Thinking ahead the Future of Additive Manufacturing –

Analysis of Promising Industries

DMRC
DIRECT MANUFACTURING RESEARCH CENTER

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Preface

Direct Manufacturing technologies that have been developed over the past decade have been interesting to engineers in the aerospace, automotive and electronics industries because of their potential to significantly reduce parts production and process costs, shorten cycle times, and better enable demand-driven production of spare parts. As opposed to common, milling technologies that “subtract” raw material away in order to create a finished part, Direct Manufacturing can eliminate the waste of raw material by “adding” or building-up parts in layers using lasers and other techniques with little or no tooling. Direct Manufacturing can be an economical and viable alternative for fabricating complex assemblies for specific requirements.

At Boeing, we strive to partner with world-class academic research institutions and industry leading suppliers and technologists to advance technologies that will benefit our products and our customers. Currently, we are using Direct Manufacturing technologies to create production parts for many of our aircraft – and we would like to expand the use of this technology in a prudent and efficient way. In 2008, we became a founding partner of the Direct Manufacturing Research Center at the University of Paderborn in Germany to work with key technology suppliers and forward-thinking users who also have the goal of advancing these technologies.

How do we make more people, especially potential users of the technologies, better aware of the fascinating possibilities of Direct Manufacturing? And how can the suppliers of Direct Manufacturing technologies become more knowledgeable of the future success factors so that they can deliver the right products at the right time?

The present study is the first study conducted under the auspices of the Direct Manufacturing Research Center. It provides the results of the project “Opportunities and Barriers of Direct Manufacturing technologies for the Aerospace Industry and Adapted Others”. The goal is to answer the questions mentioned above and to develop a vision for the future of Direct Manufacturing and to create concise and focused research projects that can help to get us there.

Our thanks go to all of the experts who have supported the Direct Manufacturing Research Center in the creation of this study, especially to Prof. Dr.-Ing. J. Gausemeier and his team from the chair for Product Engineering at the Heinz Nixdorf Institute.

Best regards

Paul Pasquier

Vice President, Global Technology
Boeing Research & Technology

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Introduction

Three public studies result from the project.

The present study is the first of three public studies resulting from the project "Opportunities and Barriers of Direct Manufacturing technologies for the Aerospace Industry and adapted others". The project is performed by the Direct Manufacturing Research Center (DMRC) and the Heinz Nixdorf Institute, University of Paderborn, Germany.

Object of the project are future influences spurring an increase in market relevance of Direct Manufacturing (DM) technologies in the aerospace industry and further adapted industries. Based on future influences, a strategic planning of future DM-applications and a planning of technologies required for the most promising applications within the next 10 years, is carried out. This enables the DMRC and its partners to be one step ahead of respectably competitive research centers worldwide. Especially, material and tool-providers of the DMRC can significantly benefit from the strategic planning of future applications, as it serves as a support to convince their customers to use DM-technologies extensively.

Goal of the project are three public and one confidential study lining out the opportunities and barriers of DM-technologies for aerospace industry and further adapted and promising industries. While the public versions present an overview of the results, the confidential version encompasses all results in detail.

Proceeding in the Project

The project is divided into four work packages (see fig. 1).

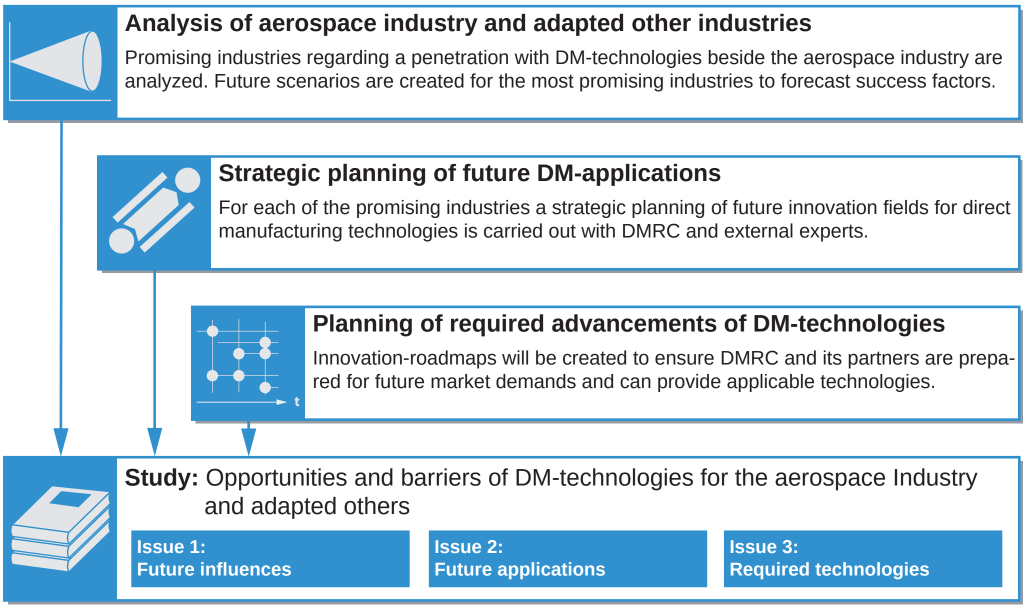

Figure 1: Proceeding in the project

Work package 1 addresses the following questions:

- Which are promising industries for the application of Additive Manufacturing (AM) technologies besides the aerospace industry?
- Which are the current success factors to push AM towards DM?
- What are the most promising industries?
- Which are the future success factors to implement DM-processes into the production of these industries?

For this purpose, promising industries regarding a penetration with DM-technologies in future are assessed. The most promising industries for DM-technologies are analyzed in detail. For each of these industries, scenarios for the year 2020 are developed. Based on the scenarios, future success factors and strategic directions are derived.

Work package 2 covers the following questions:

- Which applications might be replaced by DM-technologies within the next 10 years?
- Which future requirements need to be fulfilled?

To answer these questions, ideas for future applications for DM-technologies in the selected industries will be developed and clustered to innovation fields. The innovation fields will be ranked with a systematical idea management in close collaboration with DMRC experts and external experts. From the identified innovation fields, future requirements will be deducted and assessed by internal and external experts.

Work package 3 answers the following questions:

- Which manufacturing technologies can fulfill the requirements for DM-applications in the most promising industries at present?
- Which manufacturing technologies have the potential to fulfill the requirements for DM in the future?
- Which technological advancements have to be realized to tap the entire potential of DM?

For this purpose, advancements of existing DM-technologies will be identified that are required to overcome the challenges revealed in work package 1 and to enable future applications worked out in detail in work package 2. This encompasses advancements of product, material and production technologies.

Within **work package 4**, the confidential and the public studies are being compiled. The confidential study provides all information gathered within the project. The public studies cover three issues. Each issue will give an overview of one work package. The studies will be released during the project.

Proceeding in Study

The present study provides the outcomes resulting from work package 1. The main results of the work package emerged from seven workshops at the Heinz Nixdorf Institute, Paderborn, Germany and at Boeing, St. Louis, USA. A total of over 40 experts from the DMRC and external firms contributed their knowledge.

This study focuses work package one.

The first chapter focusses on the business of today. It provides the results from the analysis of promising industries for the application of DM regarding the application of Additive Manufacturing (AM) technologies. Initially, 14 industries have been considered. Therefore, important trends spurring an influence of DM-technologies have been deducted in the first workshop. As not all industries could be considered in the following, the industries were prioritized. Therefore, the board members of the DMRC discussed the analyzed industries in the second workshop. Based on this, the experts selected the aerospace, automotive and electronics industry as the most promising industries for the application of DM-technologies. Within these industries, the focus is put on the aircraft production, automotive production, and the electronics industry manufacturing equipment, respectively.

Chapter one covers the business of today.

The second chapter covers the business of tomorrow. To get an idea about the business of tomorrow, influence factors for the three most promising industries were developed within the three following workshops. The most relevant influence factors regarding the object of investigation were selected as key factors. Based on the identified key factors, the Heinz Nixdorf Institute developed future scenarios for the global environment and branch scenarios for the aerospace automotive and electronics industry. In the sixth and seventh workshop, the participating experts matched the branch scenarios with the scenarios of the global environment and selected the reference scenario combination. Against this background, the workshop participants deducted future chances and risks and developed strategic directions.

Chapter two covers the business of tomorrow.

The final chapter of the study summarizes the results of the work package 1 and provides an outlook for the further proceeding in the project.

Chapter three provides a summary and an outlook.

Participating Companies/Institutions

- Benteler International AG
- Blue Production GmbH & Co. KG
- BMW AG
- The BOEING Company Corp.
- Direct Manufacturing Research Center (DMRC)
- Eisenhuth GmbH & Co. KG
- EOS – Electro Optical Systems GmbH
- Evonik Degussa GmbH

- Harvest Technologies Corp.
- Heinz Nixdorf Institute, University of Paderborn
- Honda Motor Co., Ltd.
- Huntsman Advanced Materials GmbH
- Met-L-Flo Inc.
- microTEC GmbH
- PHOENIX CONTACT GmbH & Co. KG
- Siemens AG
- SLM Solutions GmbH
- Stratasys, Inc.
- Stükerjürgen Aerospace Composites GmbH & Co. KG
- UNITY AG
- University of Paderborn
- University of Siegen
- Weidmüller Interface GmbH & Co. KG
- Witte Automotive GmbH

Reading Instructions

The present study allows a quick understanding. For a fast overview of the content it is sufficient to have a look at the pictures and to read the summarized core statements in the marginalia. Each (sub-) chapter ends with a (bold printed) summary.

A short description regarding the methodological approach is provided at the beginning of each chapter. For a detailed explanation and a glossary, please see the appendix.

Management Summary

The study is divided into two parts. In the first step, current application fields are analyzed, to gain an overview of the current market penetration with AM-technologies. Based on this, future scenarios for the most promising industries are developed to deduct future success factors. This allows the AM-industry to be prepared for the business of tomorrow.

The Business of Today

Many industries are becoming aware of the advantages of AM.

The analysis of today's business shows that AM-technologies are gaining more and more importance. An increasing number of industries benefit from the advantages of the technologies such as the freedom of design, and AM is progressively pushed from Rapid Prototyping towards small series production – the so called Direct Manufacturing.

Today, AM is already widely spread within known fields of application for instance within the medical sector including dental applications, prostheses, implants etc. Progressively, AM-technologies are being applied within further industries e.g. the aerospace, automotive and electronics industry. Even, consumer industries such as the sports, the furniture or the jewelry industry are becoming aware of the advantages of DM-technologies for their business. However, the penetration of the industries by AM is still limited. To increase the penetration from today's point of view, the current, most relevant success factors across the analyzed industries are the following:

- Design rules;
- Surface quality;
- Process reliability and part reproducibility.

The Business of Tomorrow

The aerospace, automotive and electronics industry were selected as the most promising industries regarding the application of DM.

The aerospace, automotive and electronics industry were identified to be the most promising business opportunities for the application of DM in the future. A method to think ahead future developments is the scenario-technique. Based on this method, future scenarios were developed for the global environment as well as branch scenarios for the three most promising industries focusing the aircraft production, automotive production and electronics industry manufacturing equipment, respectively. In the next step, the scenarios for the global environment and the branch scenarios were matched to overall scenarios.

Aerospace: General ground rules for secondary aircraft structure are required.

The most probable scenario for the aerospace industry with the highest effect on the aircraft production describes a future, where regarding the global environment, Europe sets the pace in a globalized world. The branch scenario is characterized through individual customization of aircraft which fosters the application of AM-technologies. In this world, many manufacturers jumped on board and have been increasing their investments into AM-technologies. Thereby, they succeeded to improve the ratio of functionality and costs of AM-technologies. Functional-driven design is the key to success, and AM is mainly used for manufacturing critical parts or for low scale production. Due to the successful part implementation, additively manufactured parts started to be associated with high performance and high quality. To be successful in this future, it will be necessary to build up general ground rules for the design of secondary aircraft structures, systems etc. for AM-technologies and to flow them down to suppliers.

Automotive: Productivity and quality of AM-processes need to be increased.

The future scenario for the automotive industry also fits with the selected scenario for the global environment. In this future, the automotive production is characterized by new production concepts that drive the individuality of automotives. Further research has provided improvements in AM-processes. Thus, AM in series production is possible by now and functional-driven design is the key to success. Single parts are built just in time in order to keep up the existing schedule. In addition, a tendency towards a high scalability in the whole production process occurs: the assembly lines increasingly consist of highly flexible robotics equipped with different tools. Against this background, it is necessary to increase the productivity and the quality of additively manufactured parts to advance them to Direct Manufacturing.

Electronics: AM-processes and materials have to be enabled for highly integrated production.

In the future of the electronics industry manufacturing equipment combined with the selected global environment, highly integrated production systems for individualized production prevail. In this world, networks between global and regional operating manufacturers have been evolving; manufacturers are strongly cross-linked within the electronics industry, as value-added networking has been proven as an appropriate method to mutually increase competencies. The compatibility of AM with conventional manufacturing processes and the entire integration of AM-processes have been realized. In addition, the low standardization of products pushes the flexibility of production systems, and due to intense research on manufacturing systems, one system for all production steps is realized. Manufacturers respond to the raised complexity and mechanical challenges by implementing software into production processes. Thus, software takes over the entire production process; only boundary conditions are predefined. To succeed in this future, AM-processes and materials have to be enabled for highly integrated production.

1

The Business of Today

This chapter gives an overview of the today's business of Additive Manufacturing and its application for Direct Manufacturing. This encompasses the history and a definition of Direct Manufacturing as well as a characterization of current application fields. Based on this, current success factors are deducted.

1.1 What is Direct Manufacturing?

by Dr.-Ing. Eric Klemp, Commercial Director DMRC

When 25 years ago, design tools became 3-dimensional, engineers invented technologies, which allowed the solidification of 3D CAD drawings. The newly developed manufacturing processes were based on cutting the 3D drawing into 2D slides and building those slides layer by layer to a solid 3D model. This led to the name: "**Additive Manufacturing technologies**" (AM-technologies).

The stereolithography and the (selective) laser sintering have been the first AM-technologies. Thus, for the first time, generating a physical model out of a design-file became possible, as the 3D drawing now could easily be transferred into a real 3D physical model. In addition, compared to conventional machines, the production speed was considerably higher.

From this point, complex shapes and freeform design could be built easily, as the AM-processes do not impose the restrictions the known technologies e.g. drilling, milling or EDM do. Here, the new technologies opened a door into a new world of design.

From Rapid Prototyping to Rapid Tooling and Direct Manufacturing.

At an early stage, engineers have used AM-processes for presenting the current state of a design and to demonstrate their thoughts through physical models. Even though, these models had a rough surface and were fragile, they have been used as haptic models or prototypes; thus, these technologies got the name: "**Rapid Prototyping**".

These technologies triggered many new design ideas, even though, a lot of pre- and post-processing was still required, and the quality was not comparable to "real" parts, yet. Within the next few years, the technologies have undergone considerable growth. This is mainly due to both, the increased part quality and machine availability. A new industry has been emerging, taking care of the development of appropriate software, new materials and new applications for AM-technologies. From this point, they found more and more application in design bureaus of several industries.

However, the vision for the application of AM goes beyond the creation of haptic prototypes; in recent years, the demand for parts with serial product quality has been growing. Here, indirect technologies such as “**Rapid Tooling**” have been used. Therefore, the required metal materials have been developed as a compound of two or more different materials and the cores and cavities have been taken as tools for injection molding and die casting. An example for the big variety of materials is the still current use of sand for sand casting.

Today, there is still a group of desktop applications, which delivers more or less high quality parts with special purposes within the office environment. However, the demand for products for real applications is growing. In this area, technologies have been improved. Today, two kinds of materials can be processed in commercial machines: Polymers and Metals. There are two different kinds of processing the material: the laser based and nozzle heated process. A laser is used for processing both, polymers (Laser Sintering) and Metals (Laser Melting, DMLS). Fused Deposition Machines are based on the heated nozzle process to process thermoplastic material.

Due to new applications, the rising expectations and increasing demand with regard to AM-technologies, the development is progressively moving forward to **Direct Manufacturing** (DM). The major goal is to make parts available which have the required properties and are ready to use.

Due to newly available AM-technologies and materials, nowadays, a large variety of applications is prevalent in the market. The aerospace industry is a big pioneer regarding the application of AM-technologies, as the parts are of complex shape and series production is pretty expensive, due to small lot sizes. In addition, AM-technologies are widely spread in the market for medical applications. For instance, the number of additively manufactured artificial hips, surgery supporting tools and the teeth-substitution (dental) is growing. Furthermore, additively manufactured “spare parts on demand” and repair tools are prevalent in a number of industries.

To increase the final acceptance of additively manufactured parts in the market and to induce the association of high performance and high quality, AM-technologies have to follow the way of improvement. Especially, it is indispensable to guaranty reliable parts which have predictable properties – wherever built in the world. Additionally, the capability and speed of machines has to be improved. Further research is required, to transfer AM-technology into a dependable, production rugged technology.

1.2 Current Application Fields for Direct Manufacturing

AM has a major impact on many industries and is partially moving towards DM. The following sections provide short characteristics of important industries wherein AM is increasingly becoming important. The characteristics encompass the aerospace, armament, automotive, dental, electronics, furniture, implants/prosthetics, jewelry, specialty food, sports, surgical devices/aids, textiles, tool and mold making as well as the toys/collectibles industry.

1.2.1 Aerospace Industry

The aerospace industry requires parts that are lightweight, strong as well as geometrically complex; they are manufactured in small quantities.

Aerial vehicles have become indispensable. The spectrum ranges from unmanned aerial vehicles (UAV) and transport aircraft to vehicles for space tourism. Today, the development and research work within the aerospace industry pursues the objective of continuously improving the efficiency of aircraft and reducing the air and noise pollution [Bul09]. These objectives require parts that are lightweight, strong and electrically conductive in some cases [BLR09]. In addition, most products are geometrically complex and manufactured in small quantities with high unit costs.

Due to these special characteristics, the aerospace industry is particularly suitable for an early adoption of DM [Woh06], [Fro07]. For instance, Boeing became involved in the vanguard of the AM-technology. Thanks to major progresses within several ranges, AM has already contributed to reduce or even to eliminate tooling, welding, inventory, and entire assembly lines [BLR09].

Market Development

From the beginning of AM in the 1980s until today, AM-technologies have constantly been upgraded in the aerospace industry. The reputation of AM-technologies is high, as the benefit of these technologies at small scale production is significant; once only used for Rapid Prototyping, today these technologies are already used for parts in aircraft [Wor10]. Larger OEMs, such as Boeing and Airbus, are already trying to exploit these benefits for very large products; small companies are following. Within the last three years, the total AM-market has grown by 17.4%. The total volume is currently around $1.2 billion [Bop10]. About 9.6% thereof is attributed to the aerospace industry. This corresponds to ca. $115 million [Woh10]. Compared to the expected world market volume of the aerospace industry amounting to $478 billion in 2010, the AM-market share is still marginal [Mtu09-ol].

Technology Development and Fields of Application

AM is already being used for a great variety of applications within the aerospace industry. In particular, the design and manufacturing of lighter-weight parts play an important role for the aerospace industry. For instance, the following parts have already been manufactured additively:

- Structure parts for unmanned aircraft by SAAB Avitronics [Woh03], [Woh10];
- Special tools for the assembly [Wor07];
- Customized interior of business jets and helicopters [Woh03];
- Physical 3D mock-ups by Boeing [Woh03];
- Turbine blades [BLR09];

- Windshield defrosters by AdvaTech Manufacturing [Woh06];
- Swirler - fuel injection nozzle for gas turbine applications by Morris Technologies, Inc. (see fig. 1-1).

Figure 1-1: *Swirler (fuel injection nozzle) for gas turbine applications made from CobaltChrome MP1 (picture courtesy of* MORRIS TECHNOLOGIES*, Inc.) provided by* EOS

In addition, AM-technologies are used for reparation and remanufacture of worn component parts, such as turbine blade tips and engine seal sections e.g. by ROLLS ROYCE [Ree09a].

Value Creation Potential for DM-Technologies

AM engenders several starting points for value creation within the aerospace industry (see fig. 1-2).

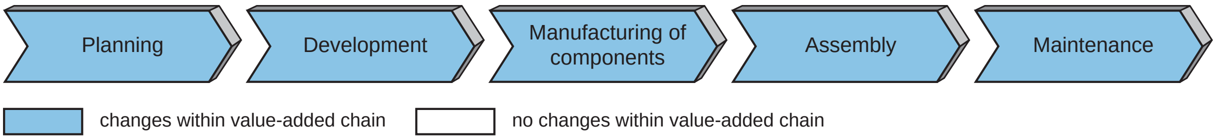

Figure 1-2: *Exemplary value-added chain for the aerospace industry*

AM matches the requirements of the aerospace industry regarding complex geometries and small lot sizes.

Due to the design-related benefits resulting from the AM-technology, engineers need to be trained to generate the maximum benefit resulting from the deployment of AM-technologies within the planning and development process of components. In addition, the manufacturing of complex and movable geometries enables a far easier and even faster assembly. Further value creation potential is provided within the maintenance of aircraft. On the one hand, AM-technologies can support the reparation of damaged parts [Ree09a]. On the other hand, fewer stocks are required, as parts can be produced just in time accordingly to the present demand [Woh03].

Trends

Different trends identified to be relevant for the aerospace industry are listed below:

- Increasing usage of lightweight structures [Bul09];
- Implementation of more organic features in designs for adding strength to components [Wor10];
- Increasing individualization of design and customization of the interior of aircraft [Wor10];
- Diversification of the product portfolio of the Tier 1/2 suppliers [Wor10];
- Intensified research in terms of developing new materials and differentiation features, e.g. individual cabin layout [Cla07];
- Growing demand for new overall traffic solutions reducing emissions, noise and costs [Bul09].
- Application of AM-technologies for tooling and fixturing [Wor10];
- High pressure on the fuel-reduction technologies, e.g. laminar flow [Bul09];
- Adaptive shapes, especially adaptive wings [Bul09];
- Changes regarding the ground handling: Increasing requirements concerning new configurations such as the Blended Wing Body, or extremely short take-off and landing characteristics [Bul09].

1.2.2 Armament Industry

The basic security environment and the requirements of the armed forces significantly changed after the Cold War. Nowadays, the performance of armies is primarily due to the impact of weapons, instead of to the number of soldiers. Furthermore, forces with heavy armaments, such as battle tanks, give way to specially armed units capable to move quickly across long distances. These requirements are reflected in the development of weapons and military systems [Bul09].

Armament industry products are mainly of great value and complex structure.

Today, weapons and military systems are mostly of great value as well as of complex structure. They are produced in low quantities, typically limited to a maximum of some thousand parts [HC06]. Many components even have to be upgraded after a production volume of ten or twenty units. As a result, tooling costs and procurement costs for updating these parts significantly increase. In addition, some parts are customized and need to be replaced regularly, which can even occur during operations in remote locations [BLR09].

Against this background, AM gains importance, as they are capable to cope with the challenges described above. For instance, the manufacturing of any kind of geometry and processing hard and soft materials, modification and repair of components become possible through AM-technologies [HC06].

Market Development

The armament industry has a high market attractiveness for AM, as military expenses are often performance and not price-driven. High expenditures for defense create a huge and still growing market volume [Jac10]. The total market volume of arms sales, including the world's 100 largest arms-producing companies (the SIPRI Top 100) increased by $39 billion in 2008 to reach $385 billion [Jac10]. Regarding the AM-market, the armament industry has a market share of approximately 6.5%, which corresponds to circa $70 million [Woh10].

Technology Development and Fields of Application

AM-technologies have already found their way into the armament industry within the recent years; several companies have demonstrated the ability to produce AM-products that can be used for combat [Ple08]. First applications have been realized such as mentioned in the following:

- ABS camera mounts for Abrams tank and Bradley fighting vehicle by EOIR [Woh03];
- Waterproof enclosure for a subsonic Unmanned Aerial Vehicle (UAV) by SAAB avitronics [Ple08];
- LS31, a hand-held, testing apparatus for laser warning systems on airborne, fixed and rotary winged platforms by SAAB avitronics [Ple08];
- Complex military airframes structures [Wor10];
- Customized gun components, such as stocks and grips [Wor07].

The armament industry is well known for its' innovations such as GPS or laser and still spends a high amount of money on the development of new technologies that are applied in the civil industry afterwards.

Value Creation Potential for DM-Technologies

The armament industry can significantly benefit from AM, as AM engenders several starting points for value creation along the value-added chain (see fig. 1-3).

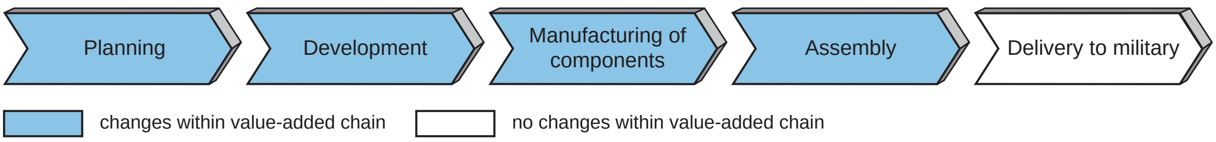

Figure 1-3: Exemplary value-added chain for the armament industry

AM can increase the performance of military equipment especially regarding light-weight structures.

Fast changing requirements are characteristic for the armament industry. To meet these requirements, high flexible manufacturing methods are needed. In this context, the CAD-based AM increases the flexibility of the design and the manufacturing process [HC06]. Thereby, changing requirements can be handled by modifying a CAD file to manufacture the new part. Re-tooling becomes obsolete, and reparation and re-manufacturing much easier [HC06]. Furthermore, AM-technologies facilitate the construction of complex geometries, which allow the creation of lightweight-structures for all kinds of products. Thereby, ergonomics are basically improved [HC06]. This can be used to create new high-tech products to meet the demands of the armament industry for being a technology leader. Thus, AM enables value creation in the planning and development processes as well as within the manufacturing and assembly of parts.

Trends

The major trends within the armament industry are: The major trends identified to be relevant in the armament industry are mentioned in the following:

- Increasing sales of armaments industry companies [Jac10];
- Modern armies that are expected to be combat ready on every place of the world within a few days;
- Rising usage of more eco-friendly products [Bec10-ol];
- Lighter body armor for soldiers and police [Erw09-ol];

Due to the expected improvements regarding materials, part quality and process reliability, the armament industry is expected to turn into a major user of AM-technologies within the next 10-12 years, especially as :

- Weight reduction becomes possible through using AM-technologies for parts and their properties which could not be realized before;
- The variety of UAV components built with AM-processes is expected to increase;
- AM enables flexible and fast production [BLR09].

1.2.3 Automotive Industry

Within the automotive industry, the integration of customer requirements is decisive.

Individual mobility plays an important role in the society. Today, a great number of various customer demands on design, environment, dynamics, variability, comfort, safety, “infotainment” and cost effectiveness have a major impact on automotives [Bul09]. To meet these demands, new technologies are required.

Compared to other industries, the automotive industry is the pioneer for applying new technologies in many instances. Since 2000, the application of AM-technologies has been propagated continuously within the automotive industry. Today, the automotive industry is already a major user of Rapid Prototyping equipment: AM-technologies are being applied for manufacturing of functional prototypes and for small and complex parts for luxury and antique cars [Fro07], [BLR09], [Woh03].

Especially, the motorsport sector constitutes an important field for the application of AM-technologies, as here high performance and low weight play a central role. In addition, AM is particularly appropriate, as the requirements of high quality functional components and shortening production times are constantly rising [CTD08], [Cev06a].

Market Development

Within the automotive industry, increasing competition reinforces the pressure for reducing the time-to-market. This challenges the automotive industry to secure and further expand the market share. Against this background, the automotive industry can derive great benefits from the application of AM-technologies, as this technology enables a rapid production of complex parts, including a wide range of material properties [Fro07].

In 2009, the automotive industry contributed 17.5% to the total AM-market volume. This corresponds to circa $190 million. Thus, the automotive industry is currently the major user of AM, as it accounts the largest market volume, compared to all examined industries [Woh10]. However, the AM-market is still marginal, compared to the world market volume of the automotive industry, which is expected to amount to $3,000,000 million in 2010 [Der01-ol].

Technology Development and Fields of Application

AM is already widely spread within the automotive industry: it is being used for a great variety of applications, such as concept modeling, functional testing, rapid manufacturing, and production planning across the automotive industry [Fro07]. However, AM is currently only used for prototyping and DM of small, complex and non-safety-relevant components within small series, as process reliability and consistency of products is still limited [BLR09]. Furthermore, the construction size plays a central role, as many parts are oversized for being manufactured by currently available AM-machines.

Some examples for notable applications are named in the following:

- Testing part design to verify correctness and completeness of parts by BMW, Caterpillar, Mitsubishi [BTW09], [Cev06a], [Woh06];
- Parts for race vehicles, e.g. aerodynamic skins, cooling ducts, electrical boxes [Cev06b], [CTD08], [Woh03], [Woh07];
- Pre-series components for luxury sport cars, e.g. intake manifolds, cylinder heads by Lamborghini [Cev06a], [Fro07];
- Replacement of series parts that are defect or cannot be delivered, e.g. cover flaps by Lamborghini [Cev06a];
- Assembly assists for series production by BMW, Jaguar [Woh06];
- Ducati engine by Stratasys, Inc. (see fig. 1-4)

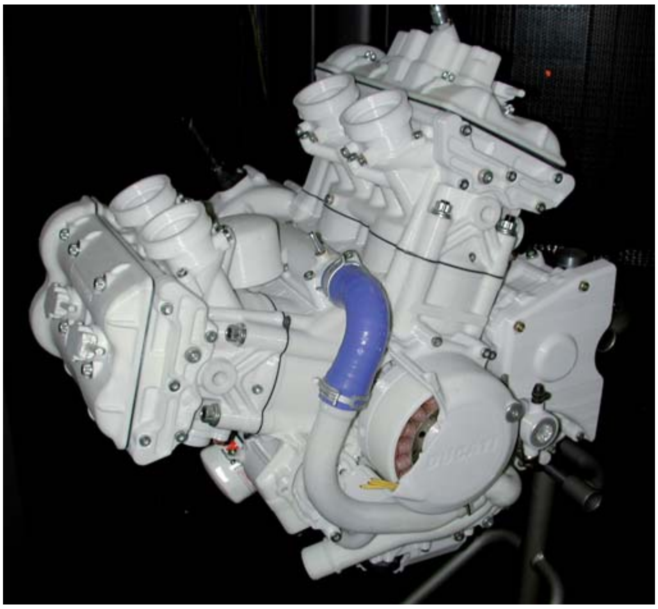

Figure 1-4: Ducati engine made by Fused Deposition Modelling (picture courtesy of STRATASYS, INC.)

Value Creation Potential for DM-Technologies

Using AM-technologies within the automotive industry provides numerous approaches for value creation along the value-added chain (see fig. 1-5). First, AM-technologies can support the development process of new cars, as the technology can be applied for prototyping instances.

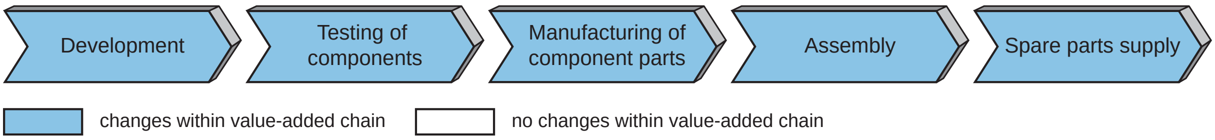

Figure 1-5: Exemplary value-added chain for the automotive industry

Second, AM can be applied for manufacturing small series of functional parts. This enables a cheaper realization of small series production, as design and manufacturing tools become dispensable. In addition, the production time can be reduced by the application of AM. Through shorter production times, replacement parts can be produced on demand. Furthermore, AM allows automotive suppliers to offer several design proposals and enables the OEMs to identify the best solution by means of performance tests.

AM allows cheaper realization of small series and replacement parts.

Trends

In the future, the automotive industry is expected to generate an immense demand for AM-equipment [Fro07]. Further trends within the automotive industry are:

- Higher demand for lightweight structures [Wor10];
- Increasing demand of replacement parts for antique cars [Cev06b];

- Raising desire for individual mobility [Bul09];
- Electrification of the power train [Bul09];
- Higher focus on sustainable mobility [Bul09];
- Increasing importance of individual customer needs [Bul09];
- Higher density of traffic [Bul09].

1.2.4 Dental Industry

Today's dental industry is significantly influenced by demography, digitalization and networking between the dental and general medicine branch. Within the dental industry, the developments range from innovations in prophylaxis and restoration to special treatments [Gfd09].

Dental industry requires products which are mainly individualized.

At present, the dental industry is changing, as increasingly new manufacturing technologies find their way into the dental industry, especially into dental restoration [Eos11-ol]. While dental restorations have long been produced by using conventional casting techniques, currently the digital dental technology proliferate and manufacturing processes are being automated [Eos11-ol]. This is mainly due to the fact that individualization and mass customization are progressively becoming important, as the patients expect exactly fitting products, such as crowns and bridges. Using AM, the requirements of individual production can be met and hand-crafted processes become obsolete [KLK08].

Market Development

In recent years, the dental industry experienced a positive market development [Vdd11-ol]. The great and rapid growth is mainly due to the progressively aging society and the growing interest in aesthetic teeth. In 2006, the total market volume of the dental industry amounted to $22.5 billion [Par06]. Especially, the AM-market has grown explosively within the dental industry, which is still the fastest growing field of application for AM [BLR09]. Together with the medical industry, the dental industry had a market share of approximately 14.7% in 2009. This corresponds to circa $157 million [Woh10].

Technology Development and Fields of Application

Within the dental industry, standardized manufacturing technologies are increasingly replaced due to great benefits from AM-technologies. First, AM-technologies are especially appropriate to manufacture any dental product of any individual shape. Second, using AM the production speed can be significantly raised. For instance, a dental technician can produce around 20 dental frames per day through using conventional casting production technologies. Using Laser-sintering, approximately 450 high-quality units of dental crowns and bridges can be produced within 24 hours. This corresponds to a production speed of approximately three minutes per unit on average; thereby, production costs can be immensely reduced.

In consequence, AM is already widely applied for manufacturing the following parts:

- All kind of digital protheses such as bridges and crowns/dental caps (see fig. 1-6) [BLR09], [Ree09a], [Woh10];
- Dental aligners and invisible dental braces [Woh03], [Woh06], [Woh07], [Sch08];
- Models of the patient's jar which are required for accuracy checks of dental restorations [KLK08], [Sch08].

Figure 1-6: Dental protheses made by SLM (picture courtesy of SLM SOLUTIONS GMBH*)*

In addition, due to perpetual developments in the area of picture-giving procedures, the number of 3D records is also rising continuously. This supports the application of the technologies within the process chain. However, there still is potential for enhancing the attractiveness of the technology, for example through shortening the manufacturing process by directly sintering ceramics to safe the veneering step.

Value Creation Potential for DM-Technologies

AM matches the requirements of individualization, and is already widely spread.

The dental industry is already one of the most decent industries for the use of DM, as reflected through the market and technology development. AM engenders several approaches for value creation along the entire value chain (see fig. 1-7). First, by digitalizing the manufacturing process, it is possible to weed out error sources from the assessment of the patient to the production in the lab, and to guarantee consistently high quality. Thereby, the risk of incorrect preparation or moldings, of imprecision in fit and during the finishing work, and costly repetitions can be immensely reduced. Second, high reproducibility of production properties and a patient-specific serial production can be realized.

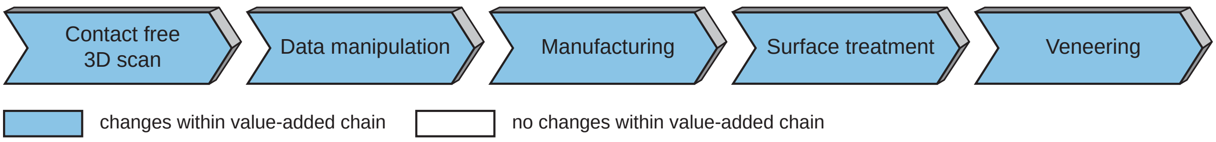

Figure 1-7: Exemplary value-added chain for the dental industry

Third, due to software supported workflows, processing times are reduced. Thus, the dental technician can concentrate on the vital peripheral processing steps such as the aesthetic and function-orientated ceramic veneering [Eos11-ol], [Eos06-ol].

Trends

In the future, the dental industry will benefit from the increasing purchasing power for dental esthetics [Vdd10-ol]. The industry must respond to an increasing demand for long-life teeth resulting from the demographic change [Gfd09]. In addition, it faces the challenge to reduce costs due to the higher cost pressure from health insurance companies. Furthermore, there is a tendency towards planning of surgeries in advance; this encompasses 3D scans of the broken tooth, the modeling of the new crowns based on the scan, fitting tests on a model of the patient's mouth, digital simulations of the surgery as well as the manufacturing of the crown and drilling template. Further trends revealed to be relevant within the dental industry are the following:

- Declining prices for crowns increase the need for new manufacturing technologies;
- Higher focus on the development of minimally invasive surgery [Vid08-ol].

1.2.5 Electronics Industry

Electronics industry products and production systems are characterized by short lifetimes.

Electronics are present in daily life; the spectrum of application ranges from mobile phones and computers to cars. Electronics products are often small in size, and therefore, high precision tools are required for the manufacturing process. As technological advance is rapid, lifetimes of electronics are often short. Thus, new manufacturing equipment is needed in short intervals.

Using new and flexible manufacturing technologies such as AM-technologies is appropriate to accelerate development processes and build times. All in all, AM can enable manufacturing equipment that can meet the challenge of the rapid technological advance, and to rapidly turn the advancements into new products [Fro07].

Furthermore, the electronics industry is characterized by product miniaturization. Against this background, the integration of functions into structures is gaining importance. AM-technologies are suitable to meet these requirements though embedding electronics (circuits) into all kind of geometries.

Market Development

The total world market volume of electronics amounted to $1.8 trillion in 2006, $2 trillion in 2007, and is expected to reach $3.2 trillion in 2012. This corresponds to a Compound Annual Growth Rate (CAGR) of 9.5%. Industrial products contribute 39.6% to the total electronics sales; computers have the second largest market share of 20%. The market share of semiconductors, consumer and communication products amounted to 13.5%, 13.4% and 9.9%, respectively. 2.6% are contributed by electronics for automotive applications [Pri07-ol].

Technology Development and Fields of Application

AM is already widely spread within the electronics industry. Especially, the production of manufacturing and tools equipment benefits from the deployment of AM. The production of embedded electronics represents another field of application. Furthermore, AM is already used for products such as:

- Embedding Radio Frequency Identification (RFID) devices inside solid metallic objects [Ree09a];
- Polymer based, three-dimensional micro-electromechanical systems by MEMS [FCM+08], [FWJ02];
- Microwave circuits fabricated on paper substrates [YRV+07];
- All kind of grippers within automated production systems (see fig. 1-8).

Figure 1-8: Gripper made by Fused Deposition Modelling (picture courtesy of Stratasys, Inc.)

The application potential for AM-technologies has been increasing significantly within the electronics production, as new polymers, and metal-based materials and inks have been emerging. Especially, inkjet printing methods are forerunners for the application of AM-technologies within the electronics industry [SA10].

Value Creation Potential for DM-Technologies

AM accelerates the product development process and enables lot size one production.

Using AM a number of value creation potentials emerge along the value-added chain (see fig. 1-9). First, manufacturing of electronics can be easier adapted to domain specific development processes, and the design process can be significantly accelerated as electrical circuit boards of any geometry and shape can be directly manufactured. Second, it is possible to functionally integrate a number of different electronic devices in just one product. Third, functional prototypes can be built, and applied for testing purposes. Finally, small lot sizes, especially lot-size-1 can be rapidly manufactured due highly flexible production. Thus, spare parts can be produced on demand, whereby tooling and storage become obsolete.

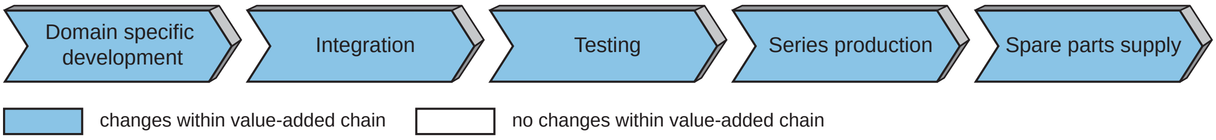

Figure 1-9: Exemplary value-added chain for the electronics industry

Trends

Different trends identified to be relevant for the electronics industry are listed below:

- Growing demand for accelerated product development require shorter lead times of tooling [Nad10], [HJ00];
- Focus on integration and services [Ros08];
- Increasing demand for embedded electronics [Bul09];
- Silicon electronics are increasingly becoming a key technology for information and communication technology [Bul09];
- Miniaturization and functional integration of devices [Bul09];
- Growing demand for smart microsystems [Bul09];
- Emerging market for polymer electronics [Bul09].

1.2.6 Furniture Industry

In the furniture and home accessories industry, design has always been an important aspect. This applies for the whole market, for the low-price as well as for the high-price segments. However, especially, high-priced furniture is expected to be an eye-catcher in terms of innovative design and functions.

High priced furniture require innovative design and functions

Regarding these aspects, the furniture industry is especially appropriate for the deployment of AM. These technologies enable designers to realize various designs and ideas, as already impressively shown by e.g. Janne Kyttanen, founder of Freedom of Creation. .MGX transferred these potentials to industrial applications, and manufactured lamps additively. Thereby, .MGX has opened up the market for additively manufactured furniture and home accessories [Woh10].

Market development

In 2009, the furniture industry reached a total market volume of $376 billion [CIS10]. Regarding the AM-technologies, less than one percent of the total market volume is contributed by additively manufactured furniture [Woh10]. This is mainly due to the actual AM-furniture product portfolio which is only focusing the high-price market segments. However, the integration of individual customer requirements into products and the penetration of the mid-price or even low-price market segments offer the possibility to increase the attractiveness of AM within the furniture market.

Technology development and fields of application

Until today, conventional manufacturing processes are not able to satisfy the designer's requirements for geometric freedom, the so called freedom of design. Therefore, numerous designers have taken advantage of AM to produce design and function-driven furniture. For instance, .MGX by MATERIALISE is manufacturing furniture and accessories using a variety of 3D printing methods. This method enables the production and customization of shapes that would otherwise be impossible to realize [MGX11-ol]. FutureFactories is using AM for the individualization and reproduction of existing design icons [Woh10]. Further individual and unique furniture products manufactured additively are e.g.:

- Limited and customized editions of lightning designs by e.g. .MGX [Woh06];
- Tables, chairs and accessories by FREEDOM OF CREATION and FUTUREFACTORIES (see Figures 1-10);
- Custom hardware for doors by METALTEC INNOVATIONS [Woh09].

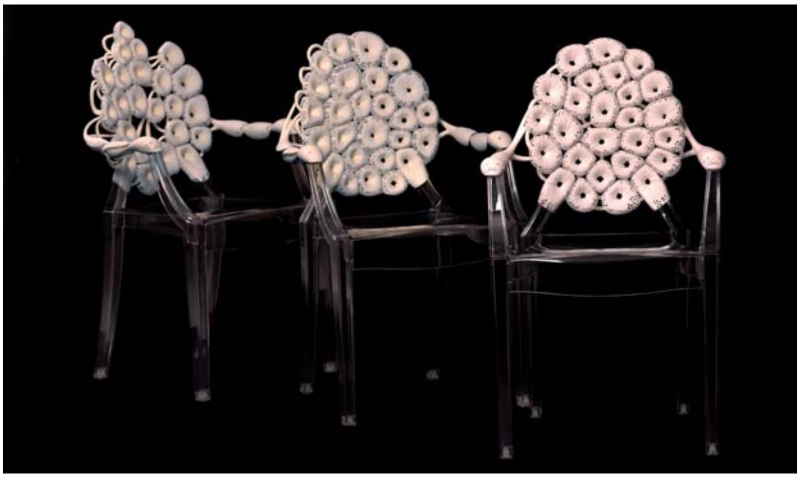

Figure 1-10: Holy Ghost chair, edition of ten, 2006 (Design: Lionel T. Dean, picture courtesy of FUTUREFACTORIES*) provided by* EOS

Value Creation Potential for DM-Technologies

The use of AM for the manufacturing of individualized and customized furniture and accessories on demand provides great value creation potentials along the value-added chain within the furniture industry (see fig. 1-11).

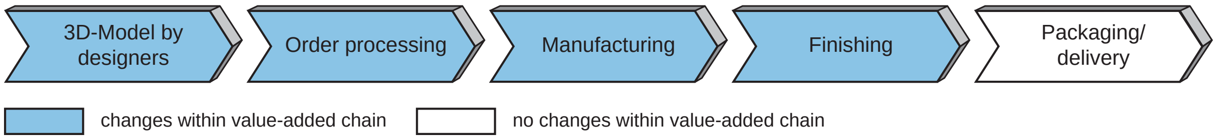

Figure 1-11: Exemplary value-added chain for the furniture industry

AM enables customer integration, production on demand and cost reduction.

First, non-AM-experts can become designers, as easy-to-use CAD systems facilitate the design process. Such 3D systems enable individualization of standard products, as any geometry and shape can be realized. Second, through using AM, production on demand becomes possible whereby the stock size can be reduced. Third, quick changes of the manufactured products are possible through using AM-machines. Finally, compared to the hand-crafted manufacturing process, AM can contribute to shorten production times and to reduce labor costs, as the manufacturing process is automated.

Trends

The furniture industry is characterized by increasing demand for individual interior design which can be fulfilled by unique furniture and accessories [Bus10-ol]. Further trends identified for the furniture industry are:

- A higher focus on renewable resources and ecologically sustainable raw materials [Bus10-ol];
- Higher utilization of different materials in one piece of furniture [Koe10-ol];
- Increasing demand for individual configurability of module systems and adjustment mechanisms [Got10a-ol];
- Higher demand for colorful furniture and pattern [Got10b-ol].

1.2.7 Implants and Prosthetics Industry

Implants and prosthetics are individual and have high requirements regarding function, design and bio compatibility.

Replacing body parts by implants and prosthetics is in progress for many years. The development process is significantly characterized by growing insights into interactions between biological and artificial functional systems. Taking these interactions into account is essential to ensure compatibility of the artificial and biolgical parts, as nothing is as individual as the human body. This imposes a number of requirements on the final products such as macroscopic (e.g. function, design) and microscopic requirements (e.g. biocompatibility, bioactivity) [Bul09].

AM is suitable to contribute within this field of application, as the technologies enable production of items that are unique in terms of tailored to the patient's requirements [Woh03]. Due to these capabilities of AM, there is great demand potential; especially equipment vendors can significantly benefit therefrom [Fro07].

Market Development

In 2008, the market volume of the implants and prosthetics industry amounted to $11.8 billion within the EU [Eur08-ol]. Regarding the AM-market, the medical and dental industry, has a market share of approximately 14.7%. This corresponds to circa $157 million [Woh10].

Technology Development and Fields of Application

Today, manufacturing replica models of almost any part of the body and creating bone-replacement material for reconstructive surgeries or customized prosthetics is possible due to AM [Ree08b]. For instance, 60% of the worldwide production of hearing aids are already manufactured additively [KL07]. Research institutes have already developed scaffold structures to promote bone growth [Woh03]. Further applications have been realized, such as mentioned in the following:

- Parts for fully integrated prosthetic arms (see fig. 1-12)
- Contact lenses by NOVARTIS [Wor07];
- Cochlaer implants [Ree09b];
- Prosthetic limbs and hibs [Ree09b], [Ree08a];
- Prosthetic legs [Woh10];
- Prosthetic gloves [AMH08].

Figure 1-12: Humeral mount for a fully integrated prosthetic arm made from EOS *Titanium Ti64 (picture courtesy of Deka) provided by* EOS

Value Creation Potential for DM-Technologies

The entire implants and prosthetics industry can benefit from the deployment of AM along the value-added chain (see fig. 1-13).

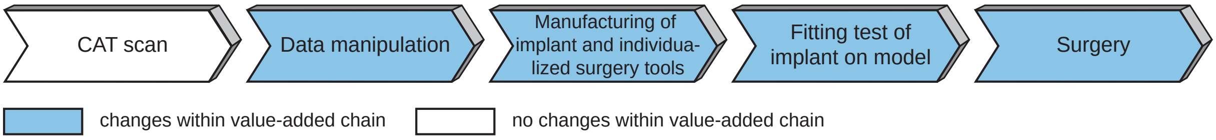

Figure 1-13: Exemplary value-added chain for the implants and prosthetics Industry

AM enables highly individualized shapes matching the human anatomy.

First, data manipulation becomes easier and error sources can be weeded out at an early stage, from the assessment of the patient to the production in the lab, due to the digital manufacturing process. Second, AM can enable manufacturing of complex shapes matching human anatomy, porous microstructures from biocompatible materials and cells, genes and proteins together and separately on the same platform. In addition, these parts can be manufactured at resolutions below 10 microns over structures greater than 1cm in size. Thereby, the compatibility of artificial parts with biological body parts can be significantly increased. For this purpose, special materials are required to match the mechanical and biological properties between bones and implants (e.g. living cells). The development of new materials and processes for the manufacturing of multi-material products can open up new markets. Furthermore, additional potentials can be generated through the development of information technology, which is needed to handle biological and communication data [BAB+04]. Finally, fitting tests can be performed easier on model.

Trends

The major trends revealed to be relevant within the implants and prosthetics industry are the following:

- Over-aging of the population and increasing awareness of health issues [Ree09c];
- Raising dissemination of custom-tailored surgery strategies that include the replication of anatomic structures, the construction of drilling templates and shortening of gauges to enable the surgeon to perform very complex surgeries [Fro08];
- Higher focus on the development of minimally invasive surgery [Vid08-ol];
- Focus on the transplantation of individually designed tissues and organs [Woh03];
- Development of equipment, which allows the printing of biomaterials [BLR09];
- Focus on the development of aids to improve patient comfort [Ree09d];
- Miniaturization and application of nanotechnologies [GSB+03].

1.2.8 Jewelry Industry

High priced jewelry requires individuality; costume jewelry focuses on creative design.

The jewelry products are often distinguished by complex geometries. Furthermore, jewelry can be differenced by value: one extreme encompasses exclusive, hand-crafted individual pieces made from expensive materials; the other extreme includes costume jewelries, which are cheap and produced in high lot sizes. Thus, the jewelry market is split into two market segments. Within the first market segment, the focus is on very high quality products; within the second, the time to market or the creativity of the design are the crucial success factors. Here, the quality is subordinate.

Especially, jewelry of complex geometries and shapes can significantly benefit from AM. This is applicable to both market segments. In addition, AM-technologies enable creative individuals to create their own designs; thereby, individual requirements regarding design and material can be included and the product can be manufactured by a service provider or jeweler.

Market Development

The market volume of the jewelry industry is estimated at $70 billion worldwide [Woh10]. The deployment of AM is considered to be highly attractive for manufacturing jewelry, as AM-technologies have the ability to replace established production methods for parts of both, the high-price and the low-price market segment. In 2009, about 24.1% of the total AM-market volume is attributed to the consumer products industry where the jewelry industry belongs to [Woh10]. This corresponds to ca. $260 million.

Technology Development and Fields of Application

Today, AM already match a number of requirements of the jewelry industry, such as the processability of high-value materials and the creation of any geometry. A central challenge is the still limited availability of materials that can be used for AM. In addition, the surface quality of additively manufactured parts still cannot be guaranteed; post-processing is still required. Currently, AM contributes within the following ranges:

- Cores and models for investment casting;
- Customized and limited edition products;
- Jewelry in gold alloys by REALIZER [Woh10];
- Wristbands by FREEDOM OF CREATION;
- Pendants for chains and wristbands by FUTUREFACTORIES (see fig. 14) [Ree08c];
- Jewelry holders [Env08];
- Sintering or melting 18 karat gold to produce fine jewelry by PARTICULAR AB [Woh06].

Figure 1-14: Icon, pendent, limited edition made from titanium, 2008 (Design: Lionel T. Dean*, picture courtesy of* FutureFactories*) provided by* EOS

Value Creation Potential for DM-Technologies

AM can substitute costly, handcrafted manufacturing steps.

AM provides value creation potential within the jewelry industry (see fig. 1-15). First, unique geometries can be designed, as digital development does not set any limits. Second, the digital sketches can easily be transferred to suppliers all over the world. Third, hand-crafted manufacturing processes can be replaced by AM, as AM-machines enable the manufacturing of highly individual parts. Thereby, personnel costs can be reduced significantly, and recycling costs of material decrease as almost no powder is wasted.

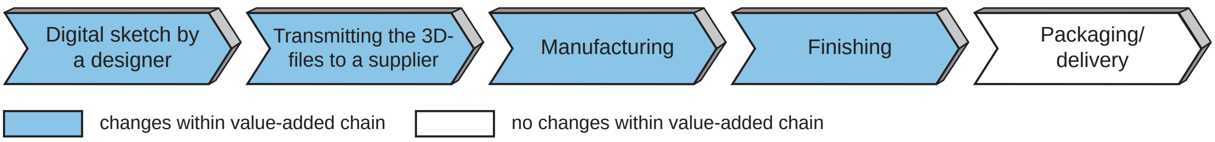

Figure 1-15: Exemplary value-added chain for the jewelry industry

Further value creation potential arises through an early integration of the customer into the design and creation process. Any customer requirements can be taken into account as well as possible.

Trends

The conventional buying habits of customers partly change and substitute the demand for conventional jewelers [Oha10-ol]. Today, the jewelers face the challenge that online selling is a growing market. Further trends identified to be relevant within the jewelry industry are the following:

- Increasing importance of products with strong branding and marketing efforts;

- Growing demand for innovative products [Oha10-ol];
- Increasing interest in individually designed rings [Bun10-ol];
- Higher production on multi-material combinations e.g. for classic jewelry [Bun10-ol];
- Increasing usage of various colors and colors combinations for costume jewelries [Bau10-ol];
- Progressive substitution of classic jewelry by costume jewelry [Bun10-ol].

1.2.9 Specialty Food Industry

Processability of edible materials into complete shapes is necessary for the application of AM within the specialty food industry.

Food technology includes all the know-how ranging from how to transform raw materials into semi-finished and finished food products. Within recent years, personalization of food is increasingly becoming important [Bul09]. Thus, the idea of fashioning food has emerged, and takes many forms nowadays. For instance, sculptures are presented on many fairs and exhibitions; custom chocolate business cards or “made-to-order” cakes are extremely popular. Food Network even provided television shows documenting the creation and construction of expensive cakes ($15 per slice). On the one hand, the individuality and the aesthetically pleasing shapes of such food products are impressive; on the other hand, hand-crafted manufacturing is required therefore [PSS+07]. To bridge this gap machines and techniques are needed that enable manufacturing of complex confections with specialized geometries and intricate material composition [PSS+07].

Within this context, AM is gaining importance, as hand-crafted manufacturing processes can be substituted. Thereby, food objects can be manufactured faster and in high lot sizes, with a single restriction that the used food has to be extrudable through a syringe, e.g. chocolate, cheese or peanut butter [BLR09].

Market Development

Worldwide, the specialty food industry has a marginal market share. However, the industry reaches an average annual turnover of $13 billion [BLR09]. The AM-market within this industry is negligible, as the application is still limited to single niche markets. Here, AM contributes within the preparation of food [PSS+07].

Technology Development and Fields of Application

Until today, AM is only used for experimental purposes within the specialty food industry. For instance, the Massachusetts Institute of Technology (MIT) developed a concept for a food factory with abilities to store, mix, deposit, and cook layers of ingredients [Woh10]. The Cornell University Computational Synthesis Laboratory began the Fab@Home project. Fab@Home is a platform, which provides printers and programs for the production of functional 3D objects. The platform is supported by a global, open-source community of professionals and hobbyists, innovating “tomorrow”

[Fab11-ol]. Thanks to these research efforts, AM is applied in the following fields:

- Production and refinement of exclusive cakes and sweets [PSS+07];
- Manufacturing of sushi made of printed layers with different flavor agents [GC06-ol];
- “Printing” menus with samples of taste [GC06-ol], [Mui05].

At present, further research encompasses printing promotion products and enabling food printing for its usage on space missions (NASA) [PSS+07], [BLR09], [Mui05].

Value Creation Potential for DM-Technologies

Even though, AM is not widespread within the specialty food industry, there are conceivable value creation potentials, especially at the end of the value-added chain (see fig. 1-16).

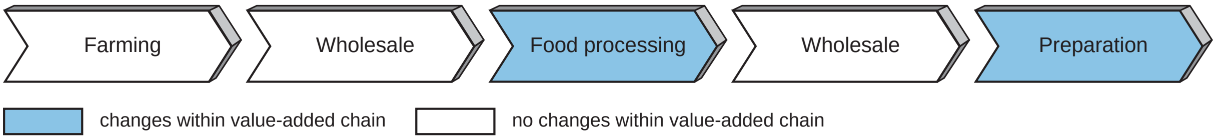

Figure 1-16: Exemplary value-added chain for the specialty food industry

Formerly hand-made products can be produced using AM.

First, through using AM for manufacturing exclusive food, originally hand-made products can be produced automatically. Thus, costs can be reduced and higher margins can be realized. Second, added value emerges within the preparation step. For instance, integrated machines can be used in remote locations and at places with limited physical space to produce meals from (food-)raw materials. This could engender a totally new market.

Trends

Future trends identified to be relevant for the specialty food industry are the the following:

- Increasing demand for natural and healthy food, which is produced without generating detrimental impact on climate [Bul09], [Hay10-ol];
- Changing habits of customers: according to statistical investigations, 77% of the population prefers eating at home [Hay10-ol];
- Personalization of food is increasingly becoming important, which raises the complexity and the costs of production [Bul09];
- The demand for international flavors and combinations, exotic food and drinks is expected to raise [Hay10-ol], [JA09].

1.2.10 Sports Industry

Sports equipment should match every customer's individual demand.

The general focus of sports equipment is to improve the performance of athletes, to prevent injury, and to increase both, comfort and enjoyment [Bul09]. As every human body is shaped individually, the equipment should adapt to everybody's individual needs. Today, basic approaches for customization, e.g. the customization of ski shoes, already exist within the sports equipment industry. However, the prevailing products do not perfectly match every customer's individual requirements.

These market requirements can be met by creating products which fit in color, form and function. Products individualized on this level can contribute to improve the performance of athletes. In addition, individualization allows consumers to create and follow design trends and quickly participate in the newest technological developments. AM can enable the required level of individualization for high-tech equipment, what the customers are willingly to pay high prices for.

Market Development

The total world market volume of the sports equipment industry amounted to $283 billion in 2008 [Ame10-ol]. The expenditures on research are raising and the interest in high quality equipment is growing. However, the high quality market segment is only a small part of the entire market. To raise the demand for AM within the sports industry, the access to the “downmarket” is necessary [Ree09d].

Technology Development and Fields of Application

At present, AM is mainly used for prototyping to carry out form and fit tests. Even though, a couple of companies and universities successfully manufactured e.g. shoes for professional athletes, AM is not widely spread within the sports equipment industry. This is mainly due to the fact that AM-technologies could not be applied for manufacturing cheap and high quality multi-material and multi-color sports equipment. Moreover, every retailer faces the challenge to manage the high complexity of CAD tools, as experts are required at any time. AM-technologies have been already applied for manufacturing a number of sophisticated sports equipment, such as the following:

- Soles of orthopedically designed footwear for performance athletes [Ree09d];
- Prototypes of snowboard bindings by Burton [Woh06];
- Personalized soccer shoes by Prior 2 Lever [Woh06];
- Individualized helmets for both, sports applications and on motorcycles [Ree09d];
- Personalized shin pads and contact sport padding [Ree09d];
- Taekwondo chest protectors [BBH+08].

Value Creation Potential for DM-Technologies

Sports equipment can be adjusted to individual properties using AM.

AM can provide many advantages within the sports equipment industry if the entire value creation potential can be tapped (see fig. 1-17). For instance, using AM-technology enables retailers to exactly match their customer's demands, as individual properties can be easily seized through the contact free 3D scan. Furthermore, stores can provide products just-in-time, even products produced years ago, without keeping products in stock. Thereby, stock costs can be reduced [Woh06].

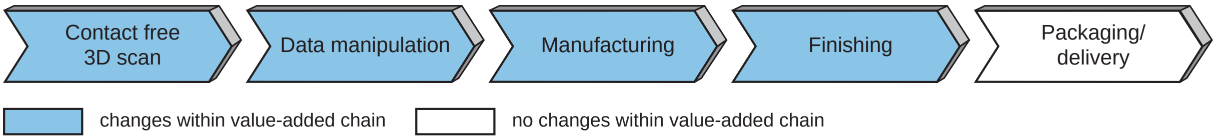

Figure 1-17: Exemplary value-added chain for the sports equipment industry

Trends

Within the sports equipment industry, a number of trends have been identified. For instance, there is a tendency towards raising demand for protective equipment for athletes, which is mainly due to the continuously increasing safety awareness. Further trends that are relevant for the sports equipment industry are:

- Due to improved living conditions, life expectancy is still increasing and people stay longer active [Ame10-ol];
- Expenditures for research in sports industry are progressively increasing [PBB+09];
- Shorter lifecycles within sports equipment industry force companies to accelerate production processes [Woh06];
- The number of suppliers is decreasing, as retailers search for reliable supply and customer service which is provided by their key suppliers [Ame10-ol];
- The timely delivery of goods is becoming more important [Ame10-ol].

1.2.11 Surgical Devices and Aids Industry

High quality and filigree are characteristic for products of the surgical devices and aids industry.

The surgical devices and aids industry has a strong focus on high quality and filigree parts. The industries‘ products can be described as complex mechanical and mechatronical devices. Due to the high complexity, cleaning and maintenance of the devices represents a major challenge.

Market development

The total market volume of the surgical devices industry amounted to $50 billion in 2008 [Eur08-ol]. Regarding the AM-technologies, the medical and dental industry, has a market share of approximately 14.7%. This corresponds to circa $157 million [Woh10].

Technology development and fields of application

Within recent years, the surgical devices industry has already been using rapid prototyping technologies, e.g. for prototyping catheters, stents etc. [Pro10-ol]. Thus, the deployment of AM is still limited to the manufacturing of functional prototypes to be used for clinical testing [Dvo10-ol]. This is mainly due to the fact that part and process quality cannot be guaranteed until now. However, there is great technology potential as AM can contribute to reduce the number of parts included in a product. Some examples for realized applications are named in the following:

- Functional prototypes for clinical testing (see fig. 1-18) [Dvo10-ol];
- Disposable surgical cutting guides [Ree09d], [Sei08];
- Housing parts for intraoral cameras by Planmeca [Woh06];
- Parts for a channel pipetting system by Tecan Group [Woh06];
- Frameless stereotatic guidance device [Wor07];
- Two-part polycarbonate housings for a handheld medical device that surgeons use for heart patients by Stratasys Redeye [Woh10];
- Veterinary tissue-stapling device [Woh10].

Figure 1-18: Prototype of an Expedium SFX Cross Connector measuring device (picture courtesy of DePuy*) provided by* EOS

Value Creation Potential for DM-Technologies

AM provides value creation potential along the entire value-added chain of the surgical devices industry, ranging from product planning with CAD software to the disposal of the synthetic material (see fig. 1-19).

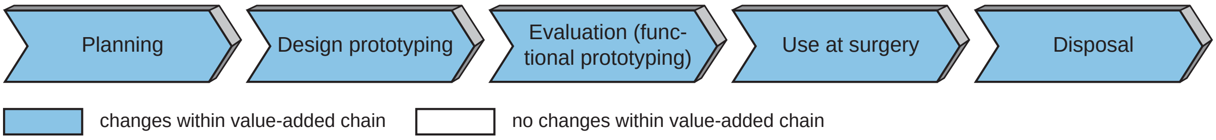

Figure 1-19: Exemplary value-added chain for the surgical devices and aids industry

AM enables the integration of kinematic functions into surgical devices.

Conventionally manufactured surgical devices, especially mechatronical products, have several challenges to face. Examples are extremely expensive cleaning and maintenance processes, which are necessary to keep reusable tools operational for years. AM-technologies can enable manufacturing of disposable products on demand. This can reduce purchase, maintenance and sterilization costs. Further added value emerges through the integration of kinematic functions into very small devices. Taking this path, it is possible to save drive elements and create cheaper products.

Trends

In the future, AM might be able to replace existing manufacturing methods within the surgical devices industry, and to improve surgery possibilities, e.g. within the minimal invasive surgery. In addition, maintenance costs can be reduced by manufacturing parts additively; maintenance can even become obsolete, due to disposable devices. Further trends identified to be relevant for the surgical devices and aids industry are the following:

- High focus on the development of new surgical tools [Vid08-ol];
- Increasing demand for disposable surgical devices [Ktw10];
- Focus on AM in the context of manufacturing medical instruments [Woh09];
- Increasing research on the development of surgical robotics [Vid08-ol];
- Replacement of traditional surgical procedures by using minimally invasive surgery [Vid08-ol].

1.2.12 Textiles Industry

Short lifecycles are characteristic for products of the textiles industry; customization is prevailiing.

Textiles are present in various area of life; the applications range from clothes and household textiles to technical textiles [Bul09]. The textile industry is a very short-lived industry. Every season, new design trends, such as new colors, new cuts, etc. penetrate the market and force many manufacturers to change their product portfolios. Therefore, short product development processes are essential within the textiles industry. In addition, the industry must respond to an increasing demand for functional high-performance textiles. Moreover, customers are demanding for customized, body-fitting clothes [Shi05]. The production of conformal textile articles is connected with restrictions. On the one hand, restrictions are imposed from the manufacturing of the textile itself, as individual production systems are needed. On the other hand, restrictions result from the design and the production of the garment, as production systems cannot proceed every kind of material [BHT+07]. Against this background, AM is suitable to be applied within the textiles industry [Lee07].

Market Development

As fashion reinvents itself every year, the textiles industry reaches a high market volume. In 2007, the market volume amounted to $500 billion [Eul09]. However, still a marginal market share thereof is contributed by AM. This is mainly due to the fact that AM are not supposed to replace conventional manufacturing methods in standard and affordable clothing in the near future. Nevertheless, especially niche markets such as the high-performance and the “intelligent” textile market are expected to benefit from AM-technologies [BHT+07].

Technology Development and Fields of Application

Until today, the penetration of the market within the textiles industry is still limited to experimental purposes. This is mainly due to the fact that conventional technologies already meet a number of the required abilities of textiles [BHT+07]. However, the following products have already been manufactured additively:

- Handbags and wristwatch bands [Woh07];
- Clothing garments (see fig.1-20) [Woh07];
- Shoes, e.g. bathing shoes by NIKE, high heels by FREEDOM OF CREATION [Woh10];
- Gloves [Woh10].

Figure 1-20: Laser Sintered dress, design: JANNE KYTTANEN *and* JIRI EVENHUIS*, part of the permanent collection of the* MUSEUM AT FIT, NEW YORK *(courtesy of* FREEDOM OF CREATION*)*

Value Creation Potential for DM-Technologies

The textiles industry engenders several starting points for added value along the value-added chain (see fig. 1-21).

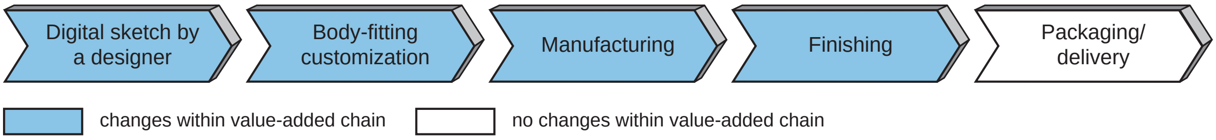

Figure 1-21: Exemplary value-added chain for the textiles industry

Integration of new functionality into textiles using AM

First, digital sketches can contribute to accelerate the development process. Additively manufactured textiles often consist of repetitive geometries, which have to be linked for the creation of garments. Using tools, such as TexGen instead of conventional CAD software to perform the linkage, can significantly reduce this effort by repeating small geometries along smoothed surfaces. This can speed the development by months. Second, unique geometries can be designed, as digital development does not set any limits. Therefore, customers can buy and even design totally individualized clothes themselves. Finally, the textile industry can benefit from AM, as fundamentally new functionalities can be integrated in smart and intelligent textiles by manufacturing them additively.

Trends

A number of trends identified for the textile industry are listed in the following:

- Growing demand for high-performance textiles [BHT+07];
- Increasing number of colorful textiles [Wie10-ol];
- Higher interest on seamless garments [SA10];
- Raising focus on body-fitting customization [Lee07];
- Higher interest in special coating with nano-technology [Gfd09];
- Increased use of conducting yarn for textile electrodes, e.g. for the control of ECG, pulse, temperature and breathing [BNB+11-ol]
- Growing demand for technical textiles, for instance increasing use of textiles in the automotive sector [Bul09];
- New spinning processes enable the creation of completely new types of fibre with novel properties [Bul09].

1.2.13 Tool and Mold Making Industry

Tooling includes moulds, dies and tools. The spectrum of tooling ranges from early-stage prototypes until full-scale production and is a capital and knowledge-intensive business [Woh10], [ETP11-ol]. Aeronautics, automotives, electronics, household equipment goods and micro-devices are some industrial products wherein tooling contributes within the design and manufacturing process. Tooling is crucial for the competitiveness, efficiency and robustness of the production system of final products, as it links final parts (products and components) and production equipment (machine-tools) [Woh10].

Manufacturing times of tooling are crucial for the success.

Today, the development and manufacturing of tooling is one of the most expensive and time consuming steps within any manufacturing process. This is mainly due to complex geometries of final parts that require high accuracy and reliability, low surface roughness, and strong mechanical properties [CPN09-ol], [Fro07]. Furthermore, tooling strongly depends on its further application, as different applications require different materials, part volume, size etc. [Woh10].

Within recent years, more and more companies have identified AM to be a promising technology to save time and money [Woh10]. AM can contribute in different ways within the tooling industry: On the one hand, AM can be applied for the production of tooling. On the other hand, AM can function as tooling substitute. Both deployment possibilities provide numerous advantages compared to conventional manufacturing technologies. AM facilitates the manufacturing process, for instance regarding the cooling channels within the tooling. Using traditional methods, the channels need to be drilled into the tooling. Due to the notch effect, this process creates stress concentrations. This negative effect can be counteracted by AM, as AM-technologies enable the production of tooling (“Rapid Tooling”) with integrated cooling channels in a single step, at lower costs and within a shorter time [Sch10]. Thereby, the time-to-market can be reduced and the product development process can be shortened [Fro07], [Geb07].

Market Development

In Europe, the tooling industry including moulds, dies and special tools reaches an average annual turnover of $13 billion [ETP11-ol]. The tooling industry belongs to the secondary market of AM, which includes tooling produced from AM-patterns and AM-systems, as well as molded parts and castings. Within the last three years, the AM-market for tooling has grown. The total volume was around $678.4 million in 2009 [Woh10]. Compared to the primary market volume amounting to $1.068 billion, the AM-market volume of the tooling industry is considerable. Thus, the manufacturing of tooling and molds is one of the most anticipated applications for AM [Fro08].

Technology Development and Fields of Application

Despite serious competition within the tooling industry regarding conventional technologies, AM is already widely spread within the tooling industry, as reflected by the positive market development. Conventional manufacturing technologies can be replaced or even eliminated in many cases. Paradoxically, the AM-technology substitutes itself regarding this field of application, as DM of final products lowers the demand for tooling within small series production [CPN09-ol].

Tooling solutions are distinguished between high-performance tooling, direct and indirect tooling approaches. For instance, EOS, SLM Solutions and other companies are creating tooling that enables reduction of cycle time of molding plastic or die casting parts. An example for direct tooling is the Fused Deposition Modeling (FDM) process. Due to improved variety and durability of AM-material, FDM can be applied to produce parts that require strength and durability. Further examples for direct tooling are the direct laser sintering from EOS, ProMetal from Ex One, and LENS from Optomec [Woh10]. In the following, further applications that have already been realized are mentioned:

- Universal tool holders with standardized casting insert pocket sizes [Nad10], [Woh03];
- Die casting forms [Nad10];
- Injection molding tooling (see fig. 1-22) [Fro07];
- Models for investment casting [Fro08];
- Fixtures for tooling [Woh10];
- Tooling for prototyping of surgical devices [Dvo10-ol].

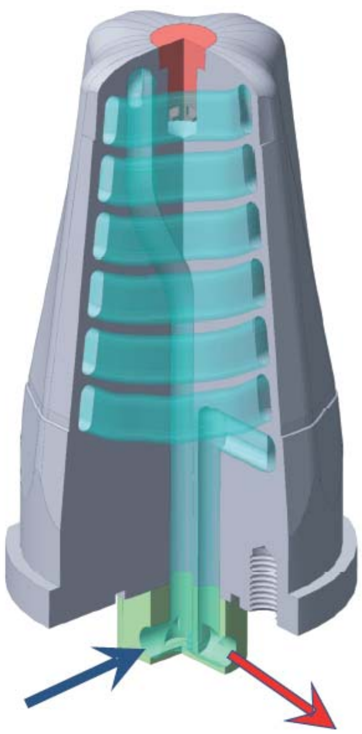

Figure 1-22: Injection molding tooling made by DMLS *(picture courtesy of* EOS*)*

Value Creation Potential for DM-Technologies

The tooling industry can significantly benefit from AM, as AM can function as manufacturing technology and as substitute for tooling (see fig. 1-23).

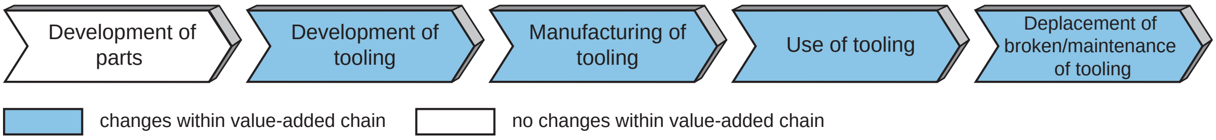

Figure 1-23: Exemplary value-added chain for the tool and mold making industry

AM allows shorter lead times of tooling.

For instance, AM enables a considerably shorter development and manufacturing process. This lowers the manufacturing costs significantly [Woh09]. Thus, investments pay-off within a shorter period. In addition, AM-technologies are already applied for the manufacturing of die-casting models and enable a fast creation of complex geometries and shapes with a minimum of manual work [Fro08]. Thereby, production times can be reduces and the quality of parts produced by using these models can be increased significantly. Finally, the replacement and maintenance of tooling becomes easier, faster and more cost-effective, especially as spare parts can be produced just-in-time.

Trends

The tooling industry is alread one important industry for AM, as it can be used for manufacturing tooling as well as a substitute for expensive tooling equipment within different industries. However, within the recent years, the development of AM has been stagnating within the tooling industry, and less research on tooling applications has taken place [Woh09]. The following trends have been identified for the tooling industry:

- The demand for accelerated product development require shorter lead times of tooling [Nad10], [HJ00];
- Efforts are made to reduce the break-even time of tooling [Nad10];
- Increasingly, shorter life cycles of tooling are required to increase production of low-volume niche products [HJ00];
- The deployment of universal tool holders and higher use of multi-component techniques while manufacturing small parts are increasing [Nad10], [Sch06].

1.2.14 Toys and Collectibles Industry

Toys industry increasingly works with 3D digital contents.

The toys and collectibles market is known for its' high level of individual demand. The main target group of the toys and collectibles industry is represented by children. Children like to be creative and adults support their creativity by letting them make objects, as this promotes the creative growth. Previously children have made this with clay or similar materials. Today, children have the possibility to create 3D digital content [BLR09]. For instance, action figures and custom dolls with one's own face can be easily printed with a 3D printer [Woh10]. However, adults also represent a target group for the collectibles' market, as e.g. older toys can also become collectibles. Due to this and based on the fact that these consumer goods are often small-sized and with low strength requirements, the toy and collectibles industry can significantly benefit from AM.

Market Development

In 2009, the total market volume amounted to $75 billion [Gui09]. Until today, just a few companies are using AM. Consumer 3D printers are still unaffordable, as they still cost about $3,000. Low prices for toys and collectibles, as well as barriers such as high printer prices reduce the attractiveness for applying AM-technologies.

Regarding the AM-technology, the consumer products industry, where the toys and collectibles industry belongs to, has a market share of 24.1%; this corresponds to circa $257 million [Woh10]. As 3D printers are expected to become less expensive in future, the market has a big growth potential [BLR09].

Technology Development and Fields of Application

AM has already been used for a number of applications within the toys and collectibles industry, such as follows:

- Action figures by Featuro [Woh10];
- Video game avatars by FigurePrints [Woh07];
- Land and air vehicles [Woh10];
- Custom dolls by Featuro [Woh10];
- Individualized model cars;
- Tin soldiers.

Value Creation Potential for DM-Technologies

Through AM, individualization of toys and collectibles becomes possible. Therefore, there is a great potential for value creation along the value-added chain (see fig. 1-24).

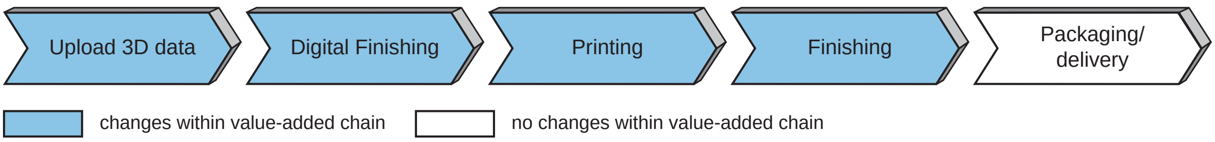

Figure 1-24: Exemplary value-added chain for the toys and collectibles industry

AM may find its way into children's room due to 3D printers.

For instance, AM can be used for the production of special editions of toys at low lots as well as for the manufacturing of totally customized products. Assumed that 3D printers are available at low costs, the development of materials as well as the creation and handling of 3D CAD models can prevail. For these purposes, easy-to-use CAD interfaces and platforms for the distribution of models are required. This will significantly increase the attractiveness of AM-technology.

Trends

In future, the use of AM-technologies is expected to rise within the toys and collectibles industry [BLR09]. Major trends identified to be relevant for the toys and collectibles industry are the following:

- Decreasing prices for consumer 3D printers; forecasted prices will fall from $3,000 to $100-150 in the near future [BLR09];
- Building of globally distributed 3D printing fulfillment services to realize short ways and short times of delivery [Ree09e];
- Increasing demand on lower priced toys (below $25) [Mir09-ol];
- Higher focus on “play value for money” [Kav08-ol];
- Increasing demand for toys based on movie and entertainment properties [Mir09-ol];
- Higher focus on science toys [Mir09-ol];
- Stronger networking between bought products and the internet [Mir09-ol].

The analysis of today’s business shows that Direct Manufacturing technologies are gaining more and more importance. An increasing number of industries benefit from the advantages of the technologies such as the freedom of design, and AM is progressively pushed from Rapid Prototyping towards DM in small series production. However, the penetration of the industries by the technologies is still limited.

1.3 Current Success Factors for Direct Manufacturing

Based on the analysis of the current fields of applications, chances and risks for each industry have been deducted by the experts in a workshop. These chances and risks are part of the confidential study. The results of this workshop and of the literature analysis of the current application fields as well as the deducted chances and risks constitute the basis for the derivations of the so called success factors. Success factors are factors, which influence the success of the business. They are often also called buying factors [GPW09].

As many of the 22 identified success factors are decisive for more than one industry, the following table 1-1 shows which factor (row) is relevant for which industry (column) from today’s point of view.

The analyzed industries have many success factors in common.

Allocation matrix

Question: "Is the success factor (row) relevant for this industry (column)?"

Success Factors	Industries	Aerospace Industry	Automotive Industry	Armament Industry	Dental Industry	Electronics Industry	Furniture Industry	Implants/Prosthetics Industry	Jewelry Industry	Specialty Food Industry	Sports Equipment Industry	Surgical Devices/Aids Industry	Textiles Industry	Tool/Mold Making Industry	Toys/Collectibles Industry
Design Rules [Geb08] [BLR09]		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Surface Quality [Geb08] [Sch08]		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Process Repeatability and Part Reproducibility [BLR09]		X	X	X	X	X	X	X	X	X	X	X	X	X	X
New Materials [BLR09]		X	X	X	X	X		X		X	X		X	X	X
Quality Assurance Systems [GSB+10]		X	X	X	X	X		X			X	X	X	X	X
Layer Thickness [SA10] [BAB+04]		X	X	X	X	X		X	X			X	X	X	
Process Costs [Woh09]			X		X	X	X		X		X		X	X	X
Multi-Material [Wor10]		X	X	X	X	X		X	X	X	X				X
Certifications [BTW09]		X	X	X	X	X		X				X		X	
Standardization [Woh10] [BLR09]		X	X	X	X	X		X				X		X	
Risk Management [GSB+10]		X	X	X	X	X		X				X		X	
Strength of Materials [Woh03]		X	X	X	X			X				X		X	
Control of Part Lifetime [Nad10]		X	X	X	X			X				X		X	
Combination of Manufacturing Technologies [SRA+09]		X	X	X	X	X					X			X	
Process Speed [Wor10]		X	X	X		X					X				X
Easy-to-Use CAD Software [BLR09]					X		X		X		X		X		X
Build Size [Cev06] [Nad10]		X	X	X			X							X	
High Temperature Resistant Plastics [Cev06]		X	X	X										X	
Multi-Color [Wor10]									X	X	X				X
Application Conform CAD Software [BTH+07]								X			X		X		X
Biocompatible Materials [BAB04]					X			X				X			
Low Budget 3D-Scanner [Wor10]											X		X		X
Easy to Transport Manufacturing Machines [BLR09]				X											X

Table 1-1: Allocation of success factors to industries

This table provides an overview of the most important success factors from today's perspective. The most relevant success factors for increasing the market penetration by AM across the analyzed industries are the following:

- Design rules;
- Surface quality;
- Process reliability and part reproducibility;
- New materials;
- Quality assurance systems;
- Layer thickness;
- Process costs;
- Multi-material processing;
- Certifications.

1.4 Summary of Today's Business

The analysis of today's business has shown that Direct Manufacturing technologies are gaining more and more importance. Beyond the established use of AM-technologies for Rapid Prototyping, an increasing number of industries have been participating in the advantages of the technologies as e.g. the freedom of design.

Design rules, surface quality and process reliability are the most relevant success factors from today's point of view.

The spectrum of the 14 focused fields of application ranges from currently established fields such as the dental industry, upcoming fields such as the aerospace industry to visionary fields such as the textiles industry. However, the overview of the identified current success factors has shown that most success factors are relevant for many industries. From today's point of view, design rules, surface quality as well as process reliability are decisive for the success of DM-technologies.

2

The Business of Tomorrow

The aerospace, automotive and electronics industry have been selected as the most promising industries.

In the previous chapter, current application fields of AM have been analyzed. Therefore, the market and technology development have been assessed, and chances and risks have been deducted (see confidential study). Based on this analysis, the experts selected the aerospace, the automotive and the electronics industry as the most promising application fields for DM-technologies in future. A detailed description of the selection is part of the confidential study.

In the following, possible future developments for the selected industries are presented. The aerospace industry and further adapted industries are confronted with changing conditions and the challenge to bring product innovations on the market. But in times of increasing complexity and increasingly dynamic environment, strategic foresight gains more importance. As a result, changes in the global and branch environment need to be thought ahead. In particular, developments of existing and untapped business areas have to be anticipated in order to early identify the success potentials of tomorrow and to develop ways to exploit these potentials on time. This allows a company to be always one step ahead of its competitors.

A method to think ahead future developments is the scenario-technique, which is shortly introduced at the beginning of the chapter [GPW09]. Afterwards, possible future developments of AM-technologies within the global environment and the aerospace, automotive and electronics industry are anticipated and presented by alternative scenarios. These scenarios are the starting point for the deduction of future chances and risks, future success factors and strategic directions.

2.1 Thinking ahead the Future using the Scenario-Technique

Anticipation of market and technology developments for the deduction of future chances and risks

The visionary insight into the future, the early identification of tomorrow's success potentials and the timely consistent exploitation of these potentials are indispensable for sustainable business success. In the context of the identification of opportunities for tomorrow's business and future success factors within a systematic foresight process, the scenario-technique is a suitable tool for the detection of future success potentials. It provides a number of benefits:

- With the help of the scenario-technique, decision makers can systematically deal with future developments.

- The exploration of the future is a comprehensible and provable thinking work.
- In contrast to the widespread market research methods, the scenario-technique enables thinking ahead future success factors.

According to SONTHEIMER, the scenario-technique is a tool for "*thinking ahead of the future and not for making predictions*" [Son70]. Scenarios describe possible situations in the future, for instance such as the future competitive arena where the own business could be positioned. Future scenarios are based on a complex network of influence factors, whereby several conceivable and possible future developments for each influence factor have to be taken into account.

The essential aim of the scenario-technique is the identification of future success potentials and threats in order to derive strategic directions, e.g. appropriate opportunities and fields of action. An entire description of the scenario-technique is available in the appendix A1.

Focus aerospace industry: aircraft production

Focus automotive industry: automotive production

Focus electronics industry: manufacturing equipment

Figure 2-1 gives an overview of the spheres of influence of the developed scenarios within this project. Initially, the scenarios for the broader influence area, the so called global environment for the year 2020 have been developed. These scenarios encompass comprehensible statements on future developments of politics, economy, society and environment. Furthermore, branch scenarios regarding the application of AM for the year 2020 were developed. In the first step, current application fields of AM have been assessed regarding their attractiveness in future. The experts identified the aircraft production, the automotive production and the electronics industry manufacturing equipment as the most promising focuses for AM. Regarding the aircraft production and the electronics industry manufacturing equipment the spheres of influence are supplliers, branch technology, regulations and market. Within the automotive production, automotive concepts is an additional sphere of influence.

For each of the application fields, branch scenarios for the year 2020 were developed. Afterwards, the scenarios for the global environment were combined with the branch scenarios to overall scenarios. In the next step, the experts selected the overall scenario with the highest impact and the highest probability of occurrence. From these consistent scenario combinations, the future chances and risks as well as future success factors and strategic directions were derived.

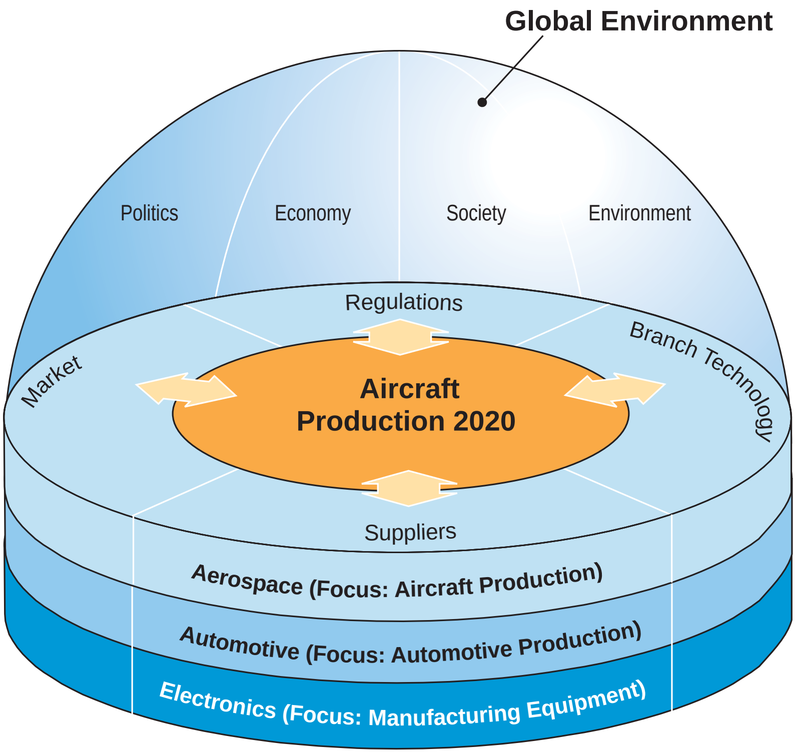

Figure 2-1: Spheres of influence for the scenario development

2.2 Future Scenarios

In this chapter, the scenarios for the global environment and the most promising industries – the aerospace, automotive and electronics industry – are developed and combined with the global scenarios to overall scenarios. From these overall scenarios, the combination with the highest impact on the field of conception and the highest probability of occurrence are selected for each industry.

2.2.1 Global Environment

Global scenarios describe possible future situations of the broader environment of AM-technologies. These scenarios encompass statements on politics, economy, society and environment. For characterizing the global environment, 17 key factors are used (see fig. 2-2).

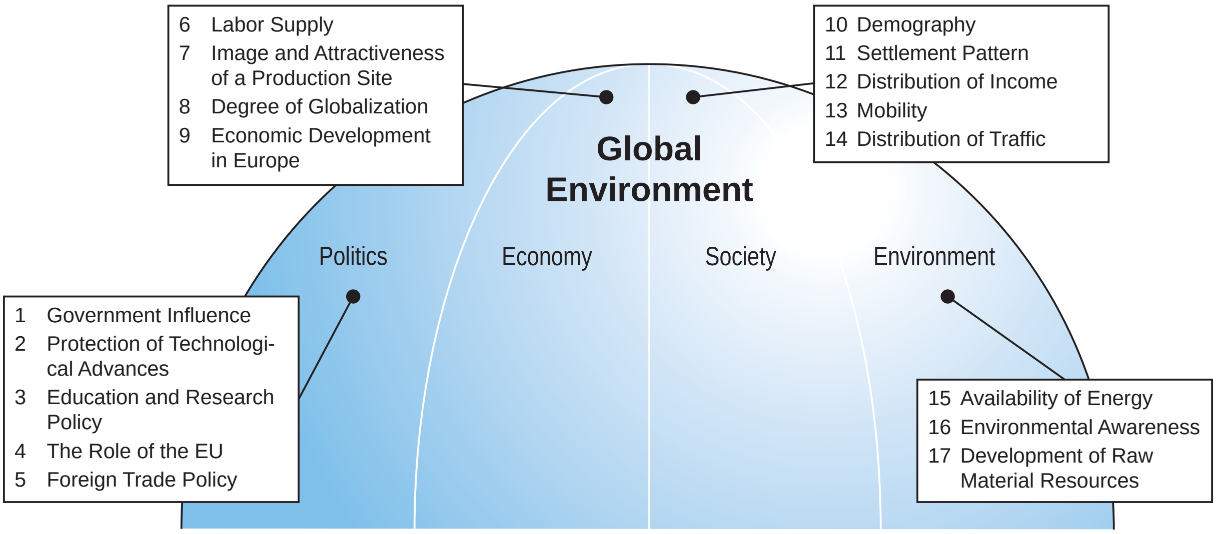

Figure 2-2: Key factors for the global environment

17 key factors were used to develop three consistent scenarios for the global environment in 2020.

These key factors were significantly contributed by the Heinz Nixdorf Institute as the institute has many years of experience in developing scenarios. The list of the key factors and their future developments, the so called projections, is provided in appendix A2. A detailed description of the key factors and projections is part of the confidential study.

The three scenarios "Europe on the Edge" (G1), "Europe Sets the Pace in a Globalized World" (G2) and "European Fortress" (G3) describe the broader environment in the year 2020 (see fig. 2-3).

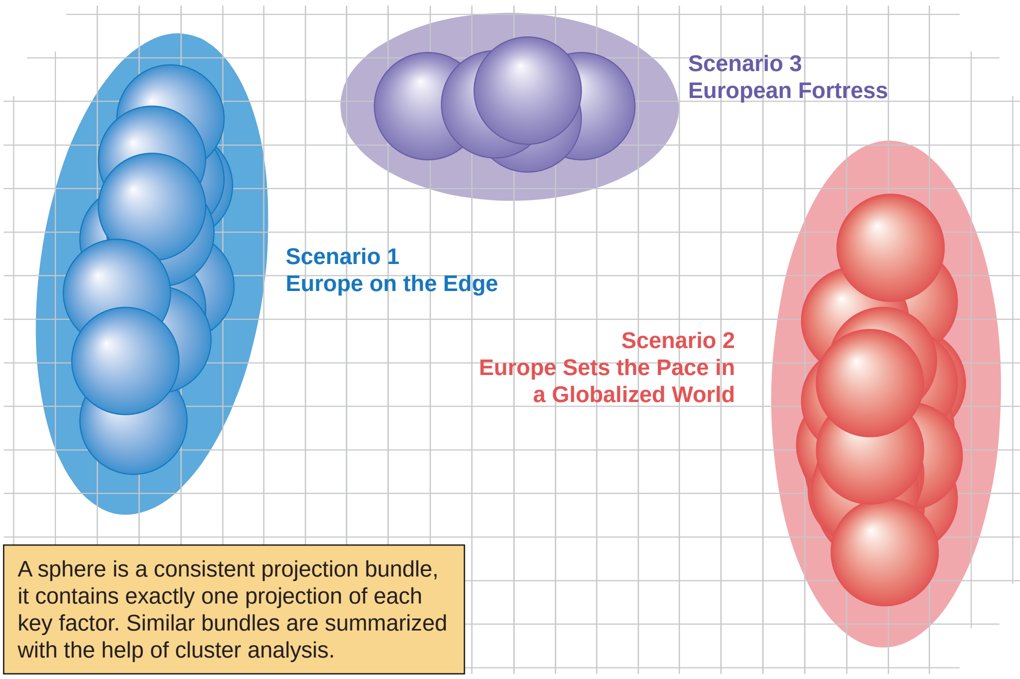

Figure 2-3: Developed scenarios for the global environment

2.2.2 Aerospace Industry

Within the aerospace industry, the production of aircraft has been selected as the most promising field. The developed scenarios encompass statements about the market, regulations, branch technology and suppliers. The future of the aircraft production is described by 13 key factors (see fig. 2-4).

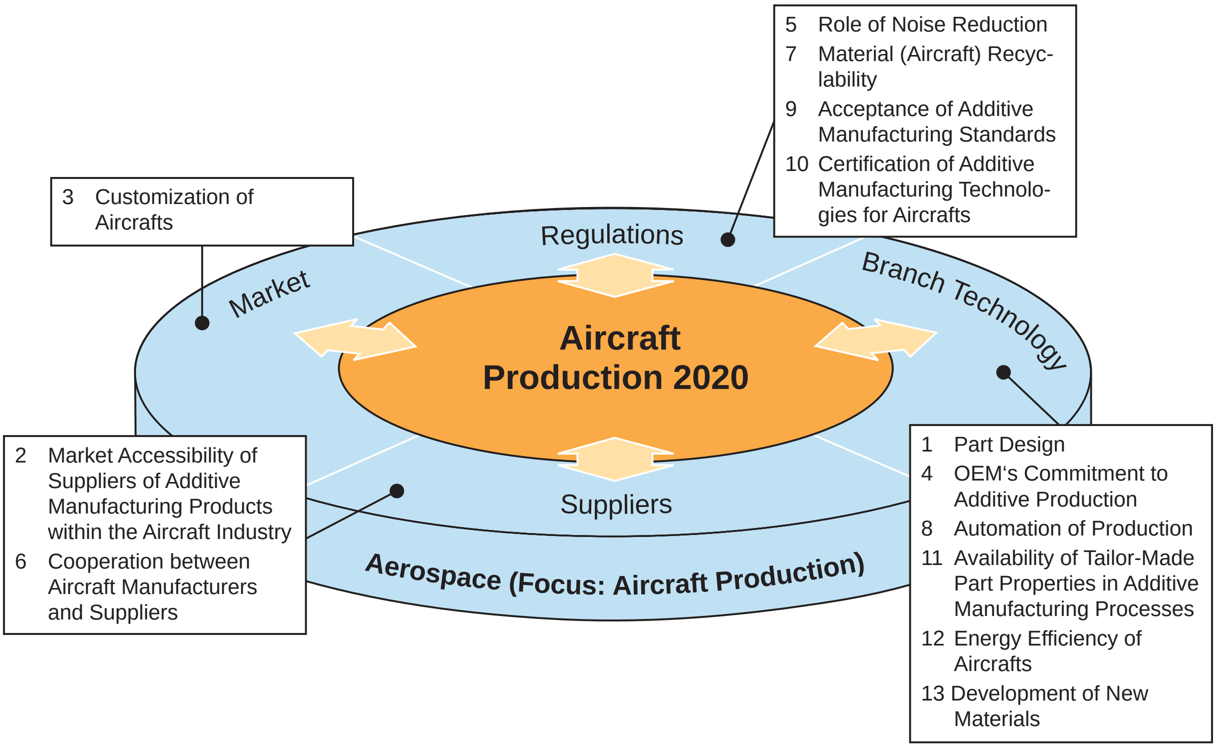

Figure 2-4: Key factors for the aircraft production

13 key factors were used to develop three consistent scenarios for the aircraft production in 2020.

Based on the future projections of these key factors, three scenarios have been developed. The three scenarios "Individual Customization Fosters AM-Technologies" (Ai1), "Uncertainties Require Enhancements in Cooperation and Collaboration" (Ai2) and "Unmet Expectations Prevent AM-Applications" (Ai3) describe possible consistent futures of the aircraft production in 2020 (see fig. 2-5). The list of the key factors and the future projections is provided in appendix A2. The detailed description of the key factors and projections is part of the confidential study.

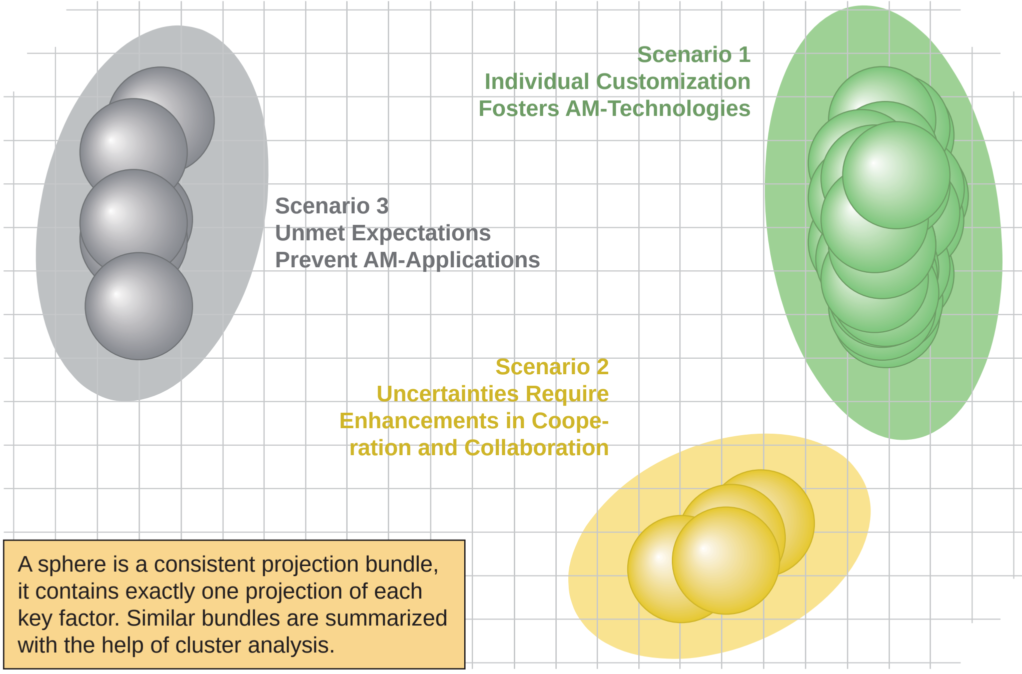

Figure 2-5: Developed scenarios for the aircraft production 2020

In the next step, the branch scenarios were matched with those for the global environment (see chapter 2.2.1) to create overall scenarios. In a workshop, the participating experts from the aerospace and the AM-industry estimated which combinations have the highest consistency. Figure 2-6 shows the results. The combinations G2/Ai1, G3/Ai2 and G1/Ai3 are consistent by means of thinkable future scenarios.

Global Environment \ **Aircraft Production**	**Scenario 1 (Ai1):** "Individual Customization Fosters AM-Technologies"	**Scenario 2 (Ai2):** "Uncertainties Require Enhancements in Cooperation and Collaboration"	**Scenario 3 (Ai3):** "Unmet Expectations Prevent AM-Applications"
Scenario 1 (G1): "Europe on the Edge"		+	+ +
Scenario 2 (G2): "Europe Sets the Pace in a Globalized World"	+ +		
Scenario 3 (G3): "European Fortress"		+ +	+

+ + Very high consistency

+ High consistency

Figure 2-6: Matching of the scenarios for the global environment with the scenarios for the aircraft production

Scenario Transfer – Selection of Reference Scenario

Scenarios constitute a profound basis for the development of strategies. Through the scenario transfer scenarios prove to be useful for strategic management decisions. In general, it is useful to develop a focused strategy to bundle the available resources. A focused strategy consequently aims at the occurrence of one scenario. Therefore, the scenario combinations have to be analyzed regarding their impact on the field of conception and their probability of occurrence in order to select the reference scenario.

The evaluation is based on the following two questions:

- How probable is the occurrence of a scenario from today's perspective?
- How strong is the impact of the scenario on the field of conception?

For each of the key factors, the experts rated, which projection has the highest probability of occurrence and which projection has the highest impact on the use of DM-technologies within the aircraft production. Based on the list of characteristics (see confidential study), the values for each scenario can be quantified, and the scenario combinations can be positioned in the portfolio, as shown in figure 2-7. For the three combinations, the ordinate intercept shows the impact; the abscissa intercept indicates the probability of occurrence. The closer a combination is to the top right corner, the higher is its importance for the strategy development.

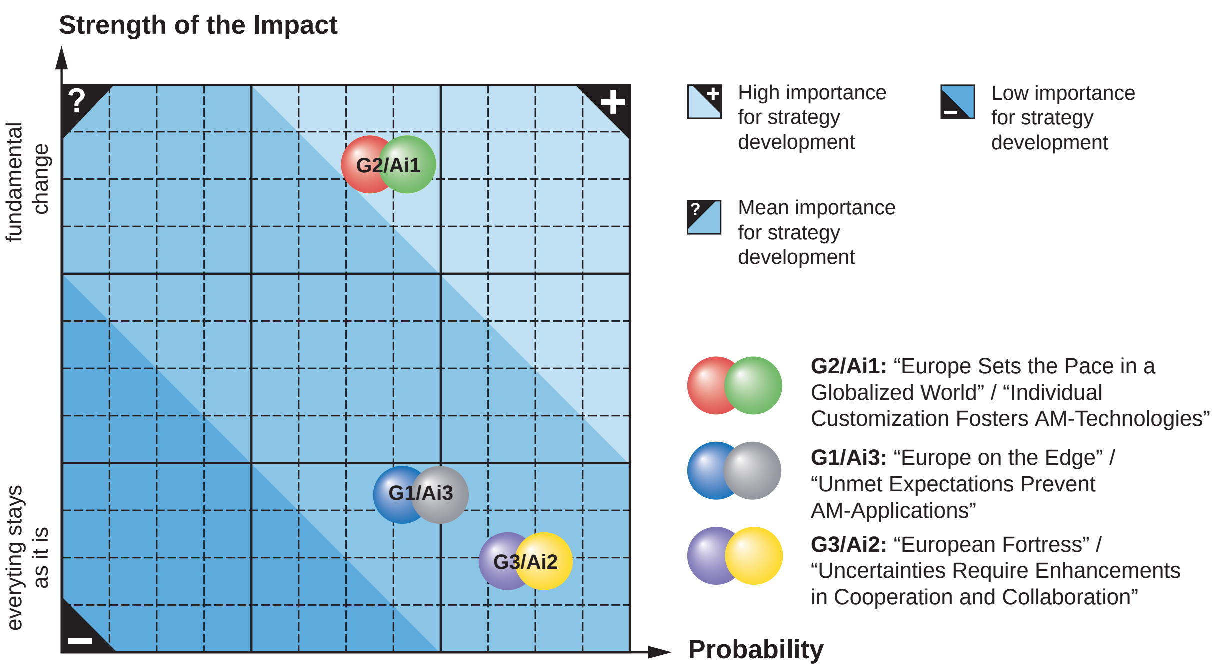

Figure 2-7: Selection of the overall reference scenario for the aicraft production

The evaluation of the three combinations shows that from today's point of view, the overall scenario G3/Ai2 is classified as the combination with the highest probability of occurrence. The overall scenario G2/Ai1 has a lower probability of occurrence, but a significantly higher strength of impact on the business of DM-technologies. Due to this, G2/Ai1 has the highest importance for the strategy development, therefore, it is selected as the reference scenario.

The following management summary gives an overview of the reference scenario combination. A detailed description of all scenario combinations is provided in the confidential study.

G2: "Europe sets the Pace in a Globalized World"

Politics:

High financial support of research institutions by the government pays off.

Increasing influence of strong and transparent governments has a major impact on the political progress within the European Union. On the one hand, governments have increased the total subsidies in recent years. On the other hand, the governments commit themselves to the education and research policy, by increasing the expenses for education and research. The investments in the educational system pay off – the research infrastructure is excellent. European universities now have an excellent international reputation, and most of them internationally rank among the top 100. The broad majority of the population is well skilled, the unemployment rate is relatively low, and the labor market is nearly balanced. Nevertheless, as increasingly more elderly people are retired from work and fewer young people move up, many companies have great difficulties to find just enough staff. This cannot be justified by lack of qualification; there is still a labor deficit.

The efficient and highly effective policy strengthens the role of the EU. In addition, prosperity is fostered through European integration. This development facilitates the foreign trade: free trade without borders is possible within the EU. Protection of technological advances is proceeding slowly. Until today, only short-term protection against product piracy is possible, as product protection has become a greyhound racing between original manufacturers and product pirates. Due to recent developments, huge steps are being made to stem product piracy.

Economy:

European economy growths due to value-creation-intesive enterprise functions.

Due to the great image and high attractiveness of the European Union as a high-tech location, many enterprises use the European Union as a "System Head". Especially, future- and high-quality-oriented as well as value-creation-intensive company divisions are settled in the EU. This enables the EU to expand its degree of globalization. European states have become key players and pacemakers of the globalization, as they succeeded to steadily increase their exports to Asia and America. Due to these developments, the EU has recovered well after the economic crisis, and has returned back to a strong organic growth; the gross domestic product is growing by 2% annually. This development has been stable for years.

Society:

Strong tendency towards urbanization

In the past years, slight population growth through migration occurred. Due to good living and working conditions, the number of immigrants has been rising continuously, whereas the number of EU inhabitants has been declining. Children and family have a high priority; however, there still is a birth deficit. Older people feel needed, and are willing to work longer. Urbanization has been propagating; more than 60%of the population is living in urban areas, as cities offer a good infrastructure, a variety of attractive jobs and entertainment possibilities. In contrast, a tendency towards the new country life is also discernible. More than 20% of all inhabitants live in the countryside. New decentralized working forms enable people to retreat from the urban areas and to work at home.

To adjust differences in income, an unconditional basic income has been introduced by law in the EU, despite initial skepticism. The governments pay every inhabitant the basic income without any repayment claims.

Awareness for highly sustainable mobility

The awareness for highly sustainable mobility is emerging. Means of transportation stand for freedom and independence. The image of sustainable development has led to a boom in the ecologically reasonable means of transportation. Due to this development as well as to the availability of modern digital forms of communication, new virtual mobility is propagating increasingly. People interact with each other through chats, forums and video conferences. However, the importance of personal contact has remained relatively high.

Environment:

The restrictive behavior of the OPEC is unbroken and the capacities of the conveyors are just enough to meet the world's demands. Therefore, scarce energy fosters high efficiency. Until now, the EU has not succeeded to free itself from its dependency on the world energy market. Although the worldwide application of sustainable and intelligent processing of raw materials as well as better recycling processes were expected to provide a reduction in demand, the raw material market is recovering just slowly.

Efficient material use and regenerative energy prevent energy crisis.

However, raw material bottlenecks still can be met largely through a slightly increasing expansion of regenerative energy sources. The resources of mineral and energetic raw materials are now estimated to meet the demand of the next 40 years. According to the recent developments, a broad consensus for environmental protection has been emerging worldwide. The population is convinced that a livable world should be preserved for future generations.

Ai1: “Individual Customization Fosters AM-Technologies”

Suppliers:

Mega suppliers cooperate with aircraft manufacturers.

The cooperation between aircraft manufacturers and suppliers within the aircraft industry has changed significantly, since partnerships with suppliers have been established. More responsibility has been transferred to suppliers; the increasing cooperation and communication between manufacturers and suppliers is good; the suppliers contribute their own ideas to solve problems, and develop all components under constant consultation with the manufacturer.

Simultaneously, the market accessibility for suppliers has changed considerably. Today, mega suppliers rule the market: as the size of orders has increased within the last years, only mega suppliers were able to handle these quantities – the number of orders handled by small suppliers decreased. The takeover of small suppliers became a more appropriate method to acquire new customer groups and expand their market power.

Market:

Increasing number of variances

Until recently, the usage of interior variants due to branding purposes has still been common. As a reaction of this continuing marketing trend, aircraft manufacturers have increased their number of variants, and each aircraft is progressively getting individual.

Branch Technology:

AM-parts are used for safety relevant parts.

As parts produced by AM-processes started to be associated with high performance and high quality, many manufacturers jumped on board, and started to invest into these technologies. For instance, additively manufactured parts are used for critical parts or for low scale production. Due to the successful part implementation, AM-technologies are incrementally on the rise, and investments into further research are made. As a result, many new materials enter the market (technology-push). These new materials have excellent properties which promise lower production costs and can be used for the implementation of new technologies (market-pull meets technology-push).

Part properties have become tailor-made.

Furthermore, new materials/machines allow the customization of material properties, as tailor-made part properties have become possible by now. Intense research and new developments in AM-technologies even provide further progress in AM-processes. As the ratio of functionality and costs has been improved, today functional-driven design is the key to success. However, production-driven design is still prevalent in just a few limited cases in order to minimize production costs. The reduction of required workforce to perform manual work was additionally supported by substantial advancements in the development of machines which are now mainly used for the highly-automated processes. These machines can substitute hand-crafted steps.

In addition, there is a high need for energy-efficient aircraft as scarcity of resources proceeds. Higher efficiency rates can be realized due to new high-tech materials enabling higher working temperatures. The increased efficiency of engines reduces fuel consumption.

Regulations:

Common set of certification standards

Progressively, the acceptance of AM-standards is increasing: the elaborated standards are described in a common set. Due to the commitment of almost all aircraft manufacturers and many suppliers for using of AM-technologies within aircraft production, certification institutions have recognized the importance of the technologies; a common understanding in the value chain has been created. Furthermore, requirements for noise reduction push AM-technologies. Newly developed materials and innovative as well as industrial-suited recycling methods now enable high recyclability. Partly, the shortage of raw materials and the increasing environmental responsibility have initiated the international community of states to determine worldwide regulations on aircraft recycling.

The most probable future scenario combination for the aerospace industry with the highest impact on its field of conception describes a world, where regarding the global environment, Europe sets the pace in a globalized world. The scenario for the aircraft production is characterized by individual customization of aircraft which fosters the application of AM-technologies.

2.2.3 Automotive Industry

Within the automotive industry, the automotive production has been selected as the most promising field. The developed scenarios encompass statements about the market, branch technology, regulations, suppliers and automotive concepts. The future of the automotive production is characterized by 13 key factors (see figure 2-8).

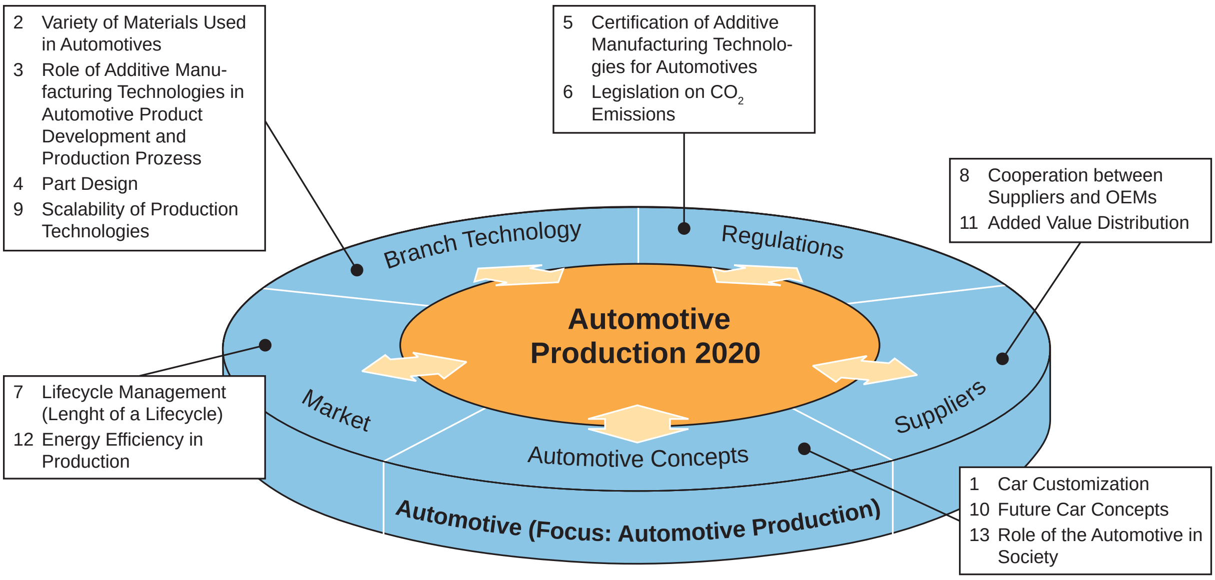

Figure 2-8: Key factors for the automotive production

Based on the future projections of these key factors, three scenarios have been developed. The three scenarios “New Production Concepts Drive Individuality” (Au1), “Pragmatism all along the Line” (Au2), “Steady Evolution” (Au3) describe possible consistent futures of the automotive production in 2020 (see fig. 2-9). The list of the key factors and their future projections are provided in appendix A2. A detailed description is part of the confidential study.

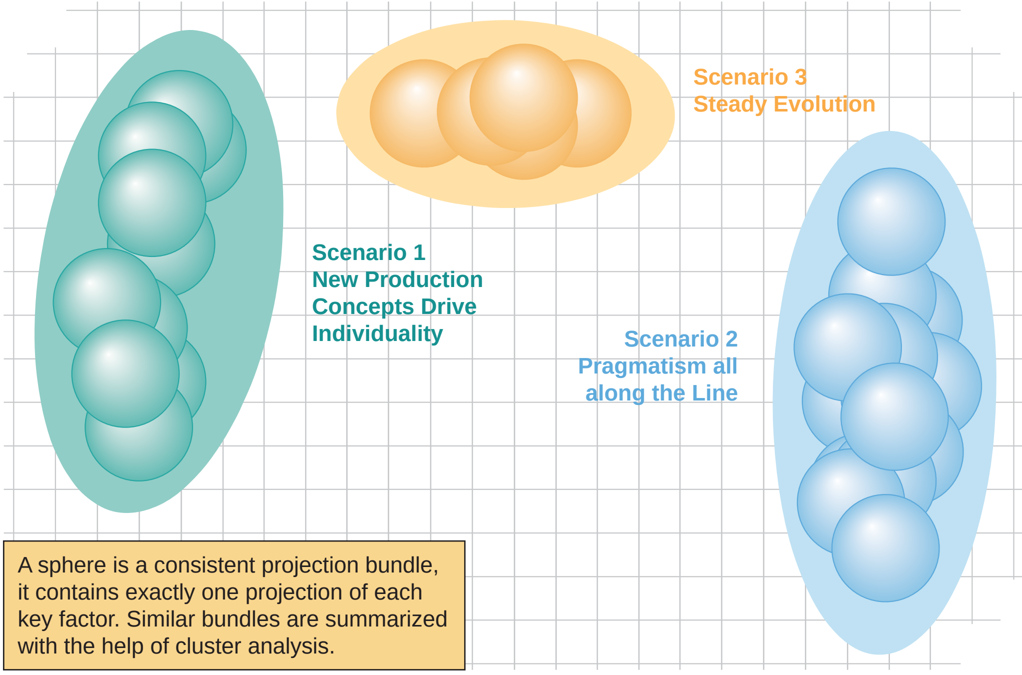

Figure 2-9: Developed scenarios for the automotive production 2020

In the next step, the branch scenarios were matched with those for the global environment (see chapter 2.2.1) to create overall scenarios. Within a workshop, the participating experts from the automotive and the AM-industry estimated which combinations have the highest consistency. Figure 2-10 shows the results. The combinations G2/Au1, G1/Au2 and G3/Au3 are consistent by means of thinkable future scenarios.

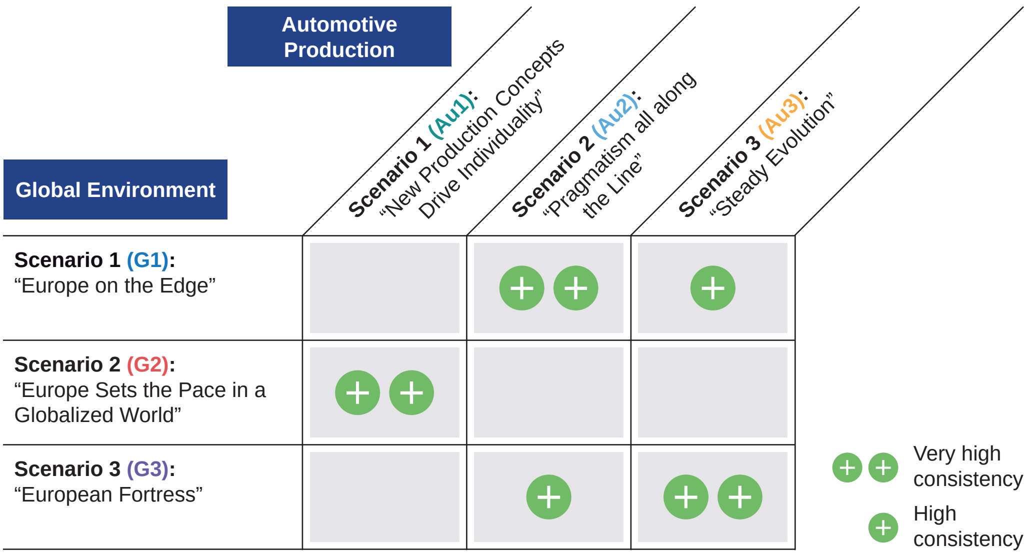

Figure 2-10: Matching of the scenarios for the global environment with the scenarios for the automotive production

Scenario Transfer – Selection of Reference Scenario

Scenarios constitute a profound basis for the development of strategies. Through the scenario transfer scenarios prove to be useful for strategic management decisions. In general, it is useful to develop a focused strategy to bundle the available resources. A focused strategy consequently aims at the occurrence of one scenario. Therefore, the scenario combinations have to be analyzed regarding their impact on the field of conception and their probability of occurrence in order to select the reference scenario.

The evaluation is based on the following two questions:

- How probable is the occurrence of a scenario from today's perspective?
- How strong is the impact of the scenario on the field of conception?

For each of the key factors, the experts rated, which projection has the highest probability of occurrence and which projection has the highest impact on the use of DM-technologies within the automotive production. Based on the list of characteristics (see confidential study), the values for each scenario can be quantified, and the scenario combinations can be positioned in the portfolio, as shown in figure 2-11. For the three combinations, the ordinate intercept shows the impact; the abscissa intercept indicates the probability of occurrence. The closer a combination is to the top right corner, the higher is its importance for the strategy development.

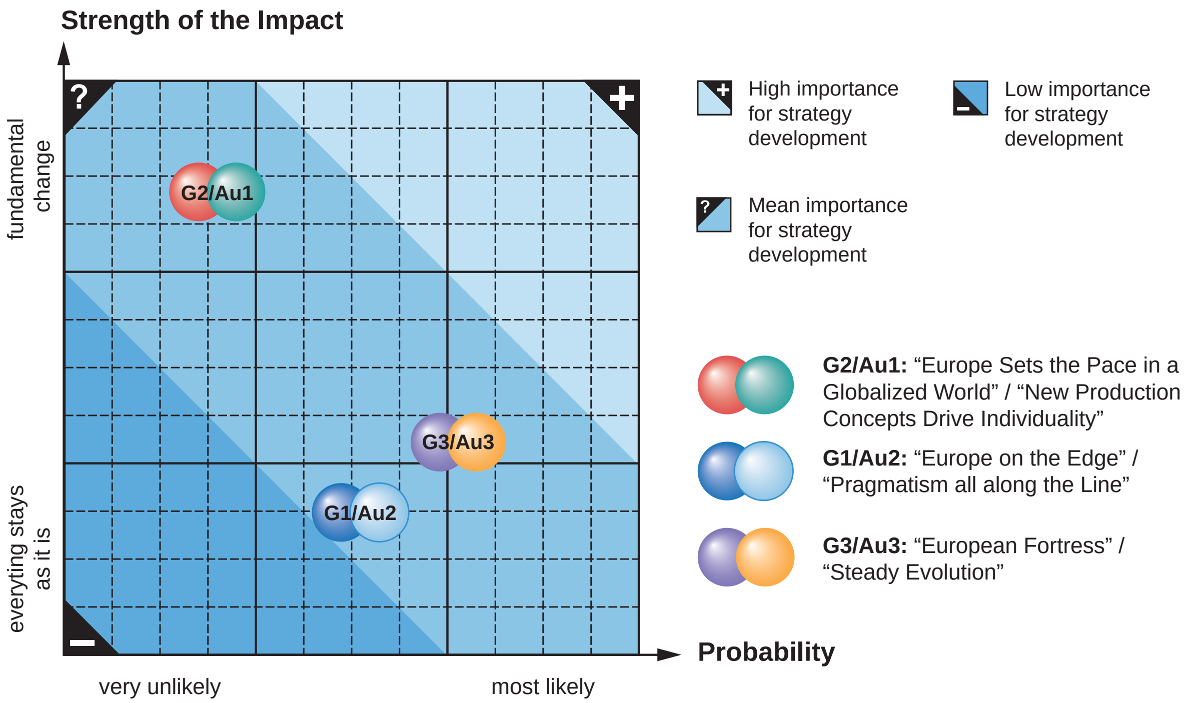

Figure 2-11: Selection of reference overall scenario for the automotive industry

13 key factors were used to develop three consistent scenarios for the automotive production in 2020.

The evaluation of the three combinations shows that from today's point of view the overall scenario G3/Au3 is classified as the most probable combination. The overall scenario G2/Au1 has a significantly lower probability of occurrence, but a considerably higher strength of impact on the business of DM-technologies. As G3/Au3 and G2/Au1 have about the same importance for strategy development, they were intensively discussed by the experts. As a result, G2/Au1 has been selected as the reference scenario.

The following management summary gives an overview of the reference scenario combination. The selected reference scenario for the global environment "Europe sets the Pace in a Globalized World" is also a part of the selected reference scenario combination of the aerospace industry. Therefore, the management summary of G2 is already provided in chapter 2.2.2. A detailed description of all scenarios is part of the confidential study.

Au1: "New Production Concepts Drive Individuality"

Suppliers:

High competition requires cooperation

The automotive market has become highly competitive. Due to lower profit margins, the percentage costs for part shipping have risen. Suppliers and manufacturers were forced to intensify their cooperation. On the one hand, a factory in factory production is growing in order to save logistic costs. On the other hand, a worldwide localized production is still on demand in order to guarantee a fast parts supply globally.

In addition, the value-added distribution has changed significantly. Mega suppliers and small specialists work side by side: while 0.5 tiers as mega suppliers develop and produce whole vehicle modules, small specialists serve niche markets focusing on only a few business fields.

Market:

Green production and spare parts business is of high importance.

Product life time of automotives has increased. As storing high amounts of spare parts is still very expensive, longer life times of automotive parts are realized by higher quality. In means of energy saving, green production is highly important for sales today.

Branch Technology:

AM prevails in series production for small lot sizes.

An intense material research has led to new materials for the automotive industry. Today, high-tech materials are widely used as they provide overwhelming qualities. The increased competition led to lower prices which resulted in a highly growing demand. Furthermore, AM in series production is possible by now, and functional-driven design is the key to success.

Parts designed for AM are only produced in small lots and they are mostly small in size, whereas most automotive parts are still designed production-technology-driven in order to minimize production costs. Single parts are built just in time in order to keep up the existing schedule. In addition, a tendency towards a high scalability in the whole production process occurs; the assembly lines increasingly consist of highly flexible robotics equipped with different tools.

Automotive concepts:

Individualized high-tech cars and conventional mass cars dominate the market.

The role of the automobile in society is ambivalent. Although prestige and the need for individuality still play an important role for the buying decision for a new car, emotionality partly yields to pragmatism regarding some customer groups. Therefore, two different future car concepts are prevailing: the individualized high-tech car and the conventional mass car.

OEMs have huge problems to fulfill the individual requirements, and core customization raises the costs along the whole value chain, which has made cars more expensive than ever before [Abd08], [RB09-ol]. Therefore, individualized production is being combined with modularized customization.

Regulations:

Certifications are available; varying levels drive costs.

Due to the commitment of almost all automotive manufacturers and many suppliers for using AM-technologies within automotive production, certification institutions recognized the importance of the technologies; common requirements for the certification of additively manufactured parts were defined widely. Manufacturers adjust their new products to these requirements.

Despite the increasing level of certification, still partly varying levels drive costs and prevent an extensive use of AM within the automotive production; finished parts as well as whole processes (material powder, machine, etc.) need to be certified with high effort. At the same time, alternative power train concepts calm down the discussion on legislation on fuel consumption.

The most probable future scenario combination for the automotive industry with the highest impact on its field of conception describes a world, where regarding the global environment, Europe sets the pace in a globalized world. The scenario for the automotive production is characterized by new production concepts that drive the individuality of automotives.

2.2.4 Electronics Industry

Within the electronics industry, the electronics industry manufacturing equipment has been selected as the most promising field. The developed scenarios encompass statements about the market, regulations, branch technology and suppliers. The future of the electronics industry manufacturing equipment is characterized by 13 key factors show in figure 2-12.

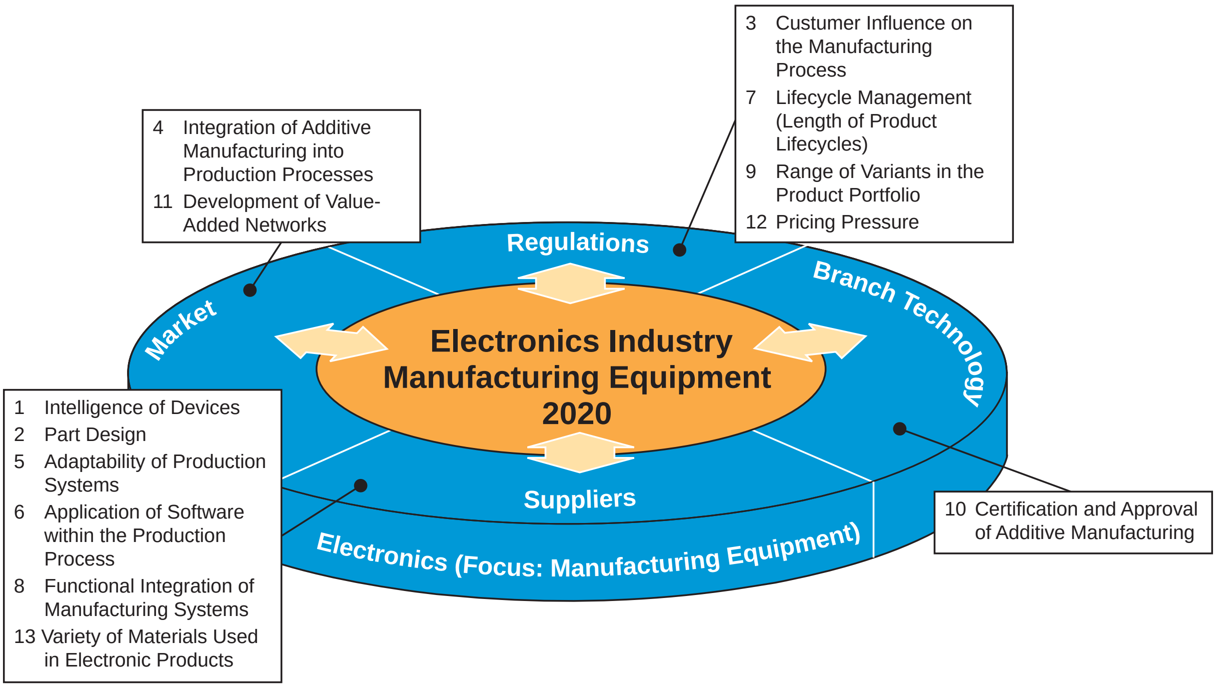

Figure 2-12: Key factors for the electronics industry manufacturing equipment

13 key factors were used to develop three consistent scenarios for the electronics industry manufacturing equipment in 2020.

Based on the future projections of these key factors, three scenarios have been developed. The three scenarios “Major Break-Through is lacking” (E1), “Risk Aversion and Stagnation Hinder Innovation” (E2), “Highly integrated Production Systems Allow Individualized Production” (E3) describe possible consistent futures of the electronics industry manufacturing equipment in 2020 (see fig. 2-13). The list of the key factors and their future projections are provided in appendix A2. A detailed description of the key factors and projections is part of the confidential study.

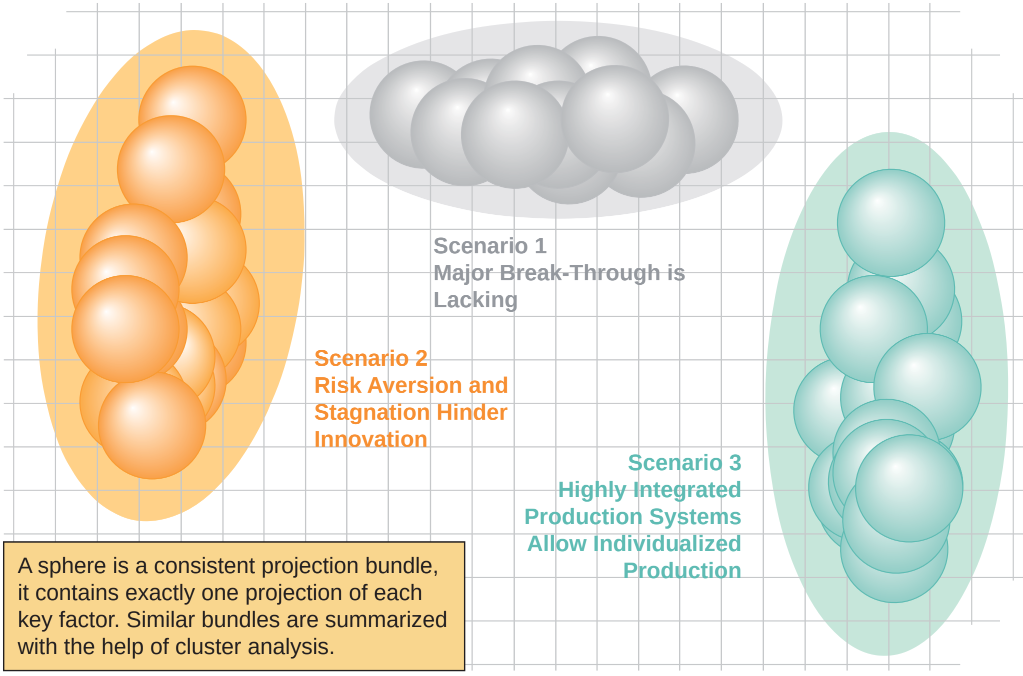

Figure 2-13: Developed scenarios for the electronics industry manufacturing equipment 2020

In the next step, the branch scenarios were matched with those for the global environment (see chapter 2.2.1) to create overall scenarios. Within a workshop, the participating experts from the electronics and the AM-industry estimated which combinations have the highest consistency. Figure 2-14 shows the results. The combinations G3/E1, G1/E2 and G2/E3 are consistent by means of thinkable future scenarios.

Global Environment / Electronics Industry Manufacturing Equipment	**Scenario 1 (E1):** “Major Break-Trough is Lacking”	**Scenario 2 (E2):** “Risk Aversion and Stagnation Hinder Innovation”	**Scenario 3 (E3):** “Highly Integrated Production Systems Allow Individualized Production”
Scenario 1 (G1): “Europe on the Edge”	+	+ +	
Scenario 2 (G2): “Europe Sets the Pace in a Globalized World”			+ +
Scenario 3 (G3): “European Fortress”	+ +	+	+

+ + Very high consistency
+ High consistency

Figure 2-14: Matching of the scenarios for the global environment with the scenarios for the electronics industry manufacturing equipment

Scenario Transfer - Selection of Reference Scenario

Scenarios constitute a profound basis for the development of strategies. Through the scenario transfer scenarios prove to be useful for strategic management decisions. In general, it is useful to develop a focused strategy to bundle the available resources. A focused strategy consequently aims at the occurrence of one scenario. Therefore, the scenario combinations have to be analyzed regarding their impact on the field of conception and their probability of occurrence in order to select the reference scenario.

The evaluation is based on the following two questions:

- How probable is the occurrence of a scenario from today's perspective?
- How strong is the impact of the scenario on the field of conception?

For each of the key factors, the experts rated, which projection has the highest probability of occurrence and which projection has the highest impact on the use of DM-technologies within the electronics industry manufacturing equipment. Based on the list of characteristics (see confidential study), the values for each scenario can be quantified, and the scenario combinations can be positioned in the portfolio, as shown in figure 2-15. For the three combinations, the ordinate intercept shows the impact; the abscissa intercept indicates the probability of occurrence. The closer a combination is to the top right corner, the higher is the importance for the strategy development.

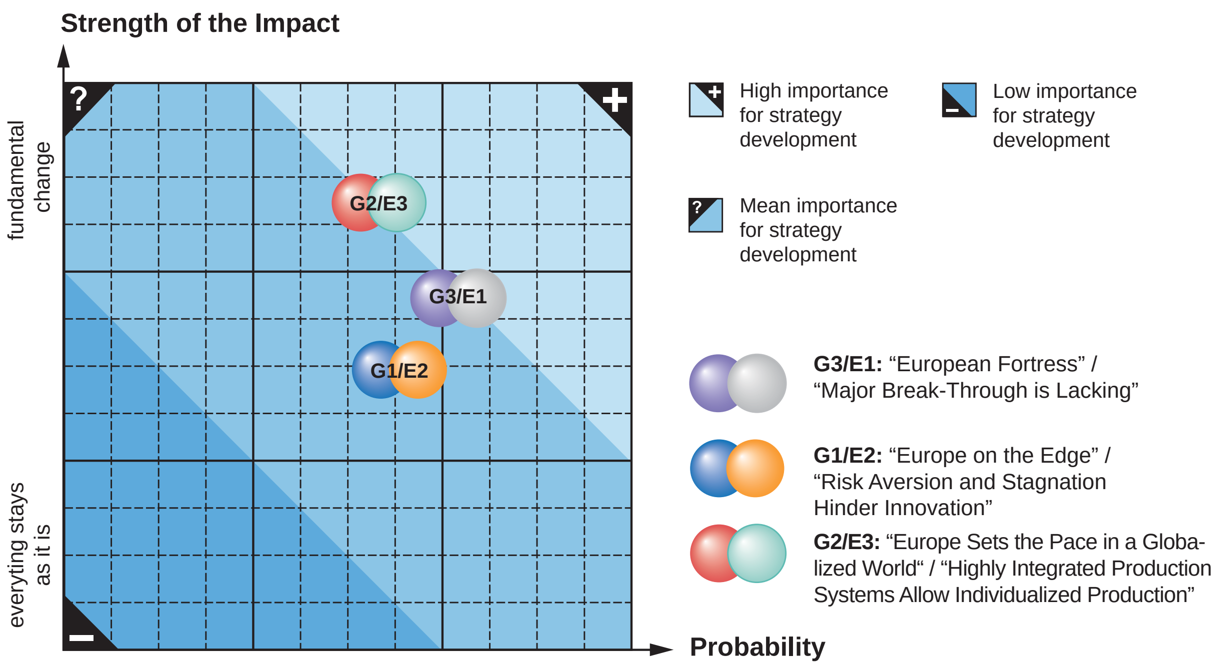

Figure 2-15: Selection of reference overall scenario for the electronics industry

The evaluation of the three combinations shows that from today's point of view the overall scenario G3/E1 is classified as the most probable scenario combination. The overall scenario G2/E3 has a marginally lower probability of occurrence, but a slightly higher strength of impact on the business of DM-technologies. As G3/E1 and G2/E3 have about the same importance for strategy development, they were intensively discussed by the participating experts. As a result, G2/E3 has been selected as the reference scenario.

The following management summary gives an overview of the reference scenario combination. The selected reference scenario of the global environment "Europe sets the Pace in a Globalized World" is also part of the selected reference scenario combination of the aerospace industry. Therefore, the management summary is already provided in chapter 2.2.2. A detailed description of all scenarios is part of the confidential study.

E3: "Highly Integrated Production Systems Allow Individualized Production"

Suppliers:

Value added networks emerge.

Today, manufacturers are strongly cross-linked within the electronics industry as value-added networking has been proven as an appropriate method to mutually increase competencies. Networks between global and regional operating manufacturers evolve.

Market:

Individual production systems on the rise

The increasing complexity of tool manufacturing projects fostered a closer networking with customers: customer influence is on the rise. Due to the growing demand for individual, customized products, innovation is considered to be the key for success within the electronics industry, and many manufacturers committed themselves to innovation. The resulting high innovation speed is progressively shortening product lifecycles. As customers are willing to pay higher prices for individuality, the number of orders that are accepted beneath the cost-recovery has been immensely reduced, compared to 2011; the price pressure on companies has been decreasing. Due to these developments, individual production systems prevailed. This leads to a high product variety for the suppliers of manufacturing systems which is realized by a modular structure. The modularized customization of production systems is increasingly realized by software.

Branch Technology:

Device-free production is partly established.

Progressively, intelligent processes and process monitoring prevail. These processes reduce the need for intelligent devices, and device-free production lines have been partly established within the electronics industry. Due to further research, improvements in AM-processes have been realized. Standardized design rules that are instrumental for part creation via AM-technologies have been developed, and are continuously added. Functional-driven design is the key to success, as the ratio of functionality and costs has

Software takes over production processes

been improved. In addition, the compatibility of AM-processes with conventional manufacturing processes is no challenge anymore; the entire integration is possible by now. Low standardization of electronic products pushes flexibility of productions systems. Highly flexible production systems are realized; lifecycles of these production systems have extended. Increasingly, manufacturers face the challenge of raising complexity. They succeeded to develop appropriate software solutions, and software takes over entire production processes; only boundary conditions are predefined. Intense material research provides new materials with overwhelming qualities; these high-tech materials widely prevail.

Regulations:

Certifications have prevailed; varying levels drive costs.

Suppliers and customers recognized the importance of AM-technologies. This forces certification institutions to define common requirements for certifying additively manufactured parts. Thus, a common understanding in the value chain has been established. In some exceptional cases, certification institutes established requirements in terms of new certification barriers. These varying levels of certification drive costs; (partly) finished parts as well as whole processes (material powder, machine, etc.) need to be certified with high effort.

The most probable future scenario combination for the electronics industry with the highest effect on its field of conception describes a world, where regarding the global environment, Europe sets the pace in a globalized world. In the scenario for the electronics industry manufacturing equipment, highly integrated production systems for individualized production prevail.

2.3 Future Chances, Risks and Success Factors for Direct Manufacturing

Within this chapter, the analysis of the reference scenarios for each selected industry takes place (see appendix A1). Therefore, future chances and risks have been deducted for the reference scenario combinations for the aerospace, the automotive and the electronics industry. Based on the chances and risks, future success factors for the application of DM within the industries have been derived. These factors constitute a profound basis for the development of strategic directions. The deducted chances and risks, the future success factors and strategic directions for all scenario combinations are provided in the confidential study.

2.3.1 Aerospace Industry

The chances and risks for the selected reference scenario combination of the global environment and the aircraft production (G2/Ai1), risks were deducted by the experts in a workshop. Figure 2-16 provides the chances and risks for the global environment “Europe sets the Pace in a Globalized World” (G2).

Chances	Risks
• European Union funds support new technological developments • Investments in product innovations pay back better due to reduced product piracy • Spreading knowledge to students in the universities is possible • Weaker European countries get the chance to contribute in high-tech • Richer customers are able to buy more expensive products • Wider use of internet increases possibilities for sellers to better reach customers • By informing the public about the energy saving opportunities for special parts, such as weight benefits through AM-technologies, AM-technologies gain good reputation for being environmentally friendly	• As product piracy is increasingly stemmed, machines are not bought for the use of creating inimitable designs anymore • Due to cheaply imported products / machines, competition increases • Low quality parts from abroad can ruin reputation of AM-technologies • Public may think „Additive Manufacturing needs a lot of energy“: Risk of wrong comparisons/ misperceptions

Figure 2-16: Chances and risks of the selected reference scenario for the global environment

Figure 2-17 shows the derived chances and risks for the branch scenario of the aircraft production “Individual Customization Fosters AM-technologies” (Ai1).

Chances	Risks
• Production of functionally oriented parts becomes more important • Due to small lot sizes, chances of customization are higher than within other industries • Using AM-technologies, ability to customize airplanes increases: Possibilities for new cabin developments • More competition fosters product quality of AM-parts • Functional design allows the lowering of noise • Higher degree of outsourcing reduces overhead costs for OEMs • Reduction of lifecycle costs of aircrafts becomes possible due to use of recyclable materials • Better reproduction of parts facilitates certification	• Supply chain changes: Higher risks for OEMs as they depend on less sources • Risk of nonperformance of mega suppliers: strong dependency of OEMs on only a few suppliers • Technology risk increases • High investments in certification, qualification of materials, processes and parts are necessary to keep up with standards • Competition between suppliers is declining due to mergers of suppliers • Smaller margins for Tier2 suppliers: Total control of supply chain is necessary

Figure 2-17: Chances and risks of the selected reference scenario for the aircraft production

Future Success Factors

Based on the current success factors, the reference scenario combination and the deducted chances and risks, future success factors have been derived and specified. The following list is an excerpt; all factors are provided in the confidential study.

- Certifications: Development of processes (short ways) for certification of newly developed AM-parts;
- Combination of manufacturing technologies: Integration of AM-technologies into basic portfolio of the OEMs;
- Control of part lifetime: Extention of knowledge regarding the precise lifetime of a part at all kind of conditions;
- Customer integration: Increasing customer integration into the development process to better fulfill their needs;
- Design rules: Showing of opportunities by developing reference parts of secondary aircraft structures, systems and deduct specific ground rules for the use of AM-technologies; flowing down of the deducted ground rules to suppliers;
- Education: Education of engineers of all age to enable them to develop functional oriented products;
- New materials/Multi material: Development of new materials, which can be processed with existing materials;
- Value-added networks: Providing of decentralized machines or identify cooperation partners to provide worldwide spare parts on demand.

Based on the analysis of the reference scenario combinations, the following strategic direction has been developed by the experts.

Strategic Direction
Build up general ground rules for design of secondary aircraft structure, systems etc. and flow them down to suppliers (Integration of the supply chain)

2.3.2 Automotive Industry

The chances and risks for the selected reference scenario combination of the global environment and the automotive production (G2/Au1), risks were deducted by the experts in a workshop. Figure 2-18 shows the derived chances and risks for the branch scenario of the automotive production “New Production Concepts Drive Individuality” (Au1).

Chances	Risks
• High amount and variation of different parts for new cars • More materials used in automobiles increase the demand for innovative production technologies • Functional-driven design is highly supported by the use of AM-machines • New market is coming up for suppliers of functional parts • Certifying AM-technologies for the automotive industry will have a positive effect on using AM in other industries. The automotive industry can be presented as a success story for AM • Alternative power train concepts push AM-technologies as many parts need to be newly designed • Higher technology know-how of bigger suppliers due to synergy effects • Discussion on CO2 pushes localized production and therefore AM-technologies	• Cannibalization of material suppliers leads to bigger suppliers and less competition • Logistical risks due to high variety of materials and automobiles • Carbon/Composites may reduce the need for AM-parts • Lots of new datasets required for the processing with AM-machines • Ramp up problems for suppliers of AM-produced parts • Older engineers did not learn to create functional designed parts and may have restraints using this principle • Low quality of series parts may damage the reputation/image of AM-technologies • Demand for part quality might grow faster than the system ability of AM-machines

Figure 2-18: Chances and risks of the selected reference scenario for the automotive production

The chances and risks of the reference scenario for global environment “Europe sets the Pace in a Globalized World” (G2) are identical with the one of the aerospace industry. They are already provided in chapter 2.3.1.

Future Success Factors

Based on the current success factors, the reference scenario combination and the deducted chances and risks, future success factors have been derived and specified. The following list is an excerpt; all factors are provided in the confidential study.

- Carbon footprint: Showing up carbon footprint advantages regarding car lifecycle (production and fuel savings due to new possibilities of lightweight construction);
- Certifications: Realization of certifications of AM-parts along with certifications of new power train concepts;
- Education: Offering education regarding the application of AM-technologies to allow getting the functional way of thinking into the development processes of new car concepts;
- New applications: Developing of parts for new car concepts (e.g. fuel cells and e-mobility), which cannot be produced using conventional manufacturing technologies to benefit from the growing market segment;
- Process repeatability and part reproducibility: Creation of success story by developing reference part for mass production (50.000+ p.a.);

Based on the analysis of the reference scenario combinations, the following strategic direction has been developed by the experts.

Strategic Direction
Create success by increasing productivity and quality

2.3.3 Electronics Industry

The chances and risks for the selected reference scenario combination of the global environment and the aircraft production (G2/E1), risks were deducted by the experts in a workshop. Figure 2-19 shows the derived chances and risks for the branch scenario of the electronics industry manufacturing equipment "Highly Integrated Production Systems Allow Individualized Production" (E3).

Chances

- AM-technologies enable intelligent devices and products with new features and functions (USP)
- Device-free production lines push the use of AM-technologies and help getting new data for further technology research
- AM-technologies enable functional-driven part design (new design elements)
- As AM-technologies higher the flexibility of production lines, customer influences can be implemented easier (quick reaction to customer demands and changing requirements, providing function body)
- A higher integration of AM-technologies in standard manufacturing processes increases the fields of application for AM-technologies and the degree of value creation in a single process
- Machines using AM-technologies are mostly "plug and produce" manufacturing systems: As a higher range of products can be produced with the same machine, investments costs are reduced
- Due to flexible production systems, spare parts can be produced on demand; stocks in circulation can be reduced thereby
- As the entire production process is controlled and done by software, controllability of production processes is improved and personnel retention can be reduced

Risks

- As intelligent devices are more complex, difficulties to manage high complexity and functional integration occur
- Functional-driven design is a challenge: High pressure to manage (limited ability of developers) and to meet functional requirements (limited ability of machines e.g. speed, product shape, etc.) is prevalent
- Using functional-driven design can entail increasing waste of resources and difficulties to guarantee part quality (durability)
- As customer influence is high, the complexity of processes increases
- Due to the entire integration of AM into conventional production processes, a standstill of AM-production systems can lead to a major shortfall within the production
- To reach integration and adaptability of production systems, high financial efforts have to be made
- As software tools are able to manage the interaction between various machines, very complex manufacturing systems, consisting of conventional machines, can be used for flexible production
- Due to missing software standards, risk of software compatibility is high

Chances	Risks
• Rapid Prototyping can be used to shorten product development times which is essential for shorter product lifecycles • As multiple manufacturing steps can be performed by a single manufacturing system, high individualization becomes possible (lot size 1) and the ability for producing every part on every production system is improved • Certifications of AM-processes foster high transparency and increase the trust in AM-technologies, as safety-relevant construction jobs become possible • Increased communication between manufacturers will help pushing the research of Additive Manufacturing technologies, an effective use of resources and the creation of new jobs • Due to value-added networks, conventional transport can be reduced (data transfer is faster) and production takes place everywhere • Decreasing price pressure allows manufacturers to increase their spendings for research which will help to push the speed of development • Decreasing price pressure and greater customer interest foster market expansion and new products (properties) • The manufacturing of parts, which are produced using AM-technologies, requires less raw material, as almost no waste will be produced	• Strong dependency on highly integrated production systems results from the high degree of functional integration • A higher use of platform strategies reduces the fields of application of AM-technologies • High costs for certifications, qualification of processes and parts reduce the attractiveness of AM-technologies • Less expensive conventional production technologies from Asia could edge out expensive AM-technologies • Many new materials have to be qualified for existing machines, as they cannot be processed using AM-technologies • Tied-up capital increases, as the overall availability of materials has to be guaranteed

Figure 2-19: Chances and risks of the selected reference scenario for the electronics industry manufacturing equipment

The chances and risks of the reference scenario for global environment "Europe sets the Pace in a Globalized World" (G2) are identical with the one of the aerospace industry. They are already provided in chapter 2.3.1.

Future Success Factors

Based on the current success factors, the reference scenario combination and the deducted chances and risks, future success factors have been derived and specified. The following list is an excerpt; all factors are provided in the confidential study.

- Built size: Qualifying AM-machines for manufacturing larger product sizes;
- Certifications: Development of processes (short ways) for certification of AM-machines for integrated production processes as well as manufacturing equipment built by AM-machines;
- Combination of manufacturing technologies: Enabling physically and software-related integration of AM-machines into conventional production lines; increasing the adaptability of AM-machines to higher flexibillity of production processes;

- Customer integration: Setting up processes for fast integration of customer requirements into products; increasing transparency of production processes for customers;
- New materials/multi materials: Increasing the availability of different materials and realization of multi-material productions processes; development of on-the-fly change of material within production processes;
- Process speed: Qualifying AM-machines for higher speed;
- Quality assurance systems: Enabling simulation of manufacturing process for high amount of "1-lot-size" production;
- Value-added networks: Establishment of value-added networks as an appropriate method to mutually increase competencies.

Based on the analysis of the reference scenario combinations, the following strategic direction has been developed by the experts.

Strategic Direction
Enable processes and materials for highly integrated production

In order to create success for DM-technologies within the future of the aircraft production, it will be necessary to build up general ground rules for the design of secondary aircraft structure, systems etc. for AM-technologies and to flow them down to suppliers. To enhance the penetration of DM-technologies within the automotive production, it is necessary to increase the productivity and the quality of additively manufactured parts. To succeed within the future of the electronics industry manufacturing equipment, AM-processes and materials have to be enabled for highly integrated production.

2.4 Summary of Tomorrow's Business

The aerospace, automotive and electronics industry were identified to be the most promising business opportunities for the application of DM in the future. The examined fields of conception were the aircraft production, the automotive production as well as the electronics industry manufacturing equipment, respectively. Within the scenario transfer, the scenarios for the global environment and the branch scenarios were matched to create three overall scenarios for each industry.

Strategic direction aerospace industry: build up general ground rules for the design of secondary aircraft structure, systems etc. and flow them down to suppliers

The most probable future scenario for the aerospace industry with the highest impact on its field of conception describes a world, where regarding the global environment, Europe sets the pace in a globalized world. The scenario for the aircraft production is characterized through individual customization of aircraft which fosters the application of AM-technologies. To be successful in this future, it will be necessary to build up general ground rules for the design of secondary aircraft structures, systems etc. for AM-technologies and to flow them down to suppliers.

Strategic direction automotive industry: create success by increasing productivity and quality

The selected reference scenario combination for the automotive industry also includes the previously selected scenario for the global environment. In this future, the field of conception of automotive production is characterized by new production concepts that drive the individuality of automotives. Against this background, it is necessary to increase the productivity of DM-technologies, and the quality of additively manufactured parts.

Strategic direction electronics industry: enable processes and materials for highly integrated production

The reference future scenario combination of the electronics industry manufacturing equipment also implies the previously selected scenario for the global environment. In the future of the branch, highly integrated production systems for individualized production prevail. To succeed in this future, AM-processes and materials have to be enabled for highly integrated production.

3

Conclusion and Outlook

The study “Thinking ahead the Future of Additive Manufacturing – Analysis of Promising Industries” reveals current and future success factors for the application of AM-technologies for Direct Manufacturing.

The market penetration by AM is still limited; identified success factors allow increased penetration

The investigations focus on the business of today and tomorrow. Regarding the business of today, 14 known and aspiring application fields are analyzed regarding their market and technology development as well as their penetration by AM-technologies. As the penetration is still limited, the study provides success factors to expand the application of AM-technologies within these fields. For example design rules and process reliability are crucial success factors for all industries.

Based on future scenarios, future success factors for the aerospace, automotive and electronics industry have been derived.

For the most promising application fields, the scenario-technique is used to think ahead the future. Based on the developed scenarios, future chances and risks as well as future success factors are presented. Beyond this, strategic directions are derived for being successful in these scenarios. For instance, AM-technologies have to be qualified for highly integrated processes to succeed within the electronics industry. Taking this path, the study gives hints for increasing the success of AM-technologies and for their advancement to Direct Manufacturing.

Further proceeding in the project: development of future applications and derivation of required technological advancements.

In the following work package 2, future applications within the developed reference scenarios will be developed; they will be pooled to innovation fields and ranked using a systematical idea management. Based on these innovation fields, future customer requirements will be deducted and validated with experts. You are kindly invited to participate.

In work package 3, these customer requirements will be taken to identify necessary product, material and production technology advancements of existing AM-technologies.

The public studies regarding work package 2 and 3 will be published by October 2011, respectively March 2012.

“Don’t worry about the future; it will not begin until tomorrow.”
– Žarko Petan

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A1

Scenario-Technique – Thinking ahead the Future

In strategic leadership, the application of the scenario-technique fundamentally differs from traditional planning. Alternative developments of influence factors have to be taken into account in order to anticipate possible future developments. The scenario-technique supports decision makers in this complex process. The “Thinking in scenarios” is based on two basic principles:

- Multiple future: As the future is not predictable, different possibilities for the future development of influence factors have to be taken into account. In this context, we are talking about multiple future.
- Networked thinking: The future is described in complex images. Our experience shows that it is not sufficient to present the environment of a company as a simple system. It is rather necessary to get a systematic view on the future by networked thinking.

As we understand the scenario-technique, a scenario is a generally understandable description of a possible situation in the future, based on a complex network of influence factors.The use of scenarios for strategic leadership purposes is known as scenario management, e.g. scenario management goes beyond the actual scenario development. Future scenarios provides a comprehensive view on the competitive environment of tomorrow, and enable decision makers to anticipate future success potentials and threats for the established business of today.

The scenario-technique can be explained by a phases/milestones diagram which consists of 5 phases, as shown in figure A-1.

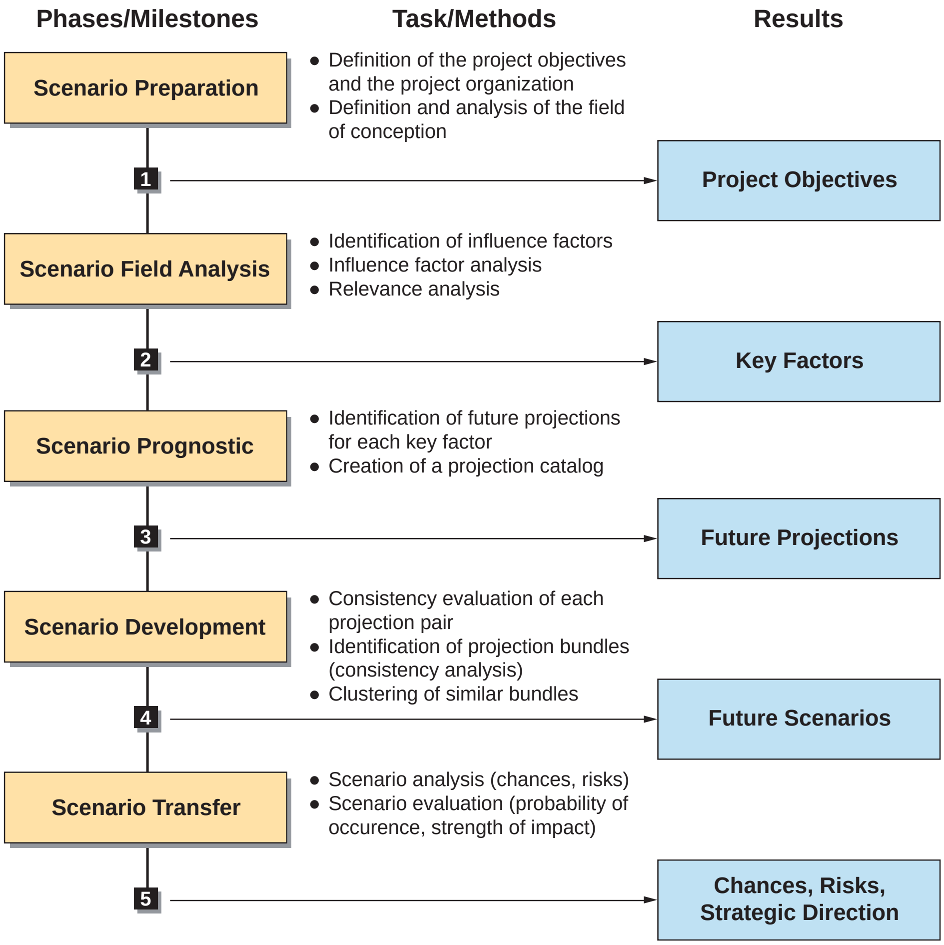

Figure A-1: Proceeding for the scenario-management

Scenario Preparation

The scenario preparation (phase 1) encompasses the definition of the project objectives and the project organization as well as the definition and analysis of the field of conception. The phases 2 to 4 will be discussed in detail in the following. The proceeding is visualized by the pictures A-2 and A-3, which are readable from left to right.

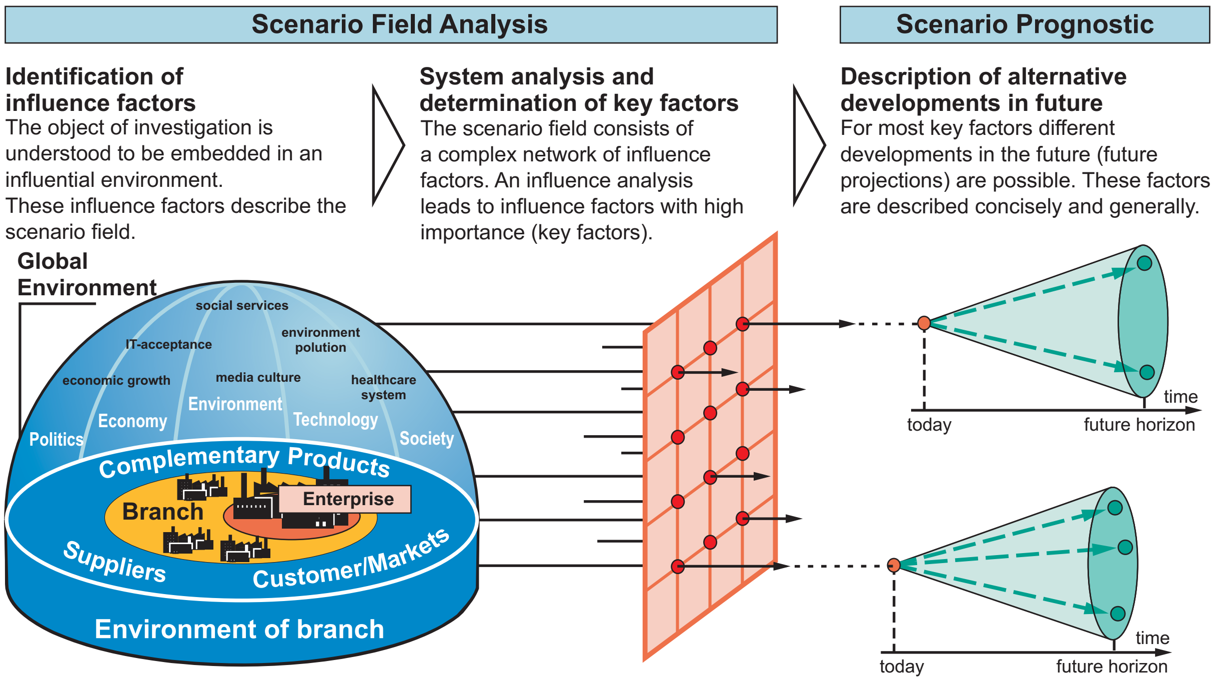

Figure A-2: Scenario development (part 1 of 2): From scenario field to future projections

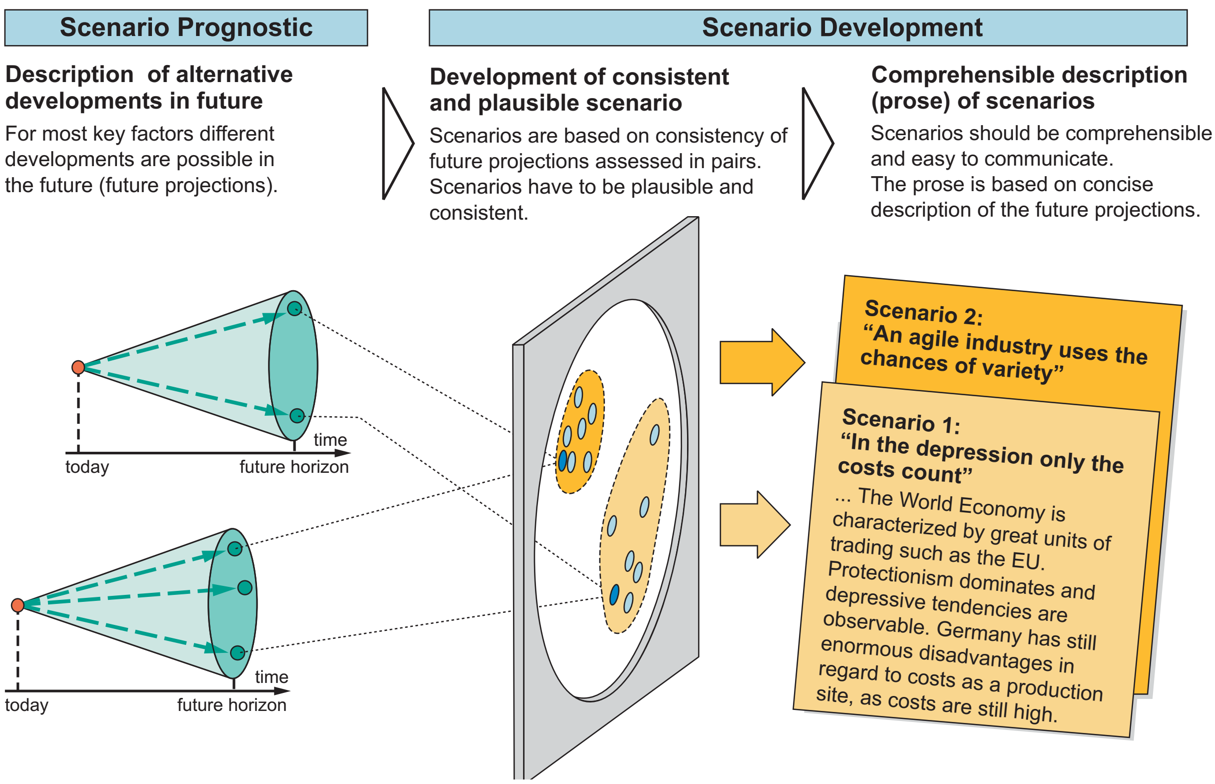

Figure A-3: *Scenario development (part 2 of 2): From future projections to scenarios*

Scenario Field Analysis

The goal of the scenario field analysis (phase 2) is the identification of the most relevant and characteristic factors which influence the future development of the scenario field. These factors are called influence factors. In our projects, a multi-stage approach for the identification of the influence factors has proven effective. First, the scenario field is divided into spheres of influence. As indicated in picture A-3, these are areas directly surrounding the object of investigation (sector, market, suppliers etc.) and areas of the global environment (politics, economy, society, technology etc.). Within these spheres of influence, we identify influence factors. For instance, “Demography” is an influence factor used in this study. For each identified influence factor an easily comprehensible title is chosen and the factor is briefly defined.

Selection of Key Factors

From a wide range of influence factors, the most relevant factors, the so called key factors, have to be selected. Key factors are those influence factors that have the highest impact on the scenario field and the object of investigation. They constitute the basis for the scenario development. To identify the key factors, different techniques such as the influence and relevance analysis are used. In general, 15-20 influence factors are selected to be the most relevant for characterizing the scenario field. In this project, the key factors were identified by the participants in a workshop.

Preparation of the Key Factors

For further processing, the selected key factors have to be prepared. Therefore, in addition to the definition for each key factor, the current situation of each key factor has to be described precisely. This description is based on indicators; the indicators are quantities that can be measured, surveyed and directly quoted. Thereby, the development of respective factors can be estimated. Furthermore, the indicators are usually used for the premises-controlling. The goal of the premises-controlling is to investigate whether the assumptions underlying the strategy (expressed by the chosen market and environment scenario) are still valid. All data must be proved with sources, in order to ensure the traceability for those people who are not directly involved in the scenario project. An exemplary indicator used for characterizing the influence factor “Demography” is the number and composition of private households within the EU.

Scenario Prognostic

The scenario prognostic (phase 3) forms the core of the scenario-technique. Here, the “insight into the future” is done. Therefore, alternative development possibilities (projections) of key factors are worked out accordingly to the principle of the multiple future. Possible projections developed for the key factor “Demography” are “Return of the Multi-Generation Households” and “Aging Single-Society”. In order to identify appropriate projections, it is previously necessary to define the time horizon. In general, we choose about ten years as a time horizon. In the context of highly dynamic businesses, for instance in areas such information technology, telecommunication or the industrial image processing, a closer time horizon can be advisable.

The development of future projections is a central step within the scenario technique, as thereby the components of the scenarios, which are developed in the next step, are created; these components directly contribute to the significance and the quality of the scenarios. In order to create suitable future projections a three-step procedure per key factor is to be carried out.

Identification of Possible Future Projections (Step 1):

For the identification of possible future projections, analytical and creative abilities are required. Using the analytical way, future projections of key factors can be identified through quantitatively measurable indicators. “Population” and “Market Development” quantities represent such possible indicators. Many key factors such as the key factor “Working Environment” can be better described by characteristics such as “Labor Law”. The procedure for the identification of possible future projections cannot be generalized. However, there are a few useful basic instructions:

- Extrapolating or simulating of developments;
- Oversubscribing developments and their characteristics;
- Accelerating developments consciously;
- Including environment developments consciously;
- Determining future projections through processes.

Selection of Future Projections (Step 2):

In general, a huge number of future projections can be developed for each key factor. From the large number of possible future projections, suitable projections, which provide a description of characteristic development possibilities, have to be selected. In addition, it is especially important to select such projections that decribe notably distinct development possibilities.

Formulating and Justification of Future Projections (Step 3):

In the final step, the future projections have to be precisely formulated and justified for being understandable easily and quickly for any uninvolved person. Therefore, a future projection should initially include a concise title. Beyond the better handling of the projections in a project, a concise title has the advantage to arouse the user’s interest, and enables a quick application of a projection in discussions. Apart from the title, a detailed description and justification for future projections is required. As a general rule: the more the projection deviates from the supposed probable and the more provocative the projection is, the more important its justification is. The descriptions of the projections constitute the basis for the following composition of the scenarios.

Scenario Development

In the scenario development (phase 4), scenarios are created based on the formulated future projections. A scenario is basically a combination of future projections that fit well together. The most basic scenario is a so called projection bundle, i.e. it is a chain of projections consisting of exactly one projection of each key factor. The consistency between the single projections is decisive for the credibility of the scenarios. For instance, a scenario is incredible if it describes a drastic increase of petrol prices simultaneously with the increase of individual mobility. Such contradictions are called inconsistencies. In contrast, the combination of increasing fuel prices and decreasing mobility in one scenario is highly consistent. The combination of increasing environmental constraints with an intensified industrial R&D-activity is a further example for a consistent projection pair. Scenarios consisting of such combinations are conclusive. The evaluation of the consistency between the different projections is to be executed by the members of the scenario project team. To generate internally consistent scenarios, each projection pair has to be reviewed on its compatibility. This pairwise consistency assessment occurs in a consistency matrix. Within the consistency matrix, consistency ratings only need to be entered on one side, as the relation between the projections is not directed. For the evaluation of the consistency, we use the following assessment scale:

1 = Total inconsistency, i.e. both projections are mutually exclusive and cannot occur in a credible scenario;

2 = Partial inconsistency, i.e. both projections contradict each other. Their joint occurrence affects the credibility of a scenario;

3 = Neutral or independent, i.e. both projections do not influence each other or their joint occurrence does not influence the credibility of a scenario;

4 = Partial consistency, i.e. both projections can well occur in the same scenario;

5 = Total consistency, i.e. due to the occurrence of one projection, the occurrence of the other projection can be expected

The consistency evaluation of each projection pair is based on subjective assessment, comparable to the influence analysis. Particularly within larger scenario projects, several consistency matrices are to be completed. The deviations resulting from the various evaluations, allow conclusions on problems of comprehension and different estimations of future developments. The discussion associated with the synchronization of the different consistency matrices per se represents a value creation of the scenario project. The following steps such as the consistency analysis, raw scenario development and future fields-mapping are automatically performed by the applied scenario software.

The goal of the last step of the scenario development is initially the creation of prose texts of the identified raw scenarios. Therefore, we use the so called characteristics list which is automatically generated by the scenario software. The characteristics list contains the key factors with their projections and indicates how frequent a projection occurs within a scenario. We distinguish between explicit, dominant and alternative projections, as explained in the following:

- Explicit characteristics of a scenario are future projections, which occur in at least 75% of all projection bundles of a raw scenario.
- Dominant characteristics of a scenario are future projections that occur in less than 75% of the bundles of a scenario. However, they dominate the scenario, as they do not occur in any other raw scenario or as there is a striking imbalance between the ambiguous projections of a key factor, which justifies theirs primarily consideration in the regarding scenario.
- Alternative characteristics are future projections that occur in more than a quarter of the projection bundles, and that are neither explicit nor dominant characteristics. They generally indicate that several future projections of a key factor can be characteristic for a scenario.

The prose texts that were formulated for the future projections constitute the basis for the description of the scenarios. These prose texts have to be linked according to the characteristics list. In addition, they have to be brought in a logical order by the scenario author; if necessary, transitions are to be formulated to make the text easily readable. To provide a logical sequence within the scenarios, it is generally required to start with the development of the global environment and to finalize the scenario with the description of the areas of influence that immediately surround the object of investigation. At this point, it is obvious that the scenarios are not fictitious. They are based on the concisely described projections of the key factors, on which a consensus was reached by the members of the scenario team.

Scenario Transfer

The developed scenarios expand the view for possible future developments. Therefore, they constitute a profound basis for the development of strategies. Through the scenario transfer, scenarios prove to be useful for strategic management decisions. In the scenario transfer (phase 5) the impact of the scenarios on the field of conception is analyzed. As a result, success potentials for the business of tomorrow and threats for the established business can be derived. Based on the identified chances and threats, a strategic direction is developed.

There are two general approaches for the application of scenarios in the strategic planning process: the future-robust strategy and the focused strategy. The advantage of the future-robust strategy is that it takes all identified scenarios into account. However, as only one single scenario will become reality, the development and pursuit of future-robust strategies is connected with a waste of resources. In general, we propose a focused strategy development. A focused strategy consequently aims at the occurrence of one scenario.

The “impact/probability of occurrence-portfolio” facilitates the discussion on the developed scenarios. The portfolio has two dimensions:

- The probability of occurrence indicates how probable the occurrence of a scenario is from today’s perspective. To perform this assessment, it is useful to ask “Which developments, which are discernible trends today, point at which scenario?”.
- The strength of the impact indicates the degree of change for today’s business if the regarded scenario becomes reality.

In the portfolio, three areas can be distinguished:

- Scenarios located in the upper right area of the portfolio are of high importance for the strategy development. They have high probability of occurrence and a major impact on the regarded business. Generally, the reference scenario that has to be applied for the focused strategy development is located in this area.
- Scenarios in the lower left area are of minor importance for the strategy development. Due to the low probability of occurrence with simultaneously minor impact on the field of conception, these scenarios are not relevant.
- The diagonal area within the portfolio has to be differentiated. For instance, it is recommendable to prepare alternative strategies for scenarios that are positioned at “low probability of occurrence/ fundamental change”, in order to be mentally prepared for changed conditions of the business.

In the context of the focused strategy development, it is important to regularly control the regarded strategy and the pre-defined assumptions made for the environment. This premises-controlling is required, as it is absolutely unsophisticatedly to mold the developed strategy into resin and hang it on the wall. This means environmental changes has to be taken into account before pursuing the strategy. The premises-controlling is based on indicators that have already been identified during the description of the influence factors’ current situation. in general, not all indicators are of equal importance. For example, the indicators whose characteristics indicate the scenarios positioned in the upper area of the portfolio, are especially relevant as their change can cause fundamental changes within the established business.

More information regarding the scenario-technique is provided in the following book:

GAUSEMEIER, J.; PLASS, C.; WENZELMANN, C.: Zukunftsorientierte Unternehmensgestaltung – Strategien, Geschäftsprozesse und IT-Systeme für die Produktion von morgen. Carl Hanser Verlag, München, Wien, 2009

A2

Titles of Key Factors and Projections

Global Environment

Key Factor	Projections	
1 Government Influence	1A	Strong and Transparent Governments
	1B	Government Light
	1C	Rampant Bureaucracy and Mismanagement
2 Protection of Technological Advances	2A	Product Piracy is being Stemmed
	2B	Protection against Product Piracy is not Possible
	2C	Short-term Protection against Product Piracy
	2D	Product Piracy is Becoming less Important
3 Education and Research Policy	3A	State Support Pays off
	3B	Privatization of Education
	3C	Europe Falls back
4 The Role of the EU	4A	Prosperity through European Integration
	4B	Europe before the Split
	4C	“Brothers Network” of the Old Europe
5 Foreign Trade Policy	5A	Free Trade without Borders
	5B	Protection of the Cherished
6 Labor Supply	6A	Labor Deficit
	6B	Balanced Labor Market
	6C	Thin Tip – Broad Masses
7 Image and Attractiveness of a Production Site	7A	The European Union as a High-Tech Location
	7B	System Head European Union
	7C	The European Union is Left Behind
8 Degree of Globalization	8A	Key Players and Pace Makers of Globalization
	8B	The European Union Falls Back
	8C	Strong Trade Bloc European Union
9 Economic Development in Europe	9A	Strong Organic Growth
	9B	Chipped Economic Power
10 Demography	10A	Slight Population Growth through Migration
	10B	Declining and Aging Single Society
	10C	Growth by Baby Boom
11 Settlement Pattern	11A	Urbanization
	11B	Escape to the Cities
	11C	The New Country Life
12 Distribution of Income	12A	The Income Gap Grows
	12B	On the Way into a Two-Class Society
	12C	Basic Incomes Adjust Differences in Income

Key Factor	Projections	
13 Mobility	13A	New Virtual Mobility
	13B	Mobility in the Cost Trap
	13C	High Sustainable Mobility
14 Distribution of Traffic	14A	Private Transportation
	14B	Public Transport, Ship and Train Win
15 Availability of Energy	15A	Energy Crisis
	15B	Scarce Energy, High Efficiency
	15C	Broad Energy Mix
16 Environmental Awareness	16A	Broad Consensus for Environmental Protection
	16B	Lip Service
	16C	Big Differences in the Environmental Protection
17 Development of Raw Material Resources	17A	Relaxation on the Raw Material Market
	17B	Raw Material Bottlenecks can be Met Largely
	17C	Worldwide Shortage of Raw Materials

Aircraft Production

Key Factor	Projections	
1 Part Design	1A	Functional-Driven Design is the Key to Success
	1B	Production-Technology-Driven Design Still Plays the Most Important Role
	1C	Production-Technology and Functional-Driven Design are Teamed
2 Market Accessibility of Suppliers of Additive Manufactured Products within the Aircraft Industry	2A	Mega Suppliers Rule the Market
	2B	Big and Small Work Side by Side
	2C	OEMs and Tier 1 Suppliers Take Additive Manufacturing in House
3 Customization of Aircrafts	3A	Variants due to Branding Purposes
	3B	Each Aircraft is Individual
	3C	Customization Becomes too Expensive in Civil Aircrafts
4 OEM's Commitment to Additive Manufacturing	4A	Many Manufacturers Jumped on Board
	4B	Knock-Backs due to AM-Part Failure
	4C	Additive Manufacturing Technologies Incrementally on the Rise
5 Role of Noise Reduction	5A	Requirements for Noise Reduction Push Additive Manufacturing Technologies
	5B	Noise Reduction is Becoming more Important
6 Cooperation between Aircraft Manufacturers and Suppliers	6A	Partnerships with Suppliers
	6B	OEMs do Not Cooperate with Suppliers
	6C	Increasing Cooperation and Communication (Collaboration)
7 Material (Aircraft) Recyclability	7A	New Materials Allow High Recyclability
	7B	Material Recyclability Development Stagnates
	7C	Legal Regulations Drive Research Efforts

Key Factor		Projections
8 Automation of Production	8A	Manual Work Prevails
	8B	Highly-Automated Processes
	8C	Hand-Crafted Steps in an Automated Process
9 Acceptance of Additive Manufacturing Standards	9A	One Set of Standards
	9B	Standards Exist – Big Differences in Content
	9C	Only Incremental Advancements on Standards
10 Certification of Additive Manufacturing Technologies for Aircrafts	10A	Common Understanding in the Value Chain
	10B	Varying Levels of Certifications Drive Costs
	10C	Emergency Solution Prevents Extensive Use
	10D	No Certifications Available
11 Availability of Tailor-Made Part Properties in Additive Manufacturing Processes	11A	Tailor-Made Part Properties are Possible due to Try and Error
	11B	New Materials/Machines Allow the Customization of Material Properties
	11C	Part Properties Still Vary
12 Energy Efficiency of Aircrafts	12A	High Need for Energy Efficiency
	12B	Increased Efficiency of Engines Reduces Fuel Consumption
	12C	Only Low Improvement of Energy Efficiency
13 Development of New Materials	13A	Market-Pull Meets Technology-Push
	13B	New Materials can Only be Realized under High Costs (Market-Pull)
	13C	Many New Materials Enter the Market (Technology-Push)

Automotive Production

Key Factor		Projections
1 Car Customization	1A	Individualized Production on Demand
	1B	Modularized Customization
	1C	Individualization is Not Economic
2 Variety of Materials Used in Automotives	2A	High-Tech Materials Widely Used
	2B	Material Research Leads to New Materials
	2C	Shortage of High-Tech Materials
3 Role of Additive Manufacturing Technologies in Automotive Product Development and Production Process	3A	Additive Manufacturing Limited to Prototyping
	3B	Additive Manufacturing in Series Production
	3C	Prototyping is Done Exclusively Digitally
4 Part Design	4A	Functional-Driven Design is the Key to Success
	4B	Production-Technology-Driven Design Still Plays Most Important Role
	4C	Production-Technology and Functional-Driven Design are Teamed

Key Factor		Projections
5 Certification of Additive Manufacturing Technologies for Automotives	5A	No Certifications Available
	5B	Common Understanding in the Value Chain
	5C	Varying Levels of Certifications Drive Costs
6 Legislation on CO2 Emissions	6A	Alternative Power Train Concepts Calm Down the Dis-cussion on Legislation on Fuel Con-sumption
	6B	Legislation Focuses on Whole Production
	6C	Legislations on Consumption due to Independency Focus of Countries
7 Lifecycle Management (Length of a Lifecycle)	7A	Longer Life Times of Automotive Parts Require Higher Part Quality
	7B	Longer Life Times are Realized by Higher Amounts of Spare Parts
	7C	Shorter Lifecycles Contribute to Lower Production Costs
8 Cooperation between Suppliers and OEMs	8A	Factory in Factory (Everything under one Roof)
	8B	Specialists all over the World
	8C	Worldwide Localized Production on Demand
9 Scalability of Production Technologies	9A	No Scalability: “Old School Production”
	9B	High Scalability in the Whole Production Process
	9C	Single Parts are Built Just in Time
10 Future Car Concepts	10A	Individualized High-Tech Car
	10B	Application-Oriented Low-Cost Car
	10C	Conventional Mass Car
	10D	Green Car
11 Added Value Distribution	11A	Suppliers as an Extended Workbench
	11B	0.5 Tiers as Powerful Mega Suppliers
	11C	Mega Suppliers and Small Specialists Side by Side
12 Energy Efficiency in Production	12A	Green Production is Highly Important for Sales
	12B	Energy Efficiency of Production is Unimportant
13 Role of the Automotive in Society	13A	The Automotive as a Commodity Product
	13B	The Automotive as an Expression of Individuality and Life Style
	13C	Emotionality Yields to Pragmatism

Electronics Industry Manufacturing Equipment

Key Factor		Projections
1 Intelligence of Devices	1A	Intelligent Devices on the Rise
	1B	Intelligent Processes Reduce the Need for Intelligent Devices (Device-Free Production)
	1C	Not Sufficient Suitable Devices Available

Key Factor	Projections	
2 Part Design	2A	Functional-Driven Design is the Key to Success
	2B	Production-Technology-Driven Design Still Plays Most Important Role
	2C	Functional-Driven Design is Becoming Important, Production Still Sets Framework Conditions
3 Customer Influence on the Manufacturing Process	3A	Customer Influence on the Rise
	3B	Closed Manufacturing Processes Impede Customer Influence
	3C	Customer Influence is Still Lacking
4 Integration of AM into Production Processes	4A	Limited Compatibility
	4B	Entire Integration is Possible
	4C	Inadequate Compatibility of Production Processes
5 Adaptability of Production Systems	5A	Low Standardization of Products Pushes Flexibility of Productions Systems
	5B	Competition Claims Highly Focused Production Systems
	5C	Flexible Production Systems Incrementally on the Rise
6 Application of Software within the Production Process	6A	Systems Become Too Complex to be Manageable
	6B	Modular Software Systems
	6C	Software Takes Over the Entire Production Process
7 Lifecycle Management (Length of Product Lifecycles)	7A	High Innovation Speed Shortens Product Lifecycles
	7B	Longer Life Times are Realized by Higher Quality
	7C	Pace of Innovation Reaches its Limits
8 Functional Integration of Manufacturing Systems	8A	Distributed Specialized Production Systems
	8B	Concatenated Production Systems
	8C	One System for All Production Steps
9 Range of Variants in the Product Portfolio	9A	Individual Production Systems
	9B	Modularized Customization of Production Systems
	9C	Diversity of Production Systems Decreases
10 Certification and Approval of Additive Manufacturing	10A	No Certifications Available
	10B	Common Understanding in the Value Chain
	10C	Varying Levels of Certifications Drive Costs
11 Development of Value-Added Networks	11A	Global Competition is Widespread
	11B	Regional Needs are Satisfied Regionally
	11C	Networks between Global and Regional Operating Manufacturers Evolve
12 Pricing Pressure	12B	Still Rising Price Pressure
	12C	Decreasing Price Pressure
13 Variety of Materials Used in Electronic Products	13A	High-Tech Materials Prevail
	13B	Material Research Provides New Materials
	13C	Reduction of High-Tech Materials

A3

Glossary

Characteristics List

The goal of the last step of the scenario development is initially the creation of prose texts of the identified raw scenarios. Therefore, we use the so called characteristics list which is automatically generated by the scenario software. The characteristics list contains the key factors with their projections and indicates how frequent a projection occurs within a scenario. We distinguish between explicit, dominant and alternative projections, as explained in the following:

- Explicit characteristics of a scenario are future projections, which occur in at least 75% of all projection bundles of a raw scenario.
- Dominant characteristics of a scenario are future projections that occur in less than 75% of the bundles of a scenario. However, they dominate the scenario, as they do not occur in any other raw scenario or as there is a striking imbalance between the ambiguous projections of a key factor, which justifies theirs primarily consideration in the regarding scenario.
- Alternative characteristics are future projections that occur in more than a quarter of the projection bundles, and that are neither explicit nor dominant characteristics. They generally indicates that several future projections of a key factor can be characteristic for a scenario.

Consistency Analysis

The consistency analysis is based on the completed consistency matrix and is performed in order to generate projection bundles. In the consistency matrix, single projection pairs are evaluated regarding their consistency. The scale of assessment ranges from 1 = total inconsistency to 5 = total consistency. If a consistency value of “3” is assigned to one projection pair, these projections are neutral or independent, i.e. both projections do not influence each other and their joint occurrence does not influence the credibility of a scenario.

Future Projections

Future projections are alternative development possibilities of key factors. The development of future projections is a central step within the scenario technique, as thereby the components of the scenarios, which are developed in the next steps, are created.

Influence Factor

Influence factors influences the scenario field and the object of investigation. They constitute the basis for characterizing the scenario field. Generally, up to 50 influence factors are identified to be relevant.

Key Factor

Key factors are those influence factors that have the highest impact on the scenario field and the object of investigation. They are selected from a wide range of identified influence factors and are the basis for the scenario development. In general, 15-20 influence factors are selected to be the most relevant for characterizing the scenario field

Projection Bundles

A projection bundle is a chain of projections, wherein exactly one projection occurs of each key factor.

Reference Scenario

The reference scenario is the scenario that is set as the basis for the development of a focused strategy. Generally, the scenario with the comparably highest probability of occurrence and the strongest impact on the regarded business is selected as reference scenario.

Scenario Software

The scenario software is an IT-Tool for the information-technological support of the scenario creation. This tool is used to perform the consistency analysis. Based on the consistency analysis, raw scenarios are developed and visualized based on multidimensional scaling by the software. The scenario software is a service offered by UNITY AG. For further information, see http://www.szenario-software.de/.

Scenario

A scenario is a generally understandable description of a possible situation in the future, based on a complex network of influence factors. Additionally, it is a presentation of a development that could lead from the present situation to a future situation.

Scenario Management

The scenario management consists of the five following phases:

- Scenario Preparation:

The scenario preparation encompasses the definition of the project objectives and the project organization as well as the definition and analysis of the field of conception.

- Scenario Field Analysis:

Within the scenario field analysis, the scenario field is described by influence factors. The key factors result from the networking and relevance of the influence factors. In this study, the key factors were identified by the participants within a workshop.

- Scenario Prognostic:

The scenario prognostic forms the core of the scenario-technique. Here, the actual “insight into the future” is done: alternative development possibilities, the so called future projections, of the previously defined key factors are worked out accordingly to the principle of the multiple future.

- Scenario Development:

In the scenario development, scenarios are created based on the formulated future projections. Therefore, a pair-wise consistency evaluation of the future projections is performed. A scenario is basically a combination of future projections that fit together well. The most basic scenario is a so called projection bundle, i.e. it is a chain of projections consisting of exactly one projection of each key factor.

- Scenario Transfer:

In the scenario transfer the impact of the scenarios on the field of conception is analyzed. This includes an impact analysis, whereby success potentials for the business of tomorrow and threats for the established business as well as the strategic direction are derived. The scenario transfer additionally encompasses the selection of the so called reference scenario; this constitutes the basis for the development of the focused strategy.