a vast majority of the developed business models are not new-to-the-world and are instead rather conservative. Almost all business models can be rooted back to established **business model patterns** which have proven to be successful in other branches. We can therefore rather confirm the findings from Jiang et al.: The authors presented empirical evidence from a multi-step delphi study for the year 2030 and came to the conclusion that business models will not be immensely influenced by AM, as it is just another production technology requiring novel knowledge and skills [JKP16]. In line with the authors, we found that the biggest changes can usually be located in the business model elements '**key activities'** and '**key partners'**, for there is usually ample technological groundwork to be conducted before launching a business model. Also, the partner structure of a company almost always changes. While not totally new, the value proposition of the developed business models usually allows for the differentiation from competitors for the products can only be produced by Additive Manufacturing.

Mostly smaller changes to business models.

When it comes to business model innovation, Additive Manufacturing is (at least for now) not an enabler of revolutionizing business models in terms of decentral manufacturing networks. It however constitutes a worthwhile escape from the so called commodity trap – market situations in which differentiation mostly occurs via price. The case studies conducted as part of the study at hand – partially documented in this document – clearly show, that Additive Manufacturing allows for significant product improvements in terms of lifecycle costs, design etc. From a strategic perspective, this means that in matured and strongly contested markets AM allows for differentiation via product features.

AM is nevertheless a viable strategic choice for differentiation.

4.5 Case Study: Stükerjürgen Aerospace Composites

The tools and methods developed at the DMRC have been validated in a short project with the company *Stükerjürgen Aerospace Composites* (SAC) from Rietberg, Germany. For the most part, SAC is an aerospace supplier but also addresses applications in the yachting business. Founded in 1996 as a subsidiary of the *Ferdinand Stükerjürgen* group, the company has developed lots of technological know-how in the development and production of products and components made from plastics. In doing so, the whole process chain from engineering, over component manufacturing, post-processing (coating/painting) over assembly to final logistics are covered. In the realm of Additive Manufacturing, SAC has a distinct focus on the Fused Deposition Modeling (FDM) technology and the post-processing of the therewith produced products via, for instance, coatings.

Business model for a spare part supplier in the container ship industry.

The case study was motivated by an attempt to broaden the service portfolio and develop the business further as a spare part supplier in the container ship industry. In a first workshop, a value proposition canvas has been developed from the perspective of the main stakeholder **ocean carrier** (see figure 4-14). In order to incorporate the customer perspective as much as possible, employees from the yachting department have been invited since their business resembles the container ship the most.

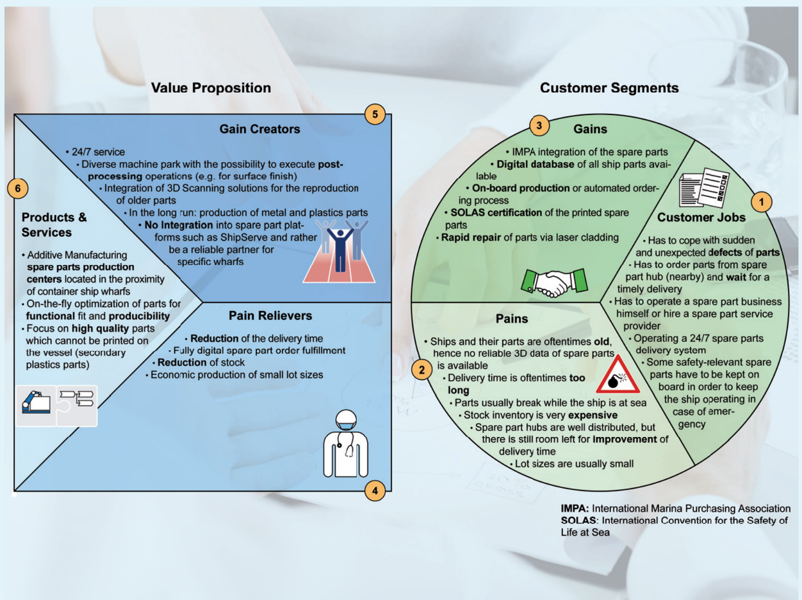


Figure 4-14: Value Proposition Canvas from the validation short project

The main customer actions are the timely overhaul of damaged ships via contract manufacturers once a part has been damaged. Either the parts are repaired on site or are replaced quickly. In order to find suppliers for parts, ocean carriers can draw on a database of maritime products which facilitates the ordering of spare parts

(IMPA). It contains 42,000 products and allows for finding suppliers. However there is no guarantee that the supplier can quickly deliver the requested part. Also, the ocean carrier occasionally witnesses a lack of information about a part, once it has been damaged. This is mainly due to the long product lifecycle of ships. Also, ships contain many (plastics) parts whose storage is expensive. Especially when being forced to store them everywhere in the world. A desired gain would be the availability of a digital database of all parts, which are operated by the company (which can also be extended via 3D scans of older parts). The corresponding products and service idea is the implementation of spare parts production hubs, located in the proximity of container ship wharfs.

Finding the key customer actions for the ocean carrier.

In a successive workshop, the business model has been detailed using the variables and options which had been developed in DynAMiCS (see chapter 4-2). Even though the business model is technically challenging, it has been evaluated as financially attractive in the long run. However, in the evaluation it was concluded, that two main challenges are going to impede the realization (see figure 4-15):

Identifying key challenges for implementation.

1) customer's fear of data security for their components

2) opposition by existing spare parts platforms which might unfold a price competition

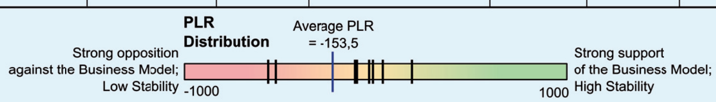
These spare parts platforms are competitors which have arisen recently. They offer the online, user-friendly request and ordering of supply parts. Even though many of them do not yet have AM capabilities, they are likely going to be able to undercut the prices of additively manufactured parts by far.

BMESA – Business Model Effects and Stability Analysis

Business Model Idea: Decentral Spare Part Manufacturing Business for Container Ships

Responsible: Oeding, M.; Dunker, E. **Date:** January, 12th 2016

Stakeholder Group	Business Model Change	(P)robability of Detection (1 to 10)	Effects of Business Model Change 1)	(L)ikelihood of Occurrence 1) (1 to 10)	(R)eaction Strength of Stakeholder 2) (±1 to ±10)	PLR P x L x R (-1000 to 1000)
Newly formed Spare Part Platforms	Selling selected spare parts for container ships with low delivery times.	7	Intensified marketing efforts by platform operator especially with regard to reliability and quality.	5	-2	-70
			Unfolding of a price competition.	8	-10	-560
Certification Committees	Usage of materials and processes which do not comply with their standards.	2	Refusing to grant e.g. SOLAS certificate to 3D printed parts.	2	-8	-32
			Tightening of security requirements.	1	-10	-20
			Acceptance of Additive Manufacturing as a production technology.	8	5	80
Conventional Spare Part Suppliers	Selling selected spare parts for container ships with low delivery times.	1	Unfolding of a price competition.	8	-7	-56
			Repetition / Copying of the Business Model.	7	-10	-70
Customers	Sending CAD or STL files of their parts.	10	Refusal to send files for fear of data security.	5	-10	-500



1) From the perspective of the stakeholder group
2) A negative number implies a conflicting reaction and vice versa

Figure 4-15: Extract from the BMESA in the validation project

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Summary

From *Identifying Potentials for Additive Manufacturing* through *Product Discovery* to *Business Planning for Additive Manufacturing* – the DMRC provides a holistic approach transferred to a practical "Additive Manufacturing Potential Check System". The study at hand presented a methodology and adequate tools developed to leverage the potential of AM in enterprises. They build a framework capable to transfer scientific and industrial innovations into actual practice.

The *first steps* give an overview about the actual usage of Additive Manufacturing (AM). Additionally, results of a survey carried out on the RapidTech exhibition 2016 in Erfurt are presented. It deals with the usage of the AM technology by companies of several branches and the approaches to identify AM potentials, use cases and business models. *Identifying Potentials for Additive Manufacturing* integrates the business analysis of market segments and product groups of companies. Another task is the identification of AM key capabilities with the help of Text Mining. A mapping of key capabilities and suitable market segments and product groups leads to a successful market possibility for AM. The *Product Discovery* contains of two approaches (creative and deductive) to identify suitable AM products, parts and services. The creative approach deals with the creation of product ideas using creativity techniques. The fundament of the deductive approach is the funnel of idea creation. By including several stages and methods, a wide range of product and part ideas is reduced to identify suitable options. Finally *Business Planning for Additive Manufacturing* deals with the development of Value Proposition Design and the enriching to a complete business model.

To illustrate the usage of methods, techniques and tools, fictive and real industrial examples are developed to demonstrate benefits.

Introduction

Today´s usage of AM technology shows a differentiation in Rapid Prototyping, Rapid Tooling, Rapid Repair and Direct Manufacturing. The topic AM generates large demand being possible to be regarded by google searches in the last five years. To analyze the actual interest and usage of companies in context AM, several expert interviews and a survey on RapidTech 2016 in Erfurt were conducted. Interviewees of several branches (Machinery and Plant Engineering, Automotive, Medical, etc.) with different numbers of employees have answered a structured survey dealing with strategies to find AM potentials.

The main results of the expert interviews and the survey are:

- Companies use AM for Design Prototypes, Functional Prototypes, Rapid Tooling and Direct Manufacturing. There is no predominant application for the AM technology.

- Interviewees identify a high future user´s interest for Rapid Tooling.
- In most companies, only one technology expert alone is responsible for the investigation of AM technologies.
- The identification of AM potentials in companies is mostly heuristic or unstructured.
- Most companies do not have a structured AM strategy yet, but see the importance of it.

The results of the survey and expert interviews show the significance of a structured AM strategy. The following chapters of the study describe approaches to identify AM potentials, products, services and business models.

Identifying Potentials for Additive Manufacturing

Before identifying possible parts, products or services, a suitable business field has to be identified in a first step. Therefore, a modified Market Segments-Product Groups (MSPG) matrix is used. Because of the specific situation of every company (depending on branch, strategy, business model, etc.) the main market segments and product groups have to be identified individually for each company. Values such as turnover, turnover growth and earning before taxes (EBT) help to identify main business fields in the conventional version of the MSPG matrix. For specific AM business fields the MSPG matrix have to be modified by particular AM features such as AM development trends in the company, production quantity in relation to the technology of AM or applied material in MSPG matrix.

Another important point is the collection of AM advantages which were identified with Text Mining. With the help of text mining approach 200 preliminary key advantages are discerned from more than 3000 documents (newspaper articles and publications on the topic). The preliminary key capabilities were clustered by the usage of a Design Structure Matrix (DSM) and reduced to 33 key capabilities. A contemplation by experts of the DMRC leads to a final chose of 13 AM key capabilities.

The last important step for the identification of AM potentials is merging of AM business fields and AM key capabilities. The combinations of market segments and product groups from the MSPG matrix and AM key capabilities describe the AM potentials.

Product Discovery

To find suitable AM parts, products and services, two approaches were used by DMRC. The creative approach includes creativity techniques in workshops to create new product ideas. For the generation of high quality product ideas the selection of creativity techniques is an important step. The portfolio of creativity techniques gives a possibility to classify techniques and methodologies by criteria such as discursive and intuitive thinking. A technique with high levels of both criteria influences the product idea generation in a positive way. As an ideal example the Design Thinking approach is described in a short excursion. The approach was already used by the DMRC in workshops.

IThe deductive approach is based on the funnel of idea creation. The basis for the procedure is a pre collection of already existing products, parts and services of a company. By the usage of a tool integrating Knock Out- as well as AM specific material and design criteria the high range of possible AM products are reduced. All remaining products, parts and services are AM suitable. The product, part or services with the best values have to be re-designed to realize the AM key capabilities. One possibility in this context is a topology optimization to create a lightweight design. After that the chances and risks have to be identified with a chances-risks portfolio. A positive assessment leads a specification of the product which can be documented with product idea profiles and modeled with modeling languages such as SysML. Finally a complete economic consideration with the “Trade-off Methodology Matrix” (TOM) have to be performed to identify the whole market potential for the specific product.

Business Planning for Additive Manufacturing

To refine and check the business idea the Value Proposition Canvas including aspects such as **Customer Segment**, **Value Proposition** and **Products and Services** can be used. A modified Business Model Canvas added by **Risks**, **Advantages for Users**, **Impact on Value Network** and **Incentives for Partners** is used to enrich the already existing business model. With the help of pattern business model options can be developed. The Business Model Variable Catalogue assign business model variables to the different fields of the Business Model Canvas. For these different variables business model options can be chosen to be integrated in the business model. To assess developed business models a tool called Business Model Effects and Stability Analysis (BMESA) was developed. The tool is borrowed from the established Failure Modes and Effects Analysis (FMEA) and allows for the analysis of entirely novel business models, as well as small business model changes.

Future research and implementation

DMRC service offer includes all described methods and tools from *Identifying Potentials for Additive Manufacturing* through *Product Discovery* to *Business Planning for Additive Manufacturing* being necessary for a holistic implementation of AM technology in companies. The DMRC is the ideal partner which possesses competencies in all mentioned areas and beyond in areas dealing with AM processes, material and property investigations.

The DMRC will accompany companies from the identification of AM potentials to the implementation in the business model. Furthermore, the DMRC is a technical consultant for the young technology.

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