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Lead time reduction at an Austrian manufacturer for high temperature furnace components

Redesign of the order fulfillment process including sales, engineering and manufacturing

MASTER'S THESIS

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Abstract

Companies in many industries are facing increasing competition due to globalizing markets and a growing number of competitors. Those conditions force companies to diversify their product range while offering high quality products at competitive prices and delivery times. This thesis deals with the problem of decreasing the lead time at Plansee SE for high temperature furnace components. Therefore, the whole order fulfillment process is reviewed to find solutions to decrease the lead time without sacrificing on quality, customer service or price competitiveness. In this context sales, engineering, production planning and manufacturing are part of the order fulfillment process. Product configuration is chosen as a viable solution to provide improved product information at an earlier point in the order fulfillment process. Especially the upstream processes like sales, engineering and production planning can capitalize on the automatically generated product information. The manufacturing process profits from an increasing standardization of products and processes due to the product configuration. Because of the promising prospects, a product configuration system is implemented using the example of a furnace shielding manufactured by Plansee SE. As a consequence, more buffering spaces are required on the shop floor to leverage the full potential of the standardization of components due to the product configuration process. In addition, new equipment is required to fulfill the customer demands. Therefore, the scarce manufacturing space situation is reviewed at the production line producing high temperature furnace components. For the review, different layout planning methods including a weighted factor analysis are applied. As a result, more manufacturing space for core processes of this production line is created and the manufacturing organization is tuned towards meeting shorter lead times. Due to the shortened lead times, the competitiveness of Plansee SE in the market of high temperature furnace components is improved.

Kurzfassung

Unternehmen vieler Branchen sehen sich aufgrund der Globalisierung der Märkte und einer wachsenden Zahl an Konkurrenten steigendem Wettbewerb ausgesetzt. Dieser Umstand zwingt Unternehmen, ihre Produktpalette zu erweitern und gleichzeitig qualitativ hochwertige Produkte zu wettbewerbsfähigen Preisen und Lieferzeiten anzubieten. Die vorliegende Masterarbeit beschäftigt sich mit dem Problem der Verkürzung der Lieferzeit für Hochtemperatur-Ofenbauteile bei Plansee SE. Dafür wird der gesamte Auftragserfüllungsprozess untersucht, um Lösungen zur Verkürzung der Lieferzeit zu finden. In diesem Zusammenhang betrifft der Auftragserfüllungsprozess alle Abteilungen vom Verkauf über Engineering, Produktionsplanung und Fertigung. Außerdem sollen Qualität, Kundenservice und Preiswettbewerbsfähigkeit nicht beeinträchtigt werden. Produktkonfiguration wird als vielversprechende Lösung ausgewählt. Dadurch sollen verbesserte Produktinformationen zu einem früheren Zeitpunkt im Auftragserfüllungsprozess bereitgestellt werden. Insbesondere die vorgelagerten Prozesse wie Vertrieb, Engineering und Produktionsplanung können von den automatisch generierten Produktinformationen profitieren. Der Nutzen im Produktionsprozess resultiert aus einer zunehmenden Prozess- und Produktstandardisierung durch die Produktkonfiguration. In Folge wird ein Produktkonfigurationssystem anhand des Beispiels einer Ofenabschirmung, hergestellt von Plansee SE, aufgebaut. Die Standardisierung hat zur Folge, dass mehr Pufferplätze in der Fertigung benötigt werden. Um das volle Potenzial der Standardisierung von Komponenten durch den Produktkonfigurations-Prozess auszuschöpfen, sollen neue Pufferflächen entstehen. Zusätzlich besteht der Bedarf für neue Analgen um die Kundenanforderungen zu erfüllen. Deshalb wird in der Produktionslinie zur Herstellung von Hochtemperaturofenbauteilen die knappe Produktionsfläche evaluiert. Dazu werden Methoden aus der Layout Planung, unter anderem eine Nutzwertanalyse, angewandt. In weiterer Folge soll mehr Produktionsfläche für die Kernprozesse dieser Produktionslinie geschaffen und die Fertigungsorganisation auf kürzere Durchlaufzeiten ausgerichtet werden. Aufgrund der verkürzten Durchlaufzeiten kann die Konkurrenzfähigkeit von Plansee SE im Markt für Hochtemperatur-Ofenbauteile verbessert werden.

Table of Contents

1 Introduction

This thesis deals with the order fulfillment process of at IFT, a department at Plansee SE. The production line IFT (Industrial Fabrication Thermal Processes) deals with the manufacturing and assembly of finished goods for thermal applications. In the context of this thesis the order fulfillment process covers all aspects starting from the proposal generation to the shipment of the final product. Since the products are engineered and manufactured by Plansee SE, engineering and manufacturing are part of the order fulfillment process as well.

The current chapter first provides information on the department IFT. Subsequently, the manufactured products and the applied manufacturing technologies are introduced. Finally, an overview of the order fulfillment process for high temperature furnace components is given.

1.1 Description of the Environment

Plansee SE[1] as part of Plansee Group entirely focuses on the production, processing and marketing of molybdenum and tungsten products. The company has been founded in the year of 1921 by Dr. Paul Schwarzkopf with its headquarters in Reutte, Tyrol (Figure 1). The activities of Plansee SE span across the world with production sites in Europe, Asia and North America. Plansee SE sells products including semi-finished goods as well as end-products in the B2B segment [PLA17a].

Products made from refractory metals like molybdenum and tungsten excel with outstanding material properties. Especially the high temperature stability, the high melting point as well as the good electric conductivity make them suitable for applications in thermal processes. Those properties are the reason for using these metals for products like furnaces, components for coating systems and electrical contacts [PLA17a].

[1] Societas Europaea

Figure 1: Headquarters of Plansee SE, Reutte [PLA17a].

Plansee SE is divided into different departments that focus on specific product categories and technologies. The department IFT is specialized in the production of finished goods made from sheet metal for thermal applications. The main products are hot zones, HIP[2] cylinders and glass melting crucibles. IFT applies cutting, forming, coating, joining, assembling and measuring technologies to manufacture its products. Pre-products as well as finished components are sourced from different departments within Plansee SE. Pre-products include mainly sheet metal, rods and wires. The most common components applied in IFT products are turned parts such as pins, and helixes. Components made from other metals than refractory alloys are mainly sourced from suppliers.

1.2 Product Description

This section provides information on the products manufactured by IFT. The description contains the application and a rough overview of the respective product design. For reasons of simplification only the most important products are described in greater detail.

[2] Hot Isostatic Press

1.2.1 Hot Zone

Industrial manufacturing often requires high temperature treatments for processes such as sintering, soldering and different heat treatments. Hot zones are metallic furnaces designed for such use cases. Common processing temperatures range between 1000°C and 2800°C. The main components include heating elements, side shielding, front shielding, rear shielding and support structure. The outer shielding layers and the support structure are made from stainless steel. Except that, all components are made from refractory alloys. Besides the operating temperature and the energy efficiency, the usable space is the most important parameter describing a hot zone. That is the space available inside the hot zone for treating goods. Those three parameters define the majority of the design, manufacturing processes as well as the costs of the final product. There are three basic types of hot zones available, those are: round-horizontal, round-vertical and rectangular-horizontal. Figure 2 shows a rectangular-horizontal hot zone. The typical usable space ranges from (WxHxL) 400x400x600 to 1,000x1,000x1,500 (dimensions in mm). Smaller options for laboratory equipment and larger options reaching up to 6,000 mm in length are manufactured as well [PLA17b].

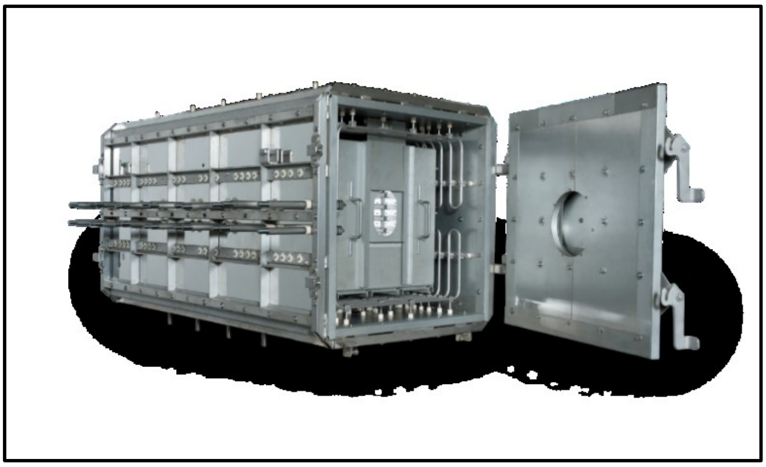

Figure 2: A rectangular horizontal hot zone [PLA17b].

1.2.2 HIP Cylinder

Hot isostatic pressing is a production process in powder metallurgy that creates products with superior properties. The parts are compacted at pressures up to 200 MPa and temperatures around 1,450°C. HIP cylinders are part of the processing equipment for hot isostatic pressing and are made from either molybdenum, ML or TZM[3]. They contain the batch and need to maintain strength at high temperatures. HIP cylinders are available with or without flange and cover. Figure 3 illustrates part of the HIP cylinder as well as the common round and cylindric shape. Diameters are usually around one meter. The length can be up to nine meters. Additionally, load carriers for HIP cylinders are part of the IFT product spectrum [PLA17b].

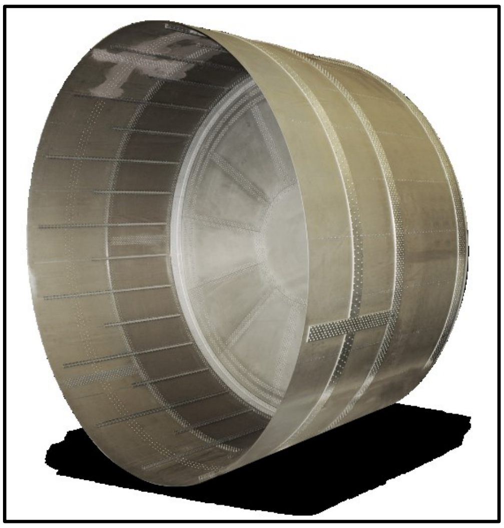

Figure 3: A HIP Cylinder [PLA17b].

1.2.3 Glass Melting Crucible

Quartz glass is produced by melting quartz sand in a crucible by means of induction or an electric arc. Similar to the continuous casting of metals the molten glass is fed to a nozzle which shapes the molten glass. This nozzle is fitted to the end of the tube-like crucible, which contains the molten quartz glass. There are two different types of glass melting crucibles defined by their respective fabrication process. The pressed and sintered type is produced by compacting, sintering and machining. The riveted type is made from formed sheet metal components that are joined by riveting. The riveted type is manufactured by IFT. Riveted glass melting crucibles are mainly made from tungsten [PLA17b].

[3] ML and TZM are both molybdenum alloys

1.2.4 Other Furnace Components

Besides from hot zones, HIP cylinders and glass melting crucibles, there are a lot more components supplied by IFT. These components include:

- Spare parts
- Screws, rivets and bolts
- Rotary tubes
- Sheet metal parts
- Shieldings
- Formed crucibles
- Charge carriers

All these components require similar manufacturing technologies and are made from preproducts produced by Plansee SE.

1.3 Order Fulfillment Process

Figure 4 shows the main processes and milestones in the order fulfillment process. This overview is very general and shows only the most important stages. The overlap between the different sub-processes indicates that some processes can be performed simultaneously. As much as parallelization saves time it also increases complexity and effort in the organization. The next paragraphs describe how the order fulfillment process works at Plansee SE for products manufactured by IFT.

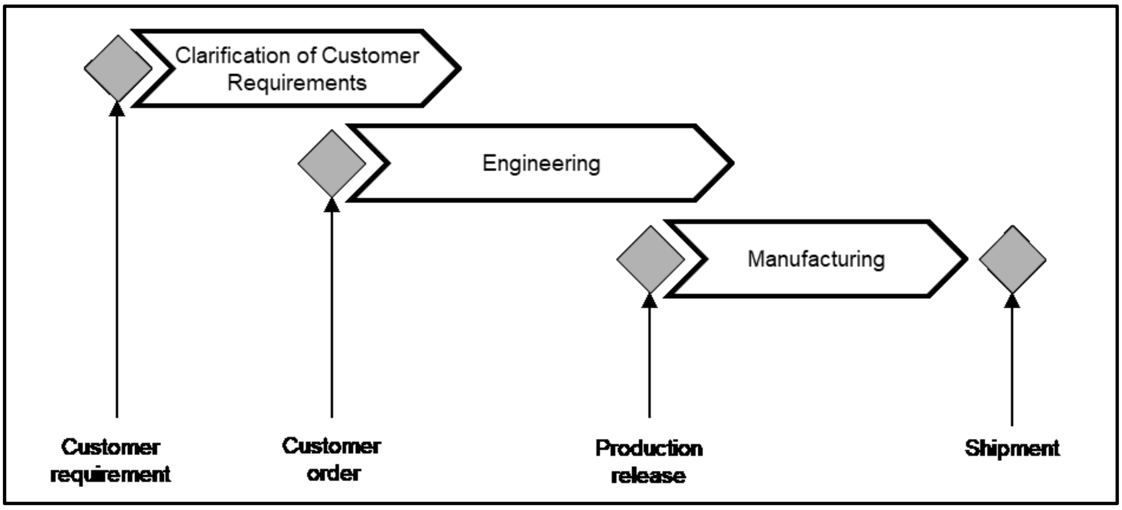

Figure 4: The order fulfillment process.

A customer requirement for a new product initializes the order fulfillment process. After the decision to source the product, Plansee SE receives a request for proposal (RFP) from its customer. This request for proposal usually only contains little information about the desired product. At Plansee SE those RFPs are handled by product managers. They ask the customer for more detailed information if required, support the customer with technical advice for the specific use case and prepare the proposal. Most of the customers expect a schematic drawing, specifications, some performance indicators and a price in the proposal. If Plansee SE wins the proposal and the product is customer specific the product managers communicate the customer order to the engineering department. Provided that the product has already been ordered once and no design changes are necessary, the order is transferred to the production planning department directly without consulting the engineering department.

The engineering department is responsible for all customer specific designs. Often the information for the proposal communicated to the technical sales office is not sufficient for the design. In those cases, the product managers need to further specify the information, required to design the product, with the customer. After all the information is available, the design process starts. The engineers first design the subassemblies that cause the most manufacturing effort and transmit them to the production planning department. This allows parallelization of design and production planning and therefore shortens the throughput time. In this manner, the design engineers prepare all the drawings necessary to manufacture the products.

After receiving the finished designs, the production planning department prepares the production routings for the workshop and creates the necessary production master data. They also deal with sourcing of required components and schedule the production processes. After all the data and manufacturing material are available, the production process starts.

1.4 Manufacturing Process

As already mentioned in section 1.1, IFT applies different manufacturing technologies focusing on the processing of sheet metal and assembly technologies. Those processes are illustrated in Figure 5.

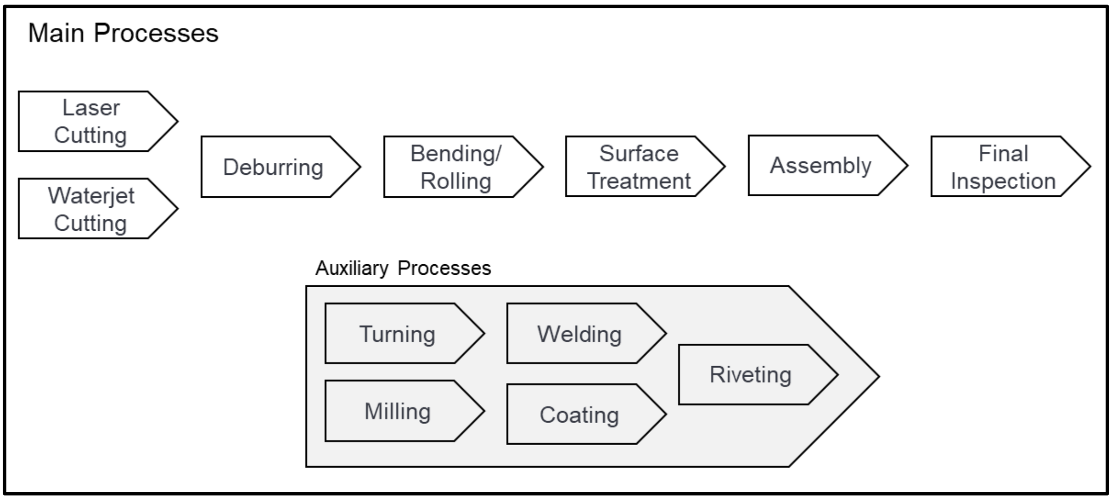

Figure 5: The manufacturing processes.

Not all the manufacturing processes at IFT are applied to the same extend. There are main processes which are performed on most of the components and auxiliary processes only necessary for some products. The auxiliary processes primarily involve enabling technologies that are only applied on a fraction of the products. Those processes are still important to maintain flexibility and to enable the great range of products manufactured at IFT.

After the production release, normally the main manufacturing process within IFT starts by cutting the sheet metal panels. Those panels are produced by Plansee SE and are stored at IFT subsequently. There are two different cutting technologies applied at IFT, laser cutting and water jet cutting. It depends on the material and sheet metal thickness which one of the two processes is chosen. Both machines have a storage nearby, containing the respective sheet metal panels as well as the excess material. Due to the cutting process, the sheet metal blanks show a burr at the cutting edge. Deburring removes the burr by grinding the surface. This step is required by most of the blanks. The process steps after cutting and deburring are optional and may change in sequence. Those processes are introduced in the upcoming paragraphs.

Bending and rolling involve a lot of craftsmanship due to the peculiar behavior of tungsten and molybdenum compared to more common materials like steel. Those materials cannot be cold formed and therefore require heating prior to the forming process. The heating is performed by welding torches and electric stoves. Due to heating the parts, the surface oxidizes and causes a change in color. A subsequent surface treatment cleans the surface and removes the oxidized layer. The surface treatment is done by another department within Plansee SE. Therefore, the parts need to leave the IFT workshop for this process step.

After manufacturing and sourcing of all the necessary components the final products are assembled. The assembly is performed manually and on a fixed position. That means all the assembly tasks are done on the same workstation. There are dedicated workstations equipped for assembling particular products and general workstations, where all products can be assembled.

The last step for finished goods is final inspection and packaging. Depending on the size of the product this process is performed either at the assembly workstation or the final inspection workstation. The inspection of incoming goods is also performed by the personnel of this workstation.

The auxiliary processes such as milling, turning and welding are done in different stages of the manufacturing process. Those processes are performed only on a fraction of the products and vary in sequence. Without the auxiliary technologies those products cannot be manufactured. Due to that reason the auxiliary processes are considered enabling technologies. Riveting is a supporting technology in the assembly of the products. Therefore, most of the assembly workstations are equipped with riveting machines. The rivets are produced by IFT as well. Coating is usually the last production technology applied after final assembly. The main coating technology is flame spraying used especially for bulky products like HIP-cylinders and glass melting crucibles.

As already mentioned, non-sheet metal components for the assembly of the final products are mainly sourced. Machined components made from refractory alloys are generally supplied by specialized departments within Plansee SE. Other components such as standard parts and ceramic components are sourced from external suppliers.

The variety of manufacturing technologies applied within IFT is rather extensive. Those technologies provide the necessary flexibility to manufacture the wide product range. On the other hand, the technology variety increases complexity and lowers efficiency in the production process.

2 Problem Analysis

Meeting short delivery times as well as high quality demands while enabling a maximum of customization can be challenging. Most of the products manufactured by IFT are customer specific and nonstandard products. Especially hot zones are engineered and designed specifically depending on customer needs. This circumstance not only boosts product variety and increases complexity, but it is time-consuming as well. Especially the engineering process is slowed down due to the customization. The efficiency in the manufacturing process is decreased as well.

Speaking of hot zones, there are already attempts towards standard components and subassemblies to reduce complexity. In the current design, most of the parts do not meet the requirements for standard components. For that reason, it is difficult to apply a make-to-stock (MTS) approach to lower lead times and level production. Furthermore, long lead times for sourced components cause delays when starting the downstream production and therefore shorten the available time for assembly.

The lead time analysis of five different hot zones illustrated in Figure 6 highlights the potential for time savings in the different stages of the order fulfillment process. The five hot zones were produced in the year of 2017 and all of them were customer specific and newly designed. Due to that reason, all departments have been involved in the order fulfillment of those hot zones. Another aspect of the selection process was the completeness and credibility of data. That selection has been necessary to provide a holistic and representative impression of the situation. The analysis shows the time shares in the order fulfillment process of the different departments involved in a sequential manner. The engineering and manufacturing department work in parallel for some parts of the process (Section 1.3). This, however, is neglected in the analysis. The first record in the production data acquisition (PDA) is the customer order date. The last date is the day of shipment. On average the delay of the five hot zones amounts to approximately one working week. The delay is determined as the time spent between the confirmed delivery date and the actual shipment date.

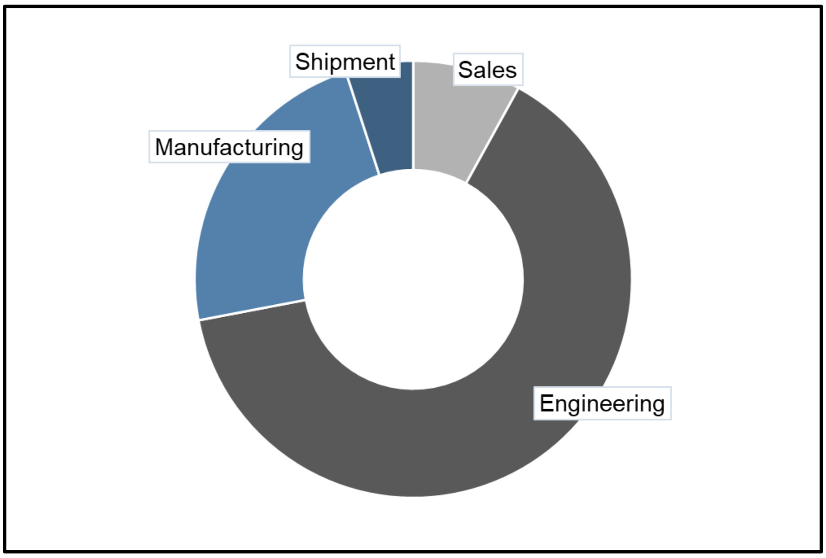

Figure 6: Lead time analysis for the product hot zone.

The engineering process requires the greatest fraction of time. Therefore, this process shows the highest potential for time savings. A detailed analysis of the engineering process for the same products illustrates that the engineering department only works on order fulfillment for 63% of the total time taken. The cause for the low productivity is a lack of information in the design process. The completeness of the available product information is currently hard to determine. Due to that, additional clarifications with the customer, resulting in delays in the design and engineering process, are necessary (Section 1.3).

Manufacturing accounts for the second largest time share. Although, the potential is much lower, there are several possibilities to increase time efficiency in the manufacturing process as well. Section 2.2 describes the issues identified in the manufacturing process in greater detail.

Both, sales and shipment require a relatively small share in the whole lead time analysis. The activity in the relevant stage of the sales process is the preparation of the order transition to the engineering department. The time for the shipment process is only the delay between packing of the finished goods and shipment. Comparing the required time and activities in both processes, sales and shipment show great potential for time savings.

Do determine the cause of the long processing times in the specific departments, interviews were conducted with personnel from sales, engineering, production planning and manufacturing. After the interviews two major problems have been determined:

- availability and transfer of product data
- inefficient material handling

The upcoming sections elaborate on the identified problems. First, the two main problems are outlined in greater detail. Subsequently, all the identified issues are summarized, and the objectives for the further steps are highlighted.

2.1 Product Information Management

Especially in upstream processes like sales, engineering and production planning the availability and transfer of data causes delays and inefficiencies in processing orders.

The product managers from the sales department collect the necessary product information from the customer to prepare the RFP (Section 1.3). This information is often received piece by piece as the customer many times does not know the exact specifications at the point of the RFP. The piecemeal collection of data causes an unstructured accumulation of specifications. Therefore, the engineering department often struggles to find the necessary product information for their designs. Additionally, the low-structured way of collecting product information makes it hard to identify missing specifications before the design engineer starts to work on the product. Frequent check backs for additional information with the product managers interrupt the design process and therefore causes delays.

During the generation of the proposal the product managers identify whether the requested product is entirely new or an already designed product can be adapted (Section 1.3). The adaption of existing products occurs rather infrequent. This usually only happens when customers order a replacement for an already purchased product from Plansee SE and require only minor changes. If there is no possibility to adapt an existing product the new product is designed from scratch. Except some standard components and design templates there is no reuse of existing designs possible. As a consequence, engineering times are long and a lot of extra work is generated in downstream processes like production planning and manufacturing.

The interface between the engineering and the production planning departments raises another issue. In the engineering department designs are made for every new component which is connected to a material number generated by the enterprise resource planning (ERP) system. In the ERP system the designs are available afterwards in PDF and CAD format. The bill of materials (BOM) is attached as well. The BOM is made available by the engineering department in CSV format, which is a format that contains database information in plain text separated by commas. Nevertheless, the structure of the assemblies cannot directly be carried over into the ERP system. This means the production planning department needs to manually edit all the BOMs in the ERP system. Since the information is already available in the CAD system this process causes unnecessary additional work.

The production planning department is also responsible for the preparation of the necessary master data for the newly designed components. The master data includes the previously mentioned BOM as well as production routings and all the data necessary for compliance with the ERP system. This data is mainly edited manually in the ERP system. For reasons of simplification and speed most of the data is generated by copy and paste from similar existing products. Such a process is not only slow, it is also error prone. Often outdated master data is added to new products and the process also is based on in-depth manufacturing knowledge of the personnel in the production planning department. Except the master data from existing products, there is little documentation of the mentioned manufacturing knowledge in place.

2.2 Production Organization

Over the past years IFT continuously grew and so did the number of production machines. This led to a shortage in space, which is hindering future growth as well as the current production. Figure 7 shows a layout of the shop floor at IFT. The different units are illustrated as blocks. The color of the production units indicates the function of the areas. The light yellow colored areas are logistics aisles.

At the moment, there is not enough buffering space for work-in-process (WIP) available. That means WIP is either stored in logistics areas or directly at the production unit. Since there are no dedicated spaces for the commissioning of goods available this task is performed in logistics aisles as well. Therefore, logistics is slowed down, and failures are promoted. Due to the growth of this production line the arrangement of the different production stages is not optimal. This problem originates from placing new equipment at the first spot available. Such an approach saves initial setup costs but hinders operations later on. Facilities are the physical representation of an operation. They promote or constrain the efficiency of the operations. That includes the arrangement of production units on the shop floor layout. The mentioned efficiency affects the lead time. The facility layout in turn, is determined by layout planning operations ([SWM06], p. 19f., [KJE01], 8.21).

In addition to the lack of buffering space, IFT requires new equipment to meet customer demands. That includes a coating system, a CNC press brake, a deburring machine and a substitution for the existing water jet cutting machine. The current layout illustrated in Figure 7 shows, that there is no space available for placing those additional machines.

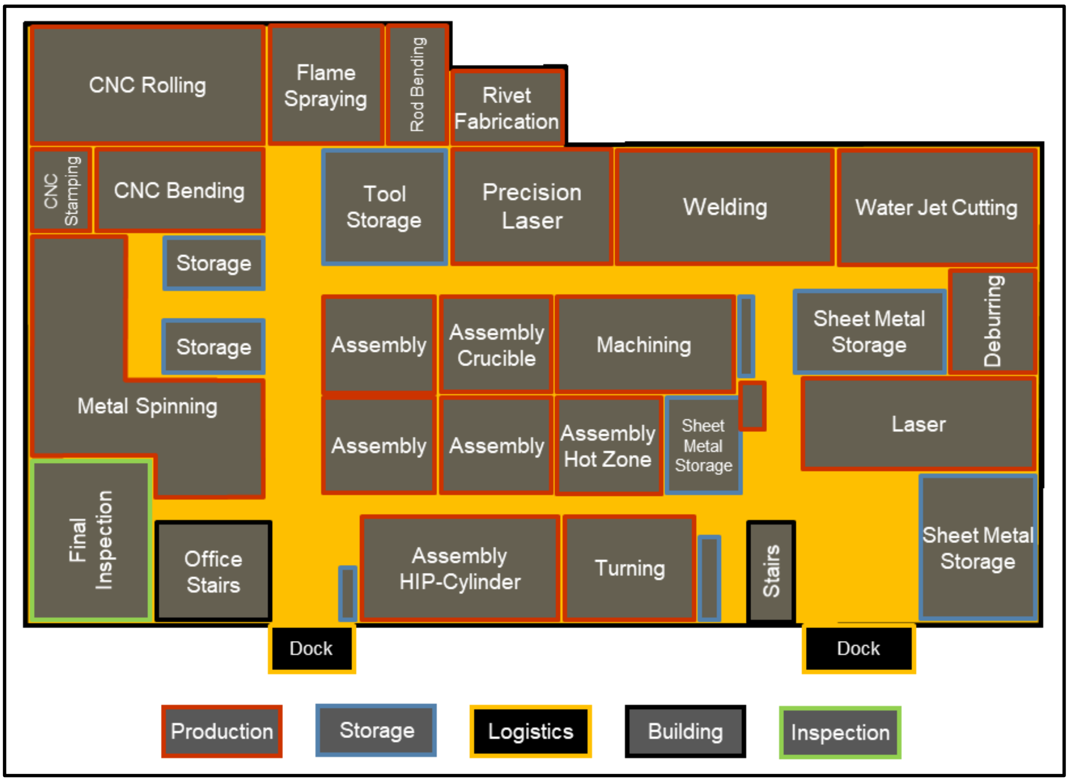

Figure 7: Shop Floor Layout at IFT.

Currently, when an assembly worker receives a production order he or she starts collecting the different components from previous workstations and from the storage. Normally, the storage place for the different components is indicated in the production schedule. Due to the lack of buffering areas the employees often spend significant time searching for the necessary parts. This is especially true for WIP which is mainly buffered on trolleys in logistics areas.

In order to benefit from learning curve effects, IFT already introduced dedicated workstation for different product categories. Still, a lot of products are manufactured on a general workstation ‘assembly’ to maintain flexibility. This issue is illustrated in Figure 8. The workstation ‘assembly’ accounts for approximately one third of the working hours at IFT. Learning curve effects especially appear in manual labor like manual assembly processes. Employees need to perform similar tasks to improve their skills and to be able to utilize on learning curve effects. Therefore, the accumulation of different tasks in one workstation hinders IFT to fully take advantage of its opportunities due to learning effects ([WIN64], p. 125).

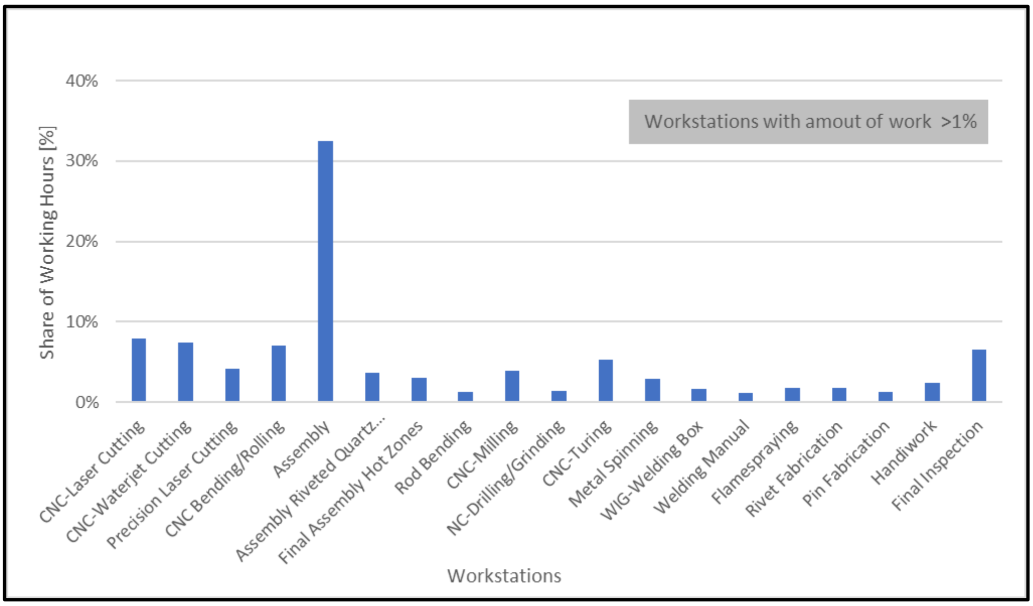

Figure 8: Share of working hours per workstation.

The already short time available for the assembly process is further reduced by the long lead time of sourced products. Especially the support structure made from stainless steel for the hot zone has a particular long lead time. The fact, that the support structure is required for starting the assembly process amplifies this issue. According to the conducted interviews there are also minor quality issues concerning around 35% of the supplied support structures. Those 35% of defect components can be repaired by IFT. An additional 5% of the delivered support structures need to be returned to the supplier due to major manufacturing defects.

2.3 Objectives of the Thesis

As mentioned in the beginning of this problem analysis the core issue at IFT is the long lead time. Therefore, a lead time analysis and interviews with the involved departments indicated several problems causing delays in the order fulfillment process. Table 1 summarizes the main issues responsible for the long lead time.

Table 1: Summary of issues in the order fulfillment process

Product Information Management	Production Organization
• Low-structured product information	• Lack of space for buffering, commissioning and additional equipment
• Design of new product from scratch	• Inefficient assembly process due to high search effort
• Inconsistent use of BOM data	• Low utilization of learning curve effects
• Manual editing of production master data	• Long lead time and quality issues of supplied components

The prevailing goal of each and every company is to increase the total value of its products to get more competitive. Since the total value is defined by the equation illustrated in Figure 9, shortening the lead time will improve the total value and therefore the competitiveness of the company. But this is only true if the remaining metrics namely quality, service and costs remain on the same level. For IFT it is essentially important to deliver superior quality and customer service. This especially includes the flexibility to meet unusual customer demands. As a result, the challenge will be to come up with ideas and possible solutions to tackle the issues identified in the problem analysis and to maintain the current high levels in the remaining three value metrics. The measures to accelerate the order fulfillment process will be deliberately chosen by their contribution to the total customer value ([NNB99], p. 108).

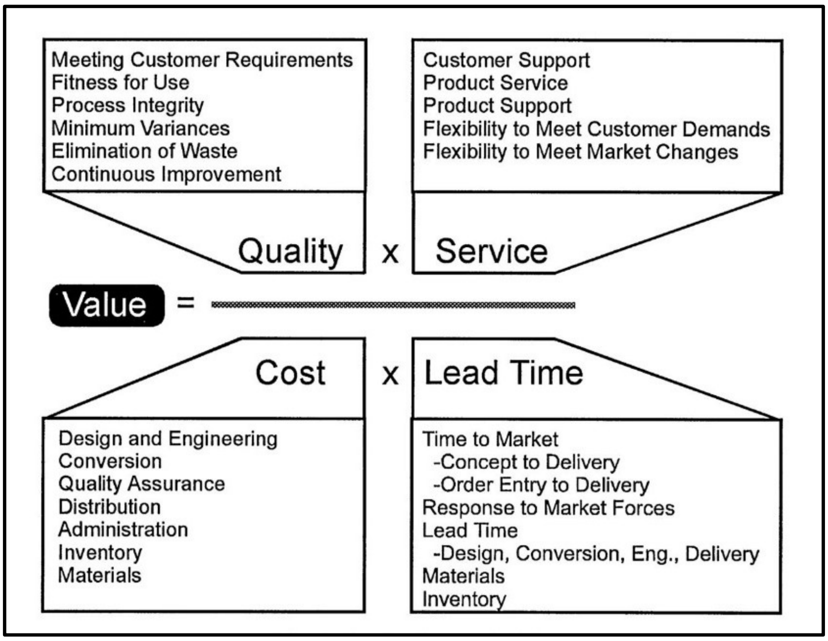

Figure 9: Equation of to determine the customer value ([NNB99], p. 109).

The problem analysis revealed the issues that are responsible for the frequent delivery delays and the overall long lead times. Those could be assigned to two fields, namely product information management and production organization. But the problem analysis also shows, that the lead time cannot be shortened at all costs. The aim is to increase the total customer value. Therefore, factors such as quality, service and cost cannot be ignored searching for solutions to address the problems. Possibilities and approaches to tackle the detected problems can be found in literature. Those possible solutions will be discussed in the following chapter.

3 Theoretical Aspects

The theoretical aspects provide the theoretical framework upon which the following chapters of this thesis are built on. In the beginning, the keywords concerning this thesis are discussed shortly. Subsequently, the results from the literature review are presented. Like the problem analysis, the literature review is also based on the two fields product information management and production organization.

3.1 Keywords

As already introduced in Section 1.3, this thesis deals with the whole order fulfillment process. Therefore, the literature review touches different scientific fields. Both, product information management and production organization are affiliated with the field of internal logistics. Whereas product information management deals with the flow of information, production organization deals with the flow of materials.

Product information management and especially product configuration are also part of the scientific fields of artificial intelligence and management sciences. Production organization also deals with aspects of operations management besides internal logistics ([FS02b], p. 37f.).

The keywords used in the research for literature are assigned to the respective topic. Table 2 shows the most important keywords used, assigned to product information management and production organization. Those keywords are used in the research for theoretical input to solve the problems identified in Section 2. They can be seen as labeling keywords for this thesis as well.

Table 2: The keywords for this thesis.

Product Information Management	Production Organization
• Product Configuration	• Plant Layout
• Mass Customization	• Manufacturing Strategy
• Knowledge Management	• Supply Chain Management
• Parametric Design	• Facility Planning
• Rule-Based Design	• Layout Planning

3.2 Heterogenic and Dynamic Product Design

This section provides the findings of the literature review concerning the problems in the field of product information management (Section 2.1). First, the detected problems are related to generalized problems described in literature. In the second step, the offered theoretical solutions and approaches are reviewed. Finally, the selected approaches are outlined in greater detail to be able to implement those solutions in the next steps.

Historically, handicraft stores offered a great variety of products tailored to their customer's needs. On an industrial scale this approach involves high efforts in design, inhibits automation and causes low productivity. Therefore the 'standardization movement' developed mass production techniques in the beginning of the twentieth century. The key to success was the low product variability combined with leveraging economies of scale. A famous example of this manufacturing concept is the Ford Model T ([FS07], p. 7f.).

As the mass markets saturated in the mid-1950s the need to satisfy specific customer demands returned. This led to micro-segmentation of products and variety proliferation. Subsequently, this inefficient segmentation strategy is disrupted by the concept of 'mass customization' in the 1990s. Key to this approach is the 'efficient variety'. Satisfying a wide range of customer demands while maintaining efficiency ([FS07], p. 8).

The 'efficient variety' basically is a combination of craft production and mass production. Figure 10 illustrates the rating of the different production strategies according to 'variety level offered to the customer', 'costs' and 'time'. To achieve the concept of the 'efficient variety' is difficult for a lot of companies ([FS07], p. 9, [FS02a], p. 87).

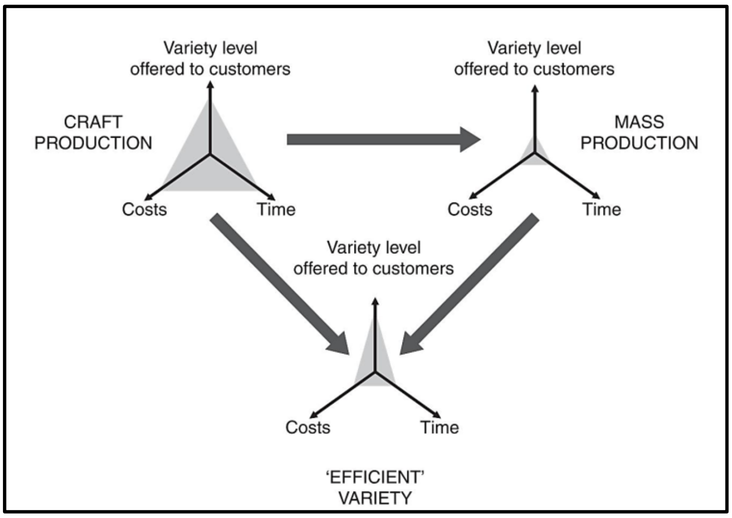

Figure 10: Development of production strategies [FS07], p. 9 (Fig. 1.2)

The next section offers possible approaches to help companies to achieve the goal of the 'efficient variety'. Afterwards, the concept of product configuration is outlined in greater detail. Because product configuration provides an opportunity to offer a great variety of products while meeting time, cost and quality demands. Therefore, it enables an efficient way for mass customization.

3.2.1 Product Customization

As mentioned in chapter 2, IFT faces the challenge to deliver highly customized products within short lead times. Such a challenge is not only demanding in manufacturing but also in the upstream processes. McCutcheon et al. describe that phenomenon as the 'customization-responsiveness squeeze' which is the need to deliver highly individualized products within short lead times. This concept is very similar to the 'efficient variety' with a focus on variety, time and stage of differentiation ([MRM94], p. 89).

Salvador and Forza describe the reason of the 'customization-responsiveness squeeze' facing to the point. A lot of companies in globalizing markets are facing this issue:

> "*As a company has more competitors, in fact, the chances that someone is offering a product better tuned to the customer's needs and/or a better delivery time grow higher, thus moving the company to further push on customization and strive to keep low delivery times*". [SF04], p. 273f.

Figure 11 illustrates the position of the 'customization-responsiveness squeeze' depending on the three dimensions 'customization', 'responsiveness' and 'differentiation stage'. According to those dimensions different production strategies can be derived. For the positions with low customization, make-to-stock (MTS) is a suitable strategy. For the remaining positions with low responsiveness a make-to-order (MTO) is generally applied. If the product design enables customization at a late stage in the production process, the situation favors the assemble-to-order (ATO) approach. This allows a MTS strategy in manufacturing of components and postpones the individualization to the assembly process. Generally, postponing the customization to the latest stage possible is recommended ([FL97], p. 117, [MRM94], p. 90).

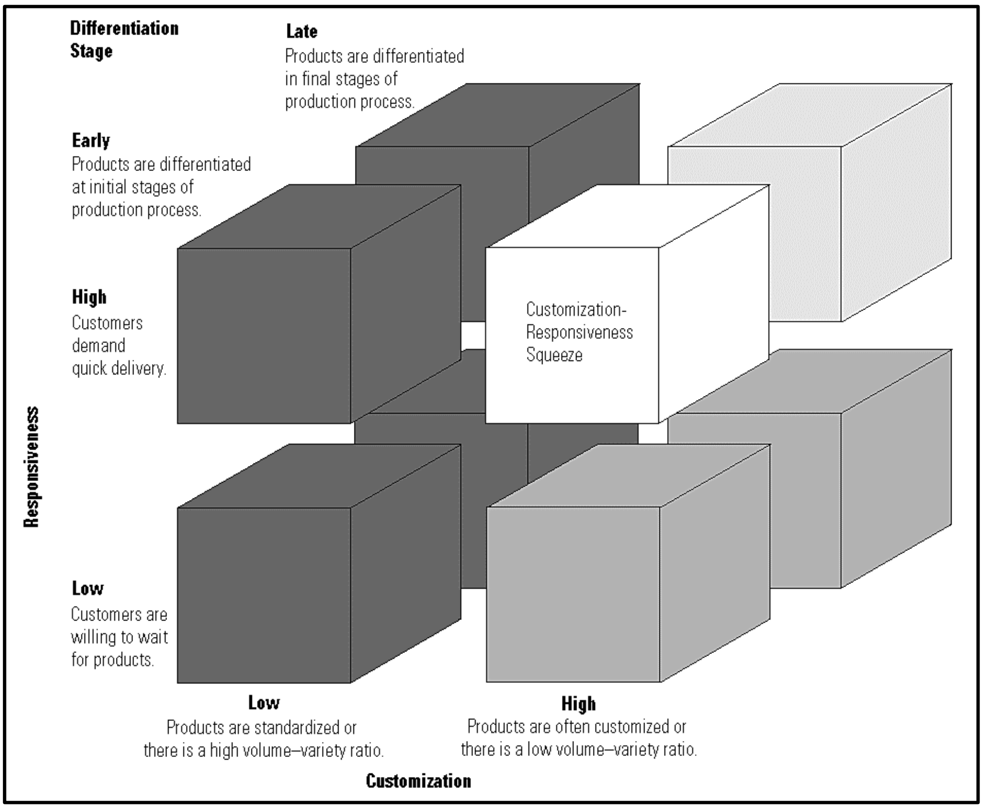

Figure 11: Range of production environments ([MRM94], p. 91) (Fig. 1).

For the 'customization-responsiveness squeeze' position a build-to-forecast (BTF) approach is popular among many companies. Addressing the problem this way is, however, not possible for engineer-to-order (ETO) businesses. Departments like IFT, that design their products from scratch to the specific customer's demands, cannot apply this approach ([MRM94], p. 90).

As already mentioned, the following paragraphs introduce a selection of possible tactics suggested by McCutcheon et al. to improve the demand fulfillment other than the BTF approach. The different responses help to cut lead times while serving customer's demands for individualization. The approaches can be combined, and synergy effects may even improve the result. Especially the most important ideas regarding the upstream processes like sales, engineering and production planning are highlighted ([MRM94], p. 90).

Modular product designs provide several benefits for manufacturing. First, the number of standard components can be increased. Standard components can be used in different products and can be manufactured by a MTS approach in this way variety can be reduced while offering a wide range of end products. Second, modular designs promote parallelization in production and assembly processes which shortens through-put times. Companies can also expect to benefit from economies of scale effects because of larger batch sizes for reusable modules. Third, it lowers complexity within the modules. Problems in the production process can be addressed easier and quality problems do not affect the whole product. Although, redesigning a product is time consuming and costly the payoffs are usually great ([FL97], p. 117, [MRM94], p. 96).

Design for manufacturability trims the design in a way to enable fast and cheap manufacturing. To do so, a cross-functional engineering team is required to combine process and design knowledge. Part of the redesign should be an emphasis on postponing the customization in the production process. This reduces complexity and provides economies of scope effects ([FL97], p. 117, [MRM94], p. 96f.).

Establish 'time fences' for particular design changes means that design changes are rejected after the manufacturing process passed specific points. This prevents changes of the production schedule and therefore delivery delays. It also lowers complexity and confusion in the production planning and production process ([MRM94], p. 97).

The introduced ideas provide possibilities to improve the organization towards shorter lead times while maintaining flexibility. Those approaches are functional, focusing especially on either product design or process design. Since engineer-to-order (ETO) businesses also require more coordination between the different functions the exchange of information is key. For example, the sales department needs to know about the feasibility and costs of a variant in the order acquisition process. At the same time, the demand information is necessary to schedule material purchasing and production. Unfortunately, enterprise resource planning (ERP) systems are not very supportive in this regard, as they require specific material numbers and related production master data to determine costs and capacity information. A multifunctional approach to address the 'customization-responsiveness squeeze' is required ([KHJ15], p. 83, [SF04], p. 274).

Automating design processes and standardization makes better use of existing capacity and data. Maximizing benefits from automation needs involvement of the whole order fulfillment process. Automation can be implemented by means of a product configuration process. The product configuration process is able to provide the necessary close coordination between sales, engineering, production planning and manufacturing. In such a process, customer requirements are translated into product information for the different stake holders. The required product information typically includes the bill of materials (BOM), product costs and production routings. Instantly providing the different departments with product information improves the coordination. Subsequently, the responsiveness is increased which helps companies to deal with heterogenic customer requirements ([FS02b], p. 37, [SF04], p. 275f.).

In ETO businesses product configuration propagates the reuse of existing components rather than designing new components. A great number of components is predefined, which is selected and adjusted according to rules. The reuse has two major effects. First, the time and costs to design and prepare the production master data are drastically reduced. Second, using existing components means that exclusively tested designs are manufactured. Therefore, manufacturability is granted and malfunctions are mitigated. This subsequently reduces design changes and service costs. Ultimately, the product costs are lowered and the time for order fulfillment is reduced ([FS07], p. 51f., [KHJ15], p. 82, [SF04], p. 275f.).

Especially the idea of design automation and standardization by means of product configuration should be adopted at Plansee SE. According to the literature review this multifunctional approach provides an integral improvement in the order fulfillment process. Modular product designs and design for manufacturability are promising concepts as well. Therefore, the design should be fine-tuned towards manufacturability and a modular structure in the following step. Since product configuration builds upon the reuse of designs it can support the incremental improvement of those aspects.

3.2.2 Product Configuration

Product configuration systems are computer tools that enable the reuse of existing designs and components. This requires some sort of standardization or product platform to utilize specific components in different products. The selection and design of shared parts can cause sacrifices in the product or manufacturing performance of single components. The reason is, that shared parts are designed not only for one purpose but for different applications. On the other hand, reusing components reduces the engineering effort and provides economies of scale effects in production process ([KHJ15], p. 82).

Information is key in the early stages of the order fulfillment process. It is important for cost estimation, purchase planning and production scheduling. Kristianto et al. describe that ERP systems often fail to provide this kind of information in ETO businesses in the early stages of the order fulfillment process. Product configuration software in contrast is able to deliver the necessary information in the early stages of the order fulfillment process and therefore makes projects more predictable ([FS02b], p. 37, [KHJ15], p. 83).

Another aspect covered by product configuration is the translation of customer needs into technical specifications. That simplifies the communication between all the involved parties, including customer, sales, engineering, planning and production. A structured documentation and translation of customer requirements minimizes failures and misunderstandings ([FS02b], p. 37).

In the upcoming sections product configuration is explained in greater detail. Starting with the principle of product configuration, the logical architecture and the consequences for the different departments are introduced subsequently. The section concludes with general benefits and challenges of product configuration projects found in literature.

3.2.2.1 Principle of Product Configuration

The precondition for product configuration is to have a configurable product. The key characteristic of a configurable product is its structure. Configurable products are a combination of pre-defined components. That means no component is designed entirely new. The pre-defined components can either be standard components or parametric components. Standard components are parts such as bolts and nuts. They have pre-defined specifications such as geometry and price. Parametric components are defined within a specific range and can vary continuously or incrementally. In this way, they can adapt dynamically to the given requirements. For example, a piece of sheet metal can vary in length and width within a specific range. The specifications of parametric components need to be adapted to the requirements. As the geometry changes dynamically, other product information like price and production routings need to be adapted alike ([SF04], p. 275).

Haug et al. describe the translation of customer requirements into specific product information using product configuration systems. Formally connecting customer demands with product information casts the knowledge of engineers into a set of rules. Such a knowledge-based system secures the knowledge of the engineers for the company. Usually, product configuration systems connect commercial, technical, manufacturing and cost information about a product. Thereby, those systems support the order acquisition and order fulfillment process ([SF04], p. 274, [HHM10b], p. 409).

> *"A product configurator can be defined as a product-oriented expert system (or knowledge-based system) that allows users to specify products by selecting components and properties under the restriction of valid combinations."* [HHM10b], p. 409

The definition of Haug et al. describes the essence of product configuration systems. The definition includes the product or customer orientation by selecting properties, the knowledge management function and the selection of validated combinations.

The first step to successfully translate customer requirements into product information the challenge is to obtain *"… the complete and congruent commercial description of the product that best fits customer requirements…"* ([FS07], p. 19). Such a commercial description precisely contains what the customer wants. It describes the product from a customer point of view. The customer is interested in what the product can offer him. That could be an operating temperature range and the size of the usable space in the case of a hot zone. Without translation into technical specifications this information is of limited use for downstream processes like production planning and manufacturing ([FS07], p. 19ff.).

To provide the technical information necessary a technical description of the product is necessary. This description contains information about the product from a technical point of view. Such information can be material and geometry data, product documents like the bill of materials (BOM) and production routings as well as cost information ([FS07], p. 19ff.).

The product configurator serves as a translator between those commercial requirements and the technical product information. In this manner, the configuration system links the different functions in a company. Therefore, the product configuration process includes all the activities from obtaining the customer requirements to provide the necessary product information to sell and produce the requested product variant. Figure 12 depicts the transition from commercial description to product configuration in the case of a hot zone. The illustration is adopted from Forza et al. tuned to the specific case of the hot zone. Product features important to the customer such as the ‘Operating Temperature’ are used to determine technical details. Those technical details include components and the respective specifications as well as generic assembly cycles necessary for the manufacturing process ([FS07], p. 19ff., [KHJ15], p. 83).

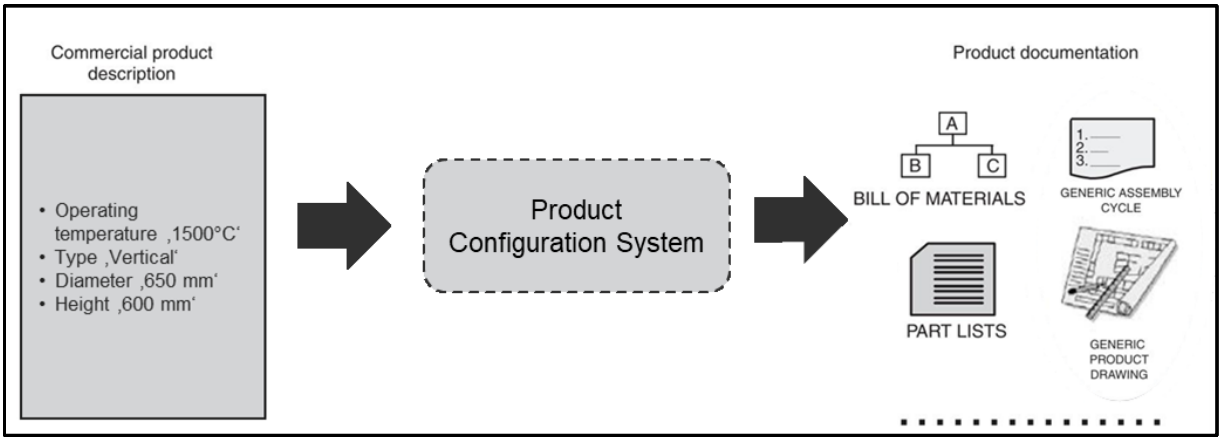

Figure 12: Commercial description & product documentation ([FS07], p. 20) (Fig. 2.2, modified).

3.2.2.2 Logical Architecture

The development of product configuration systems starts with the retrieval and structured representation of expert knowledge of the different departments. This is not only the first task but often also the most demanding one. For the description of the expert knowledge two models are used. Haug et al. call them analysis and design model, Forza et al. name them commercial and technical model. In this thesis the terms commercial and technical model will be used ([HHM10b], p. 409, [FS07], p. 53f.).

The two-model design is a logical architecture. This architecture can be implemented in a software package but can also be performed in one module. Still, the software performs two functions. It records the customer demands in a structured way, assures feasibility and further connects those demands to specific components ([FS07], p. 53f.).

Commercial Model

> *"COMMERCIAL MODEL: a formal representation of the product space and of the procedures according to which a commercial configuration can be defined within such space." [FS07], p. 53*

The definition of Forza and Salvador already contains the representation of the product towards the customer as well as the restriction of options. In this manner the commercial model supports the sales dialogue. Therefore, it contains a customer-oriented description of the product family. Depending on the type of customer the company is targeting, the language in the sales dialogue needs to be adjusted accordingly. However, the description of the product characteristics needs to be user-friendly and comprehensive. This is necessary to support the customers learning process about the product, communicate the value of the different options to the customer and constrain the possible options to choose from. The structure of the commercial model is important to guide the learning process. At the end of the commercial configuration process there should be an unambiguous description of the product variant. This is essential to avoid misunderstandings. Since the aim is to carry out a business transaction, a price, an indicative delivery time and a drawing to visualize the final product can support the decision ([FS07], p. 67, [FS07], p. 70, [FS07], p. 74, [HHM10b], p. 409).

Technical Model

> *"TECHNICAL MODEL: a formal representation of the links between commercial characteristics and the documents that describe each product variant (bills of material, production and assembly cycles, etc.)." [FS07], p. 53*

The definition of the technical model from Forza and Salvador highlights the translation of customer characteristics into technical documents. To serve that purpose, the technical model contains a model of the real world. This model captures the knowledge and different views on the product of the domain experts. Therefore, the technical model contains physical building blocks like the bill of materials (BOM) and information like production routings that are subject to change according to the specification. Those pieces of information are necessary to determine delivery times and prices ([HHM10b], p. 409, [FS07], p. 103f.).

There are different techniques available to describe product structures in product configuration projects. A very common instrument to describe product structures it the bill of materials (BOM). For configuration purposes the BOM needs to be enriched with additional information other than the BOM element and the BOM relationship which are the basic components of a BOM. In addition, the cycle element is required which contains information necessary to manufacture the variant. Figure 13 illustrates the types of information required to describe a product variant by using a BOM. To cover all possible variants the BOM used for configuration contains all the components that the product variant can possibly contain. Therefore, the kind of BOM used is a maximum generic BOM ([FS07], p. 87f.).

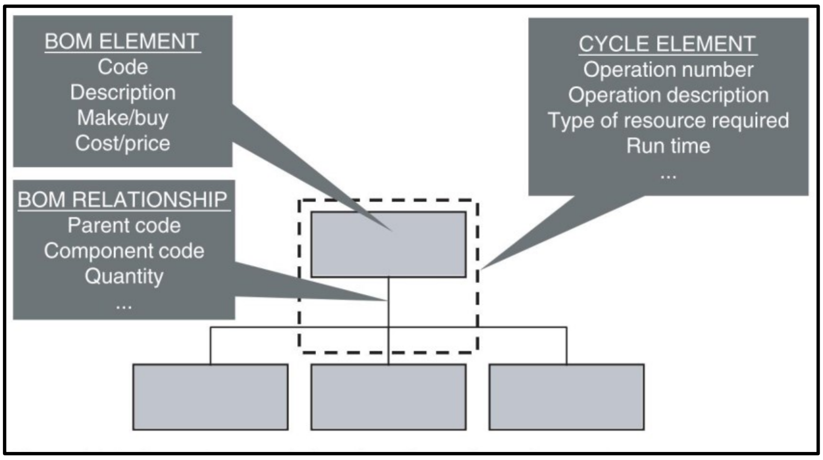

Figure 13: Information in the bill of materials ([FS07], p. 87) (Fig. 6.1).

The product variant master (PVM) diagram is another way to represent product families. The PVM diagram has a similar structure to the BOM. It compromises two sections. The part of section is more or less a bill of materials that describes the different generic parts of the product variant. The kind of section describes the different variants of a component. Figure 14 shows the structure of the PVM formalism using the example of a car family. The wind shield and the gear box are part of the sub-assembly. The station wagon, the van and the cabriolet are kinds of the car family ([HHM10b], p. 410).

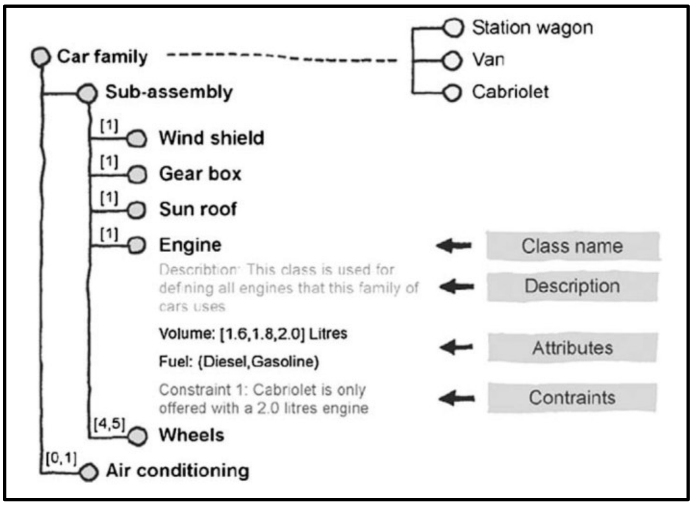

Figure 14: The PVM formalism ([HHM10b], p. 410) (Fig. 1).

Vertically aligned class diagrams (VACD) are a combination of class diagrams which are part of the unified modelling language (UML) and PVMs. Haug et al. developed this type of diagram. It is suitable for both, the commercial and the technical model. VACDs adopt the structure of PVMs and use the language, expressions and symbols from class diagrams. Figure 15 depicts a VACD using the example of a simple clock. The black, diamond shaped symbol indicates a part of relationship. The white arrow shows a kind of relationship. Constraints are always put in braces {} and constraint relations are indicated by a dotted line ([HHM10b], p. 412).

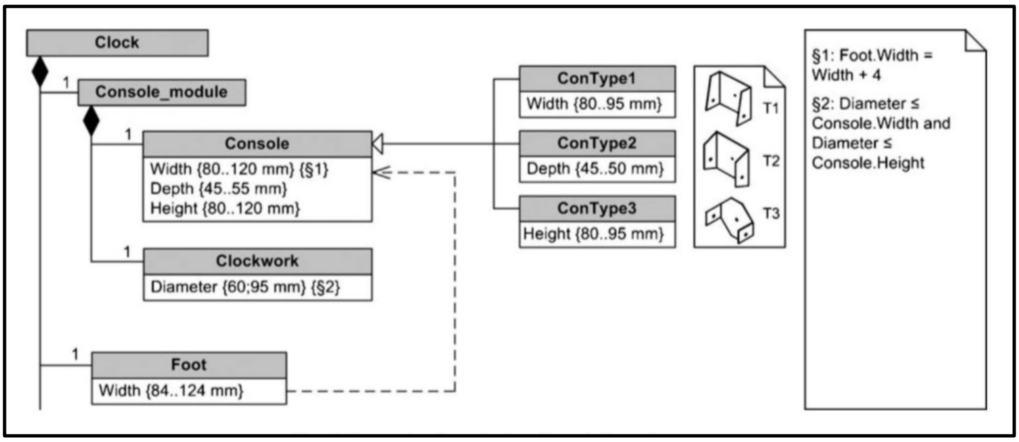

Figure 15: The vertically aligned class diagram ([HHM10b], p. 412) (Fig. 5).

There is also the opportunity to assign similar components to meta classes. That means to group for example sheet metal components with respect to their similar parameters. This concept can improve the speed of maintaining the model in case of changes in parameters and is also able to prevent failures due to missing parameters by defining mandatory ones for specific meta classes. In the case of the sheet metal meta class all components require a specific length, width, thickness and material ([SCH12], p. 182).

Link between Commercial and Technical Model

The components in the technical model need to respond to the answers from the commercial model. That means depending on the constraints and answers from the sales dialogue the variants in the technical model are chosen and adjusted to fulfill the requirements. Figure 16 depicts how the sales dialogue and technical model are linked. The constraints in this representation only contain specific values like 'C2 IF (3b AND 4a) OR (3b AND 4b)'. The constraints can be value ranges like 'C2 IF 1,000<3b<1,500' as well. It is also possible to already insert constraints in the sales dialogue. In the case of the hot zone there is no need to ask for the kind of gas system, if the answer to the question 'Gas system required? Yes/No' is 'No'.

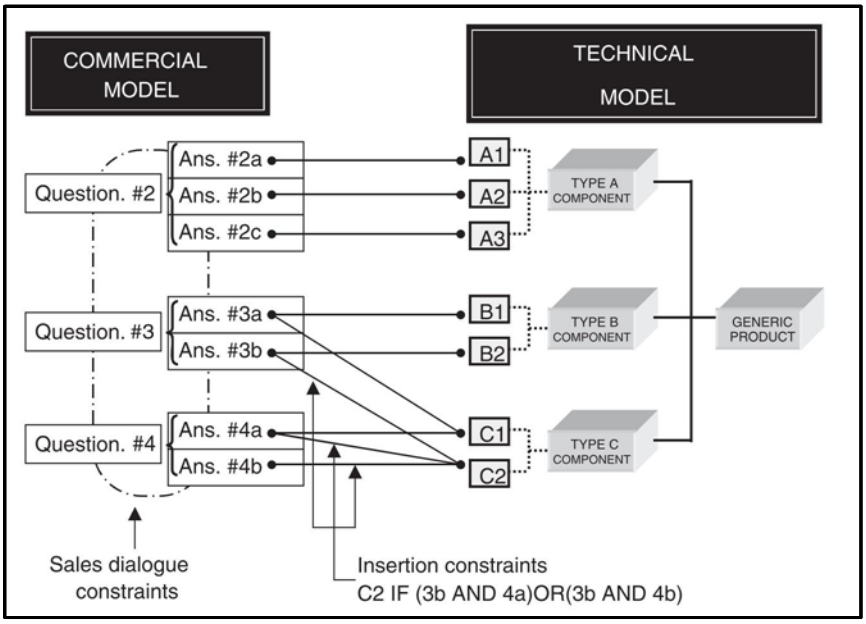

Figure 16: Sales dialogue and technical model ([FS07], p. 109) (Fig. 6.17).

Depending on the variability, it is also possible to not totally configure the product but to leave some space for customer specific modifications. The decision where to stop the configuration and start manual modification depends on the trade-off between engineering effort and the complexity to describe the possible variants. Especially for highly unpredictable features it makes sense to keep the configuration below 100% ([FS07], p. 30f., [FS02a], p. 97).

3.2.2.3 Integrated Product Information Management

As already mentioned in Section 3.2.2.1, product configuration systems support the different departments in the order fulfillment process. The collaboration is mainly improved by providing more standardized information at an earlier point in the order fulfillment process. Figure 17 depicts the different types of information that are exchanged with the product configuration system. The continuous lines indicate the flow of information in every order fulfillment process. The dotted lines indicate regular updates of the configuration system. This is necessary especially for design changes and implementation of improvements of the configurable product. For this task an interdisciplinary team is required from the different departments (sales, engineering, PPC and manufacturing) to keep the product model up-to-date ([FS02b], p. 43, [FS02a], p. 91).

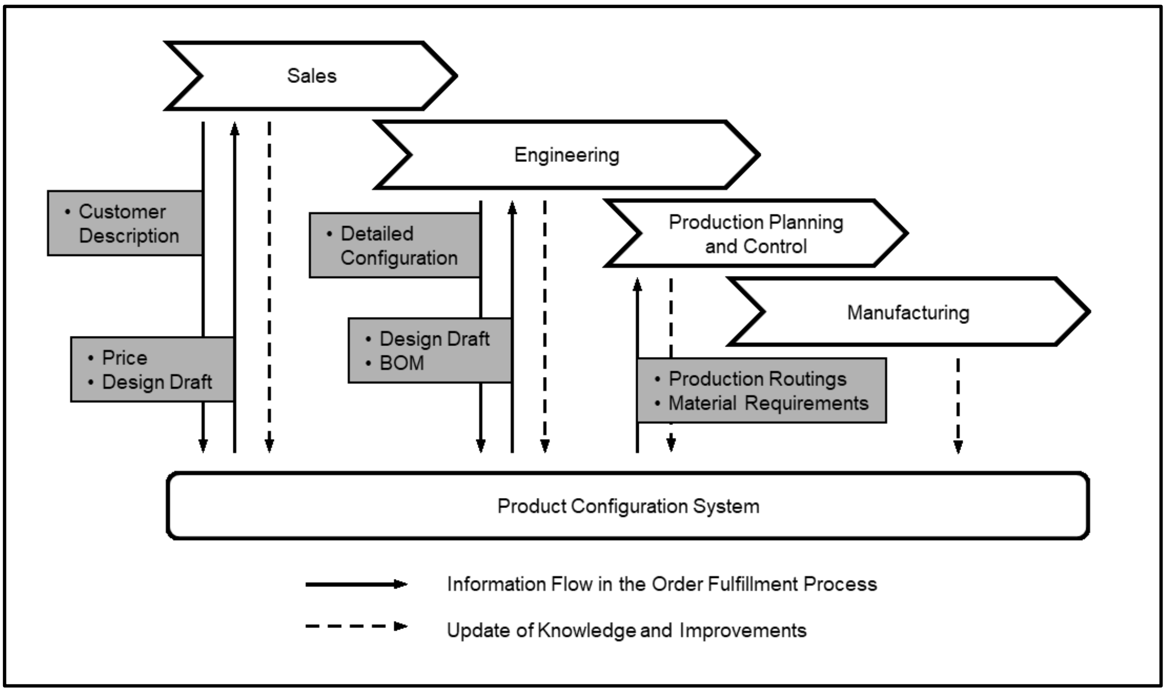

Figure 17: Integration of product configuration into the order fulfillment process.

The continuous use of the product information in the different departments is explained in greater detail in the following paragraphs. The product configuration system also enables automation and offers additional possibilities that are highlighted as well.

Sales

The structured sales dialogue retrieves and stores the customer data in a precise and reusable way. The translation of customer requirements into product information improves the communication between customer and sales personnel (Section 3.2.2.1). This reduces the risk of delivering a wrongly specified product. The configuration process also constrains the product range and therefore pushes the customer towards purchasing a normalized configurable product ([FS02b], p. 45, [FS02a], p. 91, [FS07], p. 17).

An instant price and design draft gives the customer a better impression and understanding of the product. The price can be calculated using the costs of the different components in the selected BOM. In the case of parametric components, the costs cannot be predetermined. Therefore, costs need to be a function of the used parameters like geometry is. The price can be determined by adding customer specific costs like shipping costs and a mark-up ([FS07], p. 116ff., [FS07], p. 119ff.).

Engineering

For complex product families a second configuration step can be suitable to define further details of the product. In this configuration step the designer can use calculation and experience-based values to refine the product. In return the designer is guided by the configuration system through the process which reduced mistakes. Finally, the configuration can be checked for completeness and the data can be validated ([FS02a], p. 94).

The gathered data from the configuration process can be reused for the design of the configurable product. Because of the structured nature of the product information this information can be used in parametric designs. Such designs are modeled in a CAD system. The parametric model contains the principle geometric shape of a specific component and for assemblies also the constraints between the components. Those shapes and constraints can then be driven by a set of compatible parameters to create a new instance of the parametric model. Figure 18 shows the combination of predefined parametric models, the corresponding rules and the parameters from the product configuration system in a CAD system. The generated specific instance of the parametric model can be used to illustrate the draft to the customer and as a draft to base further work on, especially useable for the engineering department ([WLF02], p. 822, [LLZ+17], p. 3633f.).

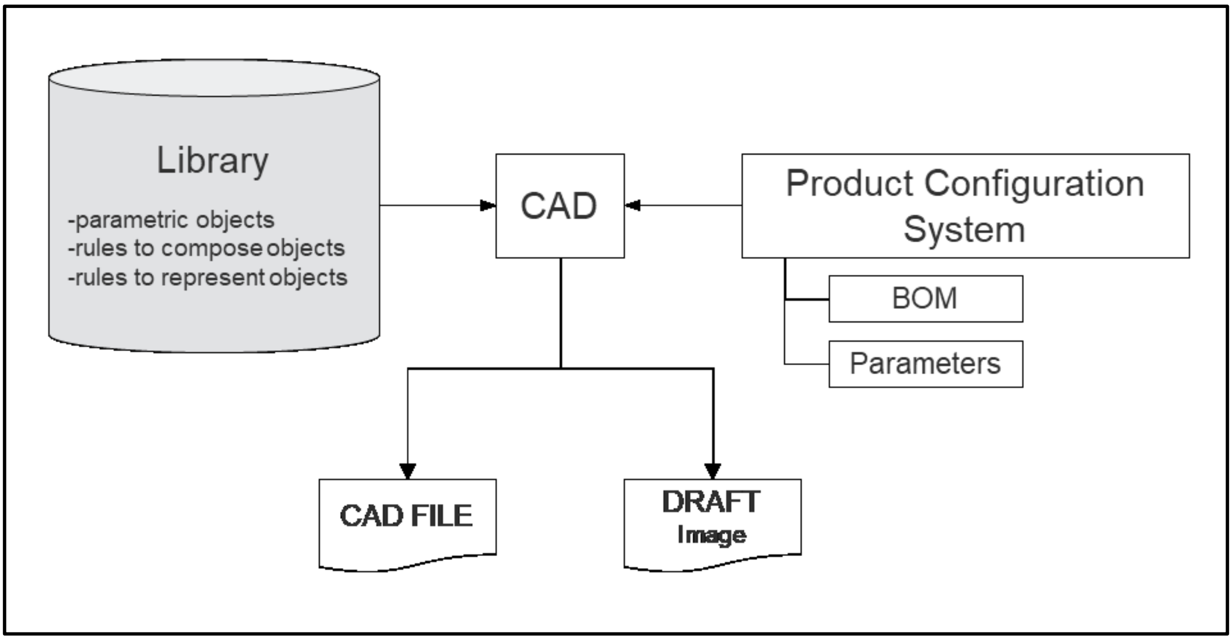

Figure 18: Parametric design and product configuration ([FS07], p. 121) (Fig. 7.9) (modified)

An automated drafting process accelerates the whole design process and provides an immediate feedback for the customer. This does not only speed-up the order fulfillment process but also accelerates the activities on the customer side. For the engineering department this reduces repetitive work and minimizes mistakes ([FS02b], p. 42, [LLZ+17], p. 3628).

Production Planning and Control

Especially for the production planning and control department, production routings and material demand information are important. Like the parametric design model, a parametric routing plan can be built. This reconfigurable routing plan works rule based and is adjusted to the specifications of each component and assembly ([XED+18], p. 207f., [FS02a], p. 94).

The specific instance of the CAD model representing the product assembly already contains product information such as the required kind and amount of material. In combination with the production routings this enables the calculation of costs and production schedules ([FS02b], p. 41).

The last paragraphs introduced the effects and opportunities in the upstream processes provided by product configuration. The effects, for example the translation of requirements, are part of the product configuration system. The opportunities, for example the design automation, are enabled by the configuration process.

3.2.2.4 Implementation of Product Configuration Projects

The different steps for establishing a product configuration system depend on the company and its products. If there is no configurable product family available, the first step is to develop a configurable product. In case there are already suitable products for configuration available the first step is to collect information about the existing products. Using the retrieved information, the constraints for the different components are established. It is important to take care which kinds of product information is necessary for the customer as well as for internal stake holders. In the next step the gathered knowledge is implemented in a suitable software package ([SF04], p. 287, [HHM12], p. 475).

After the design of the configuration process the organization needs to be redesigned. The configuration software should support the sales personnel in identifying the technical specification which relieves the engineering personnel. To leverage the time gained in the engineering process, the departments should be decoupled. This allows time for more innovation-oriented activities in the engineering department. Finally, the redesigned organization also needs to consider the continuous improvement and update of the configuration system by an interdisciplinary team ([SF04], p. 287f.).

3.2.2.5 Benefits

There are benefits from configuration projects reported in all of the four metrics defining the total customer value (Section 2.3). Although the main target of this thesis is to shorten the lead time, there are side effects that influence the other three metrics positively as well. The benefits in the four dimensions of the customer value are highlighted in the upcoming paragraphs.

Quality is affected by tested and improved products. Since the product design is unified by configuration, there is more feedback available and it is more reasonable to invest in product development. In addition, new developments and improvements in product and process technology can be spread faster across the whole value chain. The structured sales process improves the identification of customer needs and therefore the quality for the customer ([MKH17], p. 13, [FS07], p. 21ff., [TPF12], p. 851f.).

Costs can be reduced by lowering effort in engineering. Manufacturing may as well get more efficient by standardizing operations with regard to standard design configurations and the utilization of more standard components. That increases employee productivity and in turn reduces costs. The prospect of increased sales enables economies of scale effects and therefore reduces the costs per product produced ([MKH17], p. 13, [HHM10a], p. 6).

Service is improved by a tighter customer relationship and better communications. Delivering exactly what the customer wants and providing better support by improved knowledge management increases the customer satisfaction ([MKH17], p. 13, [FS02a], p. 96).

Lead time can be decreased in both, the proposal process and the order fulfillment process. Offering a high-quality proposal within a short period of time can also speed up the customer's purchasing decision. The availability of more product information at an earlier point in time additionally supports the planning process and therefore improves the dependability. Which means, the company is able to deliver an increasing number of products on time ([MKH17], p. 13, [HHM10b], p. 409).

3.2.2.6 Challenges

Although there are benefits of configuration systems, there are common challenges reported in literature as well. Haug et a. describes two major challenges. First, to keep the momentum of the development project until the configuration software is ready for use. Therefore, it is important to produce working prototypes and do not exceed the anticipated costs. This increases the potential of success. Second, if the configurator is already developed it is essential that the software is accepted and used by the organization. For that reason, it is important, that the configurator covers a sufficient portion of the product range and the extent of output and precision is good enough for use. Those are preconditions for maintaining and updating the knowledge database of the configuration software to keep it running ([HHM12], p. 471f.).

Forza et al. describe some criterions as 'killers'. First, it is important to accept that some of the roles in the organization may change due to the configuration software. This is especially the case for engineering and sales personnel. The employees in the sales department need to give up some of their freedom in developing customized solutions. In return they receive a powerful tool to determine costs at an early stage. The engineers need to formalize and share their knowledge. Second, the inter-functional collaboration between the different departments may proof challenging. The departments naturally have a different view on certain issues. Therefore, it is important to make reasonable and coordinated decisions. Third, the everyday operations of employees working on the configuration project need to be limited to enable progress in the project. The meaningful recommendation is to relieve an employee from routine tasks to entirely focus on the configuration project. Finally, only a reasonable range of products should be addressed in the beginning of the configuration project.

That means the project does not need to utilize every component or module for the configuration. Since, it is important to make fast progress in the beginning, decreasing the complexity in the early stages helps to keep the project running ([FS07], p. 178ff.).

Section 3.2 introduced different approaches to achieve the 'efficient variety' by efficient mass customization. Especially focusing on the product configuration concept and the effects on the upstream processes in the order fulfillment. The next section deals with the downstream processes. Those are affected by the configuration system as well. This originates particularly from the increasing standardization of components.

3.3 Flexible and Efficient Manufacturing

Since the lead time is also affected by the downstream processes like manufacturing and shipping, this section deals with the influences of the customized product design on the manufacturing processes. First, the organization of the manufacturing system is discussed. Especially the manufacturing strategy of the different components and the distribution and storage is reviewed. The souring process is of concern in this part as well. The second part deals with the consequences on the facility layout of the manufacturing plant.

The organization including the sourcing process of the support structures and the manufacturing strategy are associated with supply chain management. Although, the manufacturing strategy and the rearrangement of the facility layout are also part of facility and layout planning as well as operations management.

3.3.1 Organization

The product design and degree of customization influence the manufacturing system. Section 3.2.1 describes the 'efficient variety' which represents a high degree of customer orientation compromising reasonable costs and delivery times. This section highlights different strategies to achieve the concept of the 'efficient variety'. Generally, customer orientation and therefore customized products cause low batch sizes and high indirect costs. Currently, popular manufacturing paradigms like lean and agile manufacturing focus on the value creation process to reduce time and costs. Lean manufacturing aims especially for the reduction of waste. For agile manufacturing the rapid reconfiguration and robustness of the manufacturing system are especially important ([NNB99], p. 109, [WES06], p. 26f.).

The next two paragraphs introduce ideas to address the sourcing problem of the support structures. Subsequently, the utilization and benefits of learning effects are discussed. Each of the three ideas offers an opportunity to decrease the lead time in the manufacturing process. On one hand starting the manufacturing process earlier, on the other hand getting fast in the manufacturing process.

Establishing internal fabrication abilities for critical parts with a big impact on delivery times reduces dependency on suppliers. This strategy provides the firm with more control over its supply chain and improves the negotiation position. From an economic point of view a ‘buy’ strategy may be more suitable. Therefore, such production processes cannot be measured by traditional KPIs such as cost and output volume. These processes need to be measured according to the benefits regarding lead time and demand fulfillment ([MRM94], p. 98).

Alter purchasing contracts for just-in-time delivery can be done in different ways. For essential parts, quick deliveries can be assured by means of vertical integration. Another opportunity is to purchase a fixed amount in exchange for short delivery times. To negotiate long-term contracts by issuing blanket-orders is another option similar to the previous one. All the possibilities involve paying a premium for responsiveness ([MRM94], p. 98).
Altering purchasing contracts for just-in-time delivery and establishing internal manufacturing abilities is independent from the manufacturing strategy. Those competing ideas offer possibilities to address long lead times in the sourcing process.

Practice makes perfect. Introducing dedicated workplaces for specific product groups supports learning and therefore reduces the assembly time. This effect is called the learning curve. It has been scientifically determined during the second world war in manufacturing airframes for planes. Especially in manual assembly tasks this effect is predominant. The larger the proportion of manual labor in the production process, the higher is the potential. This fact is also leveraged in the group assembly strategy, where dedicated groups perform specialized tasks on stationary assembly objects. Additionally, the use of specialized tools can be leveraged on dedicated workstations ([LW12], p. 153, [WIN64], p. 125, [ERL10], p. 148).

3.3.1.1 Manufacturing Strategy

As already mentioned the product design and customization affect the production strategy. In this regard the position of the decoupling point is important. The decoupling point is the point in the production process that separates the customer demand from the customer order. To decouple the customer order and the production order usually strategic stock is held at the decoupling point. This buffer enables smooth production output for the upstream production by deliberately planning the operations ahead. The supply can be satisfied by means of forecasts or a Kanban system. Both approaches enable efficient operations ([NNB99], p. 108ff.).

Figure 19 highlights the effects of the decoupling point. The upstream side is largely independent from the customer order. The manufactured components share a low variety and demand variability. In contrast the downstream side shows a high customer orientation and therefore a large variety of products and fluctuating demands. Due to that, the decoupling point also separates standard and customized products. Customization therefore principally happens downstream of the decoupling point ([NNB99], p. 114).

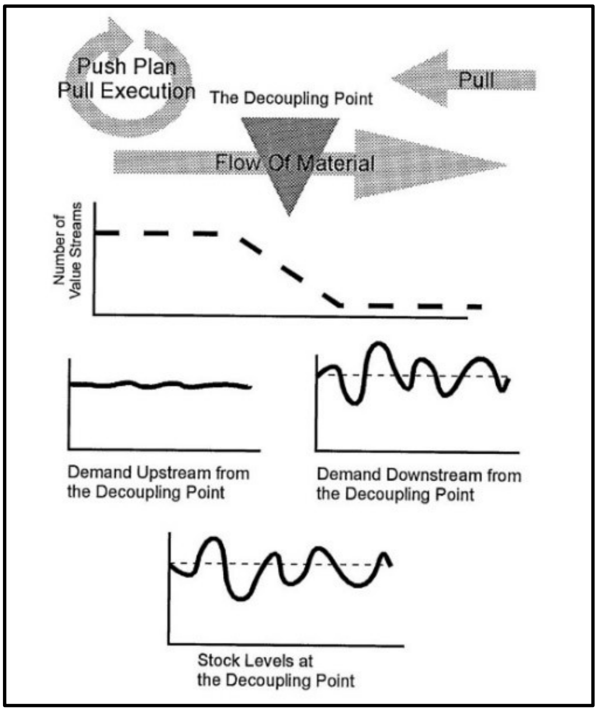

Figure 19: Effects of the decoupling point ([NNB99], p. 114) (Fig. 5).

The different manufacturing strategies are defined with regard to the dependency of the manufacturing order on the customer order. That means the position of the decoupling point determines large parts of the manufacturing strategy. The manufacturing strategy in turn heavily influences metrics like costs and lead times ([NNB99], p. 112).

Figure 20 illustrates the different manufacturing strategies in context with the delivery lead time. As mentioned in Section 3.2.1 the different approaches are restricted by the degree and point of customization of the product ([KJE01], 10.93).

Those strategies have been briefly discussed already in Section 3.2.1. In this section the focus has been on the suitability due to the dimensions responsiveness, customization and stage of differentiation. Those criterions are still important for the next paragraphs. Although, there should be a focus on the inventory and buffering strategy and the effects on the manufacturing processes.

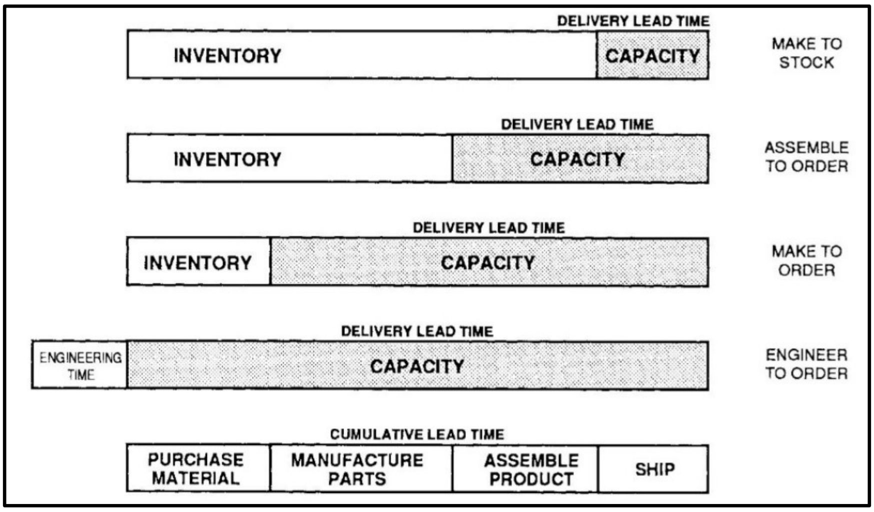

Figure 20: Manufacturing strategy and lead time ([KJE01], 10.93) (Fig. 10.5.6).

The make-to-stock (MTS) strategy features the lowest lead time of all strategies. Finished goods are kept on stock waiting for customer orders. This requires standard products with low variety and demand planning. The inventory costs are high ([KJE01], 10.92–10.93).

The assemble-to-order (ATO) strategy keeps semi-finished goods on stock. The finished goods are assembled based on specific customer orders. This enables reasonable short lead times while enabling a degree of customization and lower inventory costs than the MTS strategy. The ATO strategy requires standard components that can be used in different finished products. When pursuing this strategy the point of customization should be postponed to the latest possible point ([KJE01], 10.92–10.93).

The make-to-order (MTO) strategy only stocks raw material which is used for the different products. Behaving like this reduces inventory costs but the customers need to accept considerable lead times. The planning effort is increased due to high customer involvement and low batch sizes. Since all products are manufactured due to a specific customer demand, this strategy allows a high degree of customization ([SS14], p. 35ff., [NNB99], p. 113, [KJE01], 10.92–10.93).

The engineer-to-order (ETO) strategy virtually does not have any stock at all. Therefore, this strategy has the longest lead time. Since the manufactured products are engineered according to a certain customer demand, the degree of customization is the greatest within all presented manufacturing strategies. Customer involvement is extensive and in further consequence affects the manufacturing process ([SS14], p. 35ff., [KJE01], 10.92–10.93).

Many companies apply more than one, sometimes even all four strategies. The suitable strategy for the different components is determined depending on whether they are standard or customer specific. Even in an ETO environment it is possible to premanufacture standard components and keep them on stock. The utilization of standard components makes production planning and leveling easier ([KJE01], 10.92–10.93).

3.3.1.2 Storage Operation

Referring to the findings in Section 3.2.1 the product configuration process should enhance the utilization of standard components in the ETO environment. This in turn leads to a component manufacturing process decoupled from the assembly process and therefore decoupled from the direct customer demand.

Due to the rising number of standard components the commissioning effort is rising as well. Commissioning should not be completed by the assembly personnel. The material supply, however, should be operated by dedicated personnel. Since the combination of both, the assembly and material supply tasks, usually lead to wasted time, value-creating and non-valuecrating tasks are separated. According to lean principles, waste must be avoided. A clear distinction between the two processes enables individual optimization of the assembly and commissioning processes. The separation of logistics and assembly increases the presence of the assembly workers at the assembly station. Usually there is also a 'mental set up' time involved when the assembly workers withdraw parts from the storage themselves. This time is wasted on top of the unproductive time spent for picking up components ([ERL10], p. 290f., [KJE01], 15.91).

All the components necessary can be supplied to the assembly stations from a commissioning area. In the commissioning area the responsible employee collects all the necessary components for a manufacturing order according to the related BOM. All the parts for one manufacturing order are stored on a cart designed for this purpose. Figure 21 shows an example of such a material supply cart. The components for one assembly order can be commissioned, stored, transported and withdrawn from the cart.

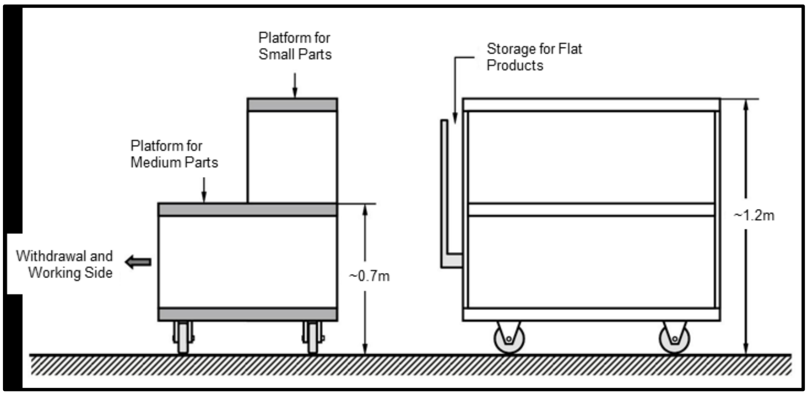

Figure 21: A material supply cart ([LW12], p. 164) (Fig. 6.16) (modified).

3.3.2 Facility Layout

The problem analysis in Section 2.2 showed a lack of buffering space and the requirement for additional equipment in combination with no available space on the shop floor. Due to that reason, a change of the shop floor layout is inevitable. As already mentioned in the problem analysis, the planning and design of production and supporting areas is part of facility layout planning. It is important, that the facility layout supports the goals and strategies of the company ([KJE01], 8.21).

Facility layout planning deals with the design of different industrial facilities including manufacturing plants. Important operations from the field of facility layout planning regrading this thesis include data collection and analysis, creating facility layouts, determining space requirements and selecting alternatives ([KJE01], 8.21–8.22).

There are several ways to solve the problem of limited space other than extending the plant by means of construction. First, working hours can be increased. That means an additional shift, working on weekends or working overtime. This measure does not create more space but improves the utilization of the existing space. Therefore, only part of the problem could be solved this way since no additional buffering space is created. Second, the operations and inventory can be decentralized. Such as step creates more space on the shop floor at IFT and provides the additional space for buffering and equipment in this manner. To do so the operations are divided into groups and spread across available buildings at Plansee SE ([MH15], p. 138).

The methods to select suitable technologies are adopted form material flow planning which is part of facility layout planning. Suitable technologies in this regard involve technologies that are not essentially necessary to be performed on the IFT shop floor. Because rearranging the whole layout is beyond the scope of this thesis, only some of the stages from the material flow planning procedure are required. The required stages for this thesis are listed below. The aim is in principal is to find technologies that interfere the least with the current operations when performed outside IFT.

1. Formulate the Problem
2. Analyze the Problem
3. Choose the Right Solution ([SWM06], p. 30ff.)

First, the problem as well as the objectives need to be formulated. The description of the problem and the aims of this master thesis can be found in chapter 2. The following bullet points summarize the objectives concerning the facility layout.

- Lack of space for buffering and additional equipment
- Inefficient assembly process due to high search effort
- Low utilization of learning curve effects

Second, the current situation of the plant is analyzed. Therefore, the product mix and the market trends are evaluated. A volume-variety analysis is an effective way to get an impression of the current product mix. Market trends are usually provided by the sales department or can be derived from records. The most important products according to the volume-variety analysis are examined in greater detail. A bill of materials (BOM) explosion is used for this purpose. For each position in the BOM the production routing is reviewed. This provides information about the interaction of the different workstations. Those evaluations provide good insight into the product structure and the manufacturing processes. The production routing usually contains standard times, the sequence of manufacturing tasks and all the further information needed to manufacture each component properly. Another aspect of the current situation is the current layout and its capabilities. An analysis of the used space can be applied as basis for the future layout. The capacities regarding all workstations can be used as a reference as well ([MDS+14], p. 513).

VDI 1689, a guideline for material flow studies, lists possible data sources to analyze the initial situation for material flow studies. Table 3 shows a selection of the possible data sources.

Table 3: Data sources for material flow analysis ([VDI10], p. 11).

Organigram	Bill of Materials (BOM)
Production Program	Production Routings
Construction Plans	Production Data Acquisition (PDA)
Layout Charts	Material Movements
	Warehouse Stocks

Analysis of the required space

To determine the required space the different types of spaces need to be considered. Those spaces are the net floor space for installing the machine, auxiliary equipment, the worker main space, material buffering area and a service/maintenance space. Those spaces are illustrated in Figure 22. The described spaces can also be overlapping ([MH15], p. 121, [GRU14], p. 105).

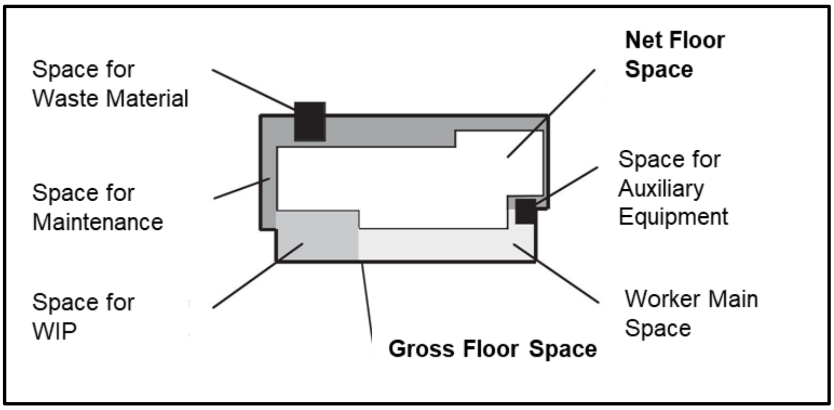

Figure 22: Determining the gross floor space ([GRU14], p. 105) (Fig. 3.15, modified)

The used space in manufacturing facilities can be divided into manufacturing, storage and materials handling spaces. Typically, the aisle space for materials handling accounts for 20% to 28% including 5% to 10% of dock areas and 15% to 18% of logistics areas inside the facility. Storage areas account for approximately 10% to 20% of the totals space. Those values from the literature review do not consider the manufacturing strategy. Therefore, they can only be seen as a rough guideline ([MH15], p. 139, [MH15], p. 136).

Volume-Variety Analysis

Pareto's law says that for a great number of applications a small group of products contributes to a bulk of costs, value, impact and comparable aspects. The volume variety analysis aims for detecting the most important products in terms of sales, volume, effort ([KJE01], 10.103).

1. The products, items or materials are assigned to suitable groups
2. The quantity, costs or impact for the group is calculated
3. The groups are arranged in sequence from high to low, for the diagram
4. The curve is plotted accumulating the values of the groups ([MH15], p. 39f.)

Third, the different layout alternatives are evaluated according to their strength and weaknesses. One way to do so is a weighted-factor analysis. This analysis provides a transparent and guided decision-making process. It should also promote objectiveness and reduce biases ([KJE01], p. 978).

Weighted Factor Analysis

The weighted factor analysis is a decision-making tool for the rating of alternative solutions. This analytical method combines qualitative and quantitative factors that make it very versatile. The procedure works in the following manner:

1. List the factors relevant for the evaluation
2. Weigh the importance of the factors among each other
3. Rate the options against one factor at a time
4. The scores for each option are totaled ([MH15], p. 181, [KJE01], 8.50)

The preferred option shows the highest score after this procedure. When performing a weighted factor analysis, it should be considered that the weighting and rating of the factors and options is subjective and biased. Therefore, the result always depends on the people conducting the analysis. Nevertheless, the weighted factor analysis creates a meaningful discussion and reduces the range of options. This way, it serves the purpose to support the decision-making process ([KJE01], 8.50).

4 Implementation

This chapter deals with the practical implementation of the theoretical approaches introduced in chapter 3. The theoretical principles are adapted to the needs of Plansee SE and the specific products and organization. First, the elaboration deals with the market-oriented product configuration for the order fulfillment process. The product configuration model is developed using the sub-assembly 'side shielding' of the hot zone. The second part deals with the organization and layout of the production process at IFT.

4.1 Market Oriented Product Configuration

The approach for the market oriented product configuration results from the problem analysis concerning product information management in Section 2.1 and the literature review in Section 3.2. The literature review suggests product configuration as a suitable solution for the issues detected. The product configuration should provide increased product information at an earlier point in the order fulfillment process, enable the consistent use of product master data and reduce the lead time in the engineering process.

The following sections outline the implementation of the product configuration idea at Plansee SE. In the beginning the initial situation is analyzed to find starting points to build on. Next the product design is adapted to a configurable product design. Subsequently, the models introduced in Section 3.2.2.2 are implemented. Afterwards, the possibilities for automation in the different stages of the order fulfillment process are pointed out. Finally, an estimation of the saved time is provided.

4.1.1 Analysis of the Initial Situation

Building on especially the design related issues mentioned in Section 2.1, this section focuses on the product design and its suitability for product configuration. A configurable product design is a precondition for successful product configuration projects (Section 3.2.2.1).

Currently, the design engineers start the design process using templates and the specification provided by the sales department. The side shielding mainly consists of a support structure made from steel, several standard components (pins, gas nozzles etc.) and shielding panels made from sheet metal. The shielding panels and the support structure are designed product specific. Figure 23 shows the most important components of a side shielding. To provide the best shielding performance the design engineers try to reduce the number of standard components inside the shielding. This is a task requiring expert knowledge and a lot of experience. Since there are no certain rules for this process, the design outcome varies depending on the design engineer.

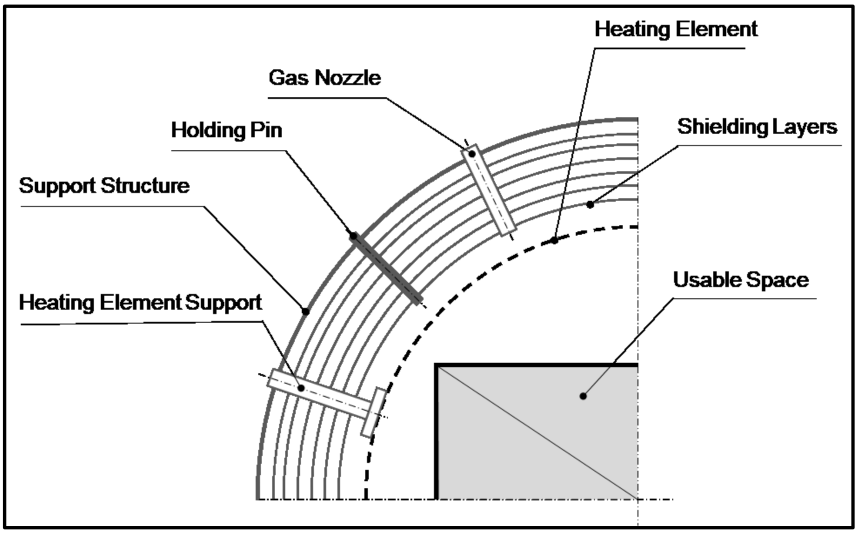

Figure 23: Schematic cross-section of a side shielding.

Product configuration systems need standard components to work properly. Those standard components can either have fixed dimensions or can be parametric. This enables the selection and adjustment of the required components according to a set of rules. Because of those preconditions the current design needs some adjustment to work well within a product configuration system. The next section explains the necessary adjustments to the product design in greater detail.

4.1.2 Configurable Product Design

The existing standard components can be reused in the configurable product design. The shielding layers and the distribution of the standard components need to be defined according to certain rules. Depending on the diameter and the length of the side shielding a different number of sheets in radial and axial direction is required. Considering the necessary overlapping, maximum sheet length and width of the outermost layer, the number of necessary sheets can be determined. To simplify the rules, the sheet size within a layer does not vary. Given those constraints the sheet size for each layer can be calculated. Because the dimensions of the sheets are not pre-defined those sheets are parametric components and are defined according to rules for each side shielding configuration.

Figure 24 illustrates the different sheet metal shielding components of a schematic cylindric side shielding. The shielding consists of different layers depending on the temperature and the type. The innermost layer is called 'Hot Face'. The remaining layers are labeled with 'Layer' and the number of the layer starting with two from inside to outside. The cylinders in axial direction are referred to as 'Rows'. The numbering starts in the front row with one. The radial sheets are labeled 'Position' starting with one and counting upwards in a clockwise manner. Following that labeling scheme, every sheet metal component can be identified. The code 'HF-1-1' refers to the component of the 'Hot Face', 'Row 1' and 'Position 1'.

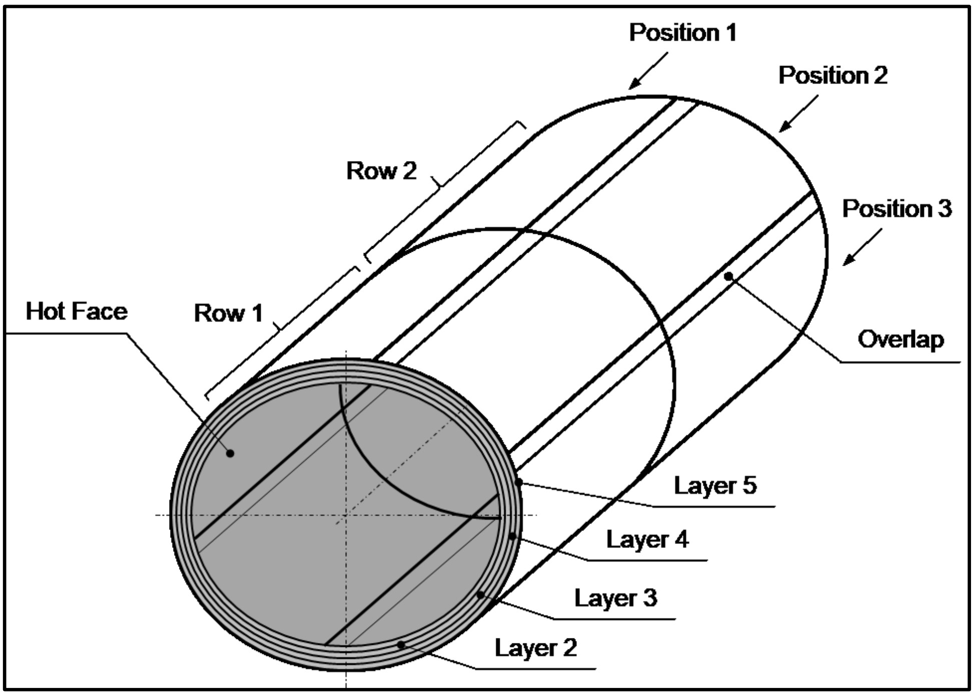

Figure 24: Sheet metal modification, side shielding.

The holes necessary for the standard components are created in a second step. This reduces the complexity and increases the usability of the CAD model. For each type of hole (e.g. pins, gas nozzles, heating element support) a virtual model is subtracted from the shielding package. Those models are used only for design purposes and are parametric as well. That means the number and size of the holes is ruled by the size of the sheet metal components. To enable maximum flexibility for the design engineers, each row in the cylinder refers to a separate virtual model. In addition, those models can be adjusted to the customer needs if the customer requirements are not covered by the parametric components.

4.1.3 Commercial Model

Referring to Section 3.2.2.2 the commercial model is the interface to the customer and sales personnel. Therefore, the design should be clear and easy to understand.

Currently, the product managers are using a list of specifications as a guideline to identify the customer needs. This list contains characteristics relevant for the customer and specifications relevant for the engineering department. A product description as well as the mentioned list of specifications provide the basis for the commercial model.

To prevent mistakes and misunderstandings only predefined answers can be selected. In the case of dimensions this leads to a multitude of possible answers and product variants. Therefore, a decision tree is unfeasible in this case. Due to that reason, the answers are included in the technical model as constraints. According to the questions and answers the components fulfilling the demands are selected.

After each filled-in answer, the software runs a check if there are still components left in the technical model, that contain an answer to the remaining questions. If there are questions and answers that do not have any relation to components in the technical model anymore, the questions and answers are skipped.

Table 4 shows the structure of the commercial model and a selection of questions and answers. As mentioned before, some of the questions/answers make subsequent questions/answers unnecessary. For example, if 'Useable Space Type' = 'Round' the 'Side Shielding Type' 'Rectangular' is not an option. This gets automatically detected by the software and the answer 'Rectangular' is skipped. The same is true for the 'Usable Space Diameter' this parameter can only be filled in if 'Useable Space Type' = 'Round'. Because the parameter 'Usable Space Diameter' is still important for all round side shieldings, no matter if the useable space is round or rectangular, the parameter 'Usable Space Diameter' is software driven for round side shieldings with rectangular usable space.

Table 4: The commercial model.

Question	Answer
Useable Space Type	'Round'/'Rectangular'
Side Shielding Type	'Round'/'Rectangular'
Orientation	'Vertical'/'Horizontal'
Useable Space Length	10…10,000mm, incr. 1
Useable Space Height	10…10,000mm, incr. 1
Useable Space Width	10…10,000mm, incr. 1
Useable Space Diameter	10…10,000mm, incr. 1
Operating Temperature	1,000…2,500°C, incr. 10
Maximum Temperature	1,000…2,700°C, incr. 10
Gas System	'Yes'/'No'

In contrast to the current approach, the commercial dialogue is more structured using the commercial model. Currently, a checklist is used to guide the sales dialogue. Such a checklist does not allow restrictions to the answers, answers can be even left blank. In the newly designed sales dialogue the questions are asked in a predefined sequence and the space for answers is constrained. Such an approach ensures the reusability of the retrieved data which is not possible in the current sales dialogue. The sales process using the commercial model also ensures the completeness of the customer information.

4.1.4 Technical Model

The technical model contains all the knowledge from the design engineers and is therefore more complex than the commercial model. For the basic structure the vertically aligned class diagram (VACD) proposed by Haug et al. is adopted (Section 3.2.2.2). The structure of the technical model is illustrated in Figure 25. To enrich the information more sections are added in comparison to the VACD. Since the VACD makes use of class diagrams, UML expressions and concepts are used in the technical model.

First, the information to directly related files or documents is added. In the case of the 'Hot Zone Round' this are CAD-files and the related material number in the ERP system. Those pieces of information are necessary for the parametric design, the cost calculation and production routings which are discussed later.

Second, like in the VACD there are determined features. This section contains the knowledge in the technical model and is related to the commercial model. The determined features represent the answers to the questions in the commercial model. Those answers can either be represented by an exact value or a range of values. Those features constrain the use of the different components. The components are only selected if the features and the answers given in the commercial model match.

Third, there are methods or functions available that are necessary to calculate specific values and execute operations. For example, if the usable space is rectangular the determining feature for the section of components is still the diameter of the usable space. The calculation of the diameter can be implemented in a method. Determining dimensions for parametric components or quantities are other examples for used methods.

To minimize repetitions, the concept of stereotypes is also adopted in the technical model. Stereotypes are available in UML and are marked by guillemets <<>>. The advantage of such abstract classes is that features and methods can be inherited to subclasses. This decreases the modeling effort and supports readability of the model. Stereotypes also contain features without determination illustrated with empty braces. Those are used to indicate mandatory features for subclasses ([FFJ00], p. 450, [BEL04]).

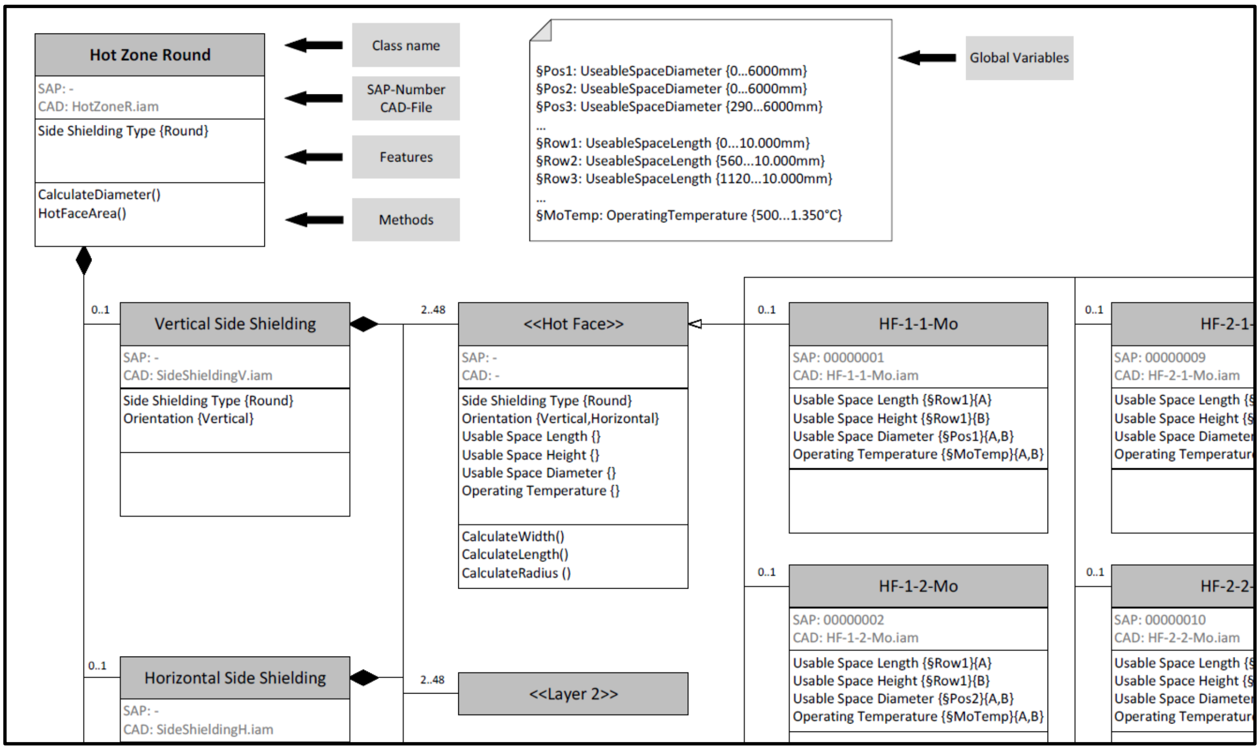

Figure 25: Structure of the technical model.

Because especially the sheet metal panels share specific features global variables are introduced. Those can be identified by starting with the § symbol. For example, all the sheet metal panels in row 1 share the same constraint for the feature 'Usable Space Length'. By defining the global variable '§Row1' all constraints can be controlled by one globally defined variable. Since some components can be used in different cases different bundles of features exist. Bundles are indicated by a set of letters after the feature in braces {}. The different constraints are connected by an 'and' by default if there are no letters. This is especially true for inherited features. Otherwise, the letters indicate a specific bundle. The features within the same bundle and the features without a bundle are connected by an 'and' constraint. The bundles are connected by an 'or' constraint among each other. Features can also be in more than one bundle.

The value above the association connector indicates the multiplicity. It shows how many instances of the given class are possible.

The structured data from the technical model can be utilized for automation purposes in different applications. The reuse of data for automation is the reason why references to the ERP and CAD systems are already included in the technical model. The following sections describe the automation of design processes, generation of production routings and cost and price calculations.

4.1.4.1 Rule Based Parametric Design

Generating design drafts at an early stage has two major benefits. First, it enriches the proposal and gives customers a better impression of the desired product. Second, it provides the design engineers with a template to further work on. This enables faster and better decision on the customer side and reduces repetitive and tedious design tasks.
As already mentioned in Section 3.2.2.3 the parametric models are predefined as templates in the CAD system and a specific instance of the models is created for each particular configuration. Additionally, most of the modern CAD software packages offer an opportunity to code specific design rules within parts and assemblies. Usually that covers reading of values from spread sheets, changing dimensions according to functions, changing parameters, suppressing parts and many more. This enables a CAD model to adapt to given specifications.

Using the example of the 'Vertical Side Shielding', a CAD model that adapts to different specifications has been developed. The aim has been to proof the usability of the product information made available by the configuration system. To increase the usability, all dimensions are calculated outside the CAD system and therefore in the product configuration software. The configuration software features functionalities from Microsoft Excel. Due to that, the design engineers can change calculations even without coding skills. In this manner all necessary parameters for the CAD system can be calculated. Consequently, the CAD software reads all the necessary values from the product configuration software and adapts the parametric models accordingly. Therefore, the configuration software contains most of the knowledge. This enables maximum independency of the CAD package and knowledge management inside the configuration system.

The structure of the CAD model is designed as follows: The main assembly model contains all possible parts including each standard and parametric component. For each part the model checks whether it is required for the current configuration or not. If the part is not necessary it gets suppressed, otherwise it remains in the model. For the parametric parts the

CAD software additionally reads the parametric dimensions and adapts the parts accordingly. Both, the status of the component, if it is required or not, and the dimensions are provided by the product configuration software.

Figure 26 shows the evolution of the parametric model according to changes in the configuration. In this specific case, the initial CAD model with two rows (number of axial sheets) and two positions (number of radial sheets). This model is changed to one row and two positions with smaller diameter. The images from left to right show first the initial model. In the second image the unnecessary parts are already suppressed, and the parametric components are adjusted to the new dimensions. The last image shows the final assembly. All unnecessary components are suppressed, and the dimensions of the parametric components are adjusted to the requirements.

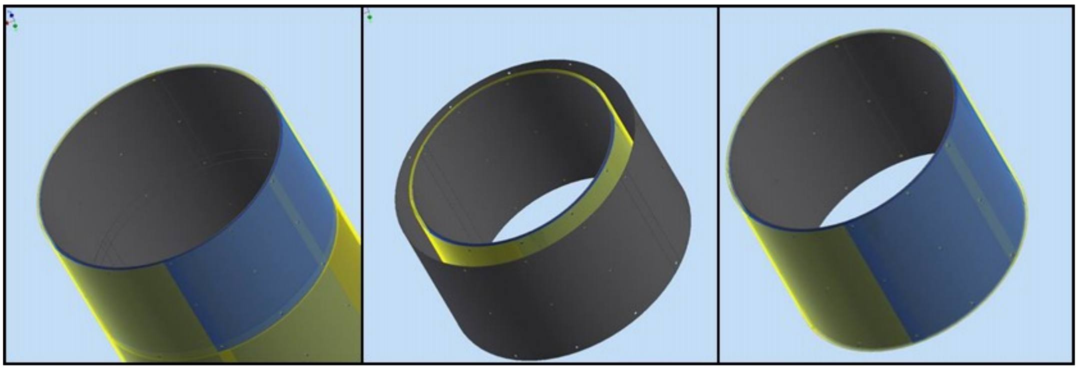

Figure 26: The parametric CAD model.

After finishing the configuration process and updating the CAD model, all the generated components and assemblies are transferred to the ERP system. For each new component, a new material number is created. The available master data is automatically retrieved from the CAD package and the product configuration software. This covers information necessary for the production like material, weight, cutting length and number of starting holes for laser or water jet cutting.

Figure 27 illustrates the relationship between the product configuration system, the CAD system and the ERP system. Section 3.2.2.3 shows a similar image, though without the feedback loop from the CAD system and the integration of the ERP system. As already described above the product configuration system provides all the data necessary to generate the CAD model. The CAD model also contains geometric and physical specifications which are transferred back to the product configuration system. Those specifications and the cost and price information build the foundation for the generation of the production routings and cost calculations. Therefore, the rule-based design is a precondition for automated generation of production routings and cost calculation, which will be discussed in the next sections.

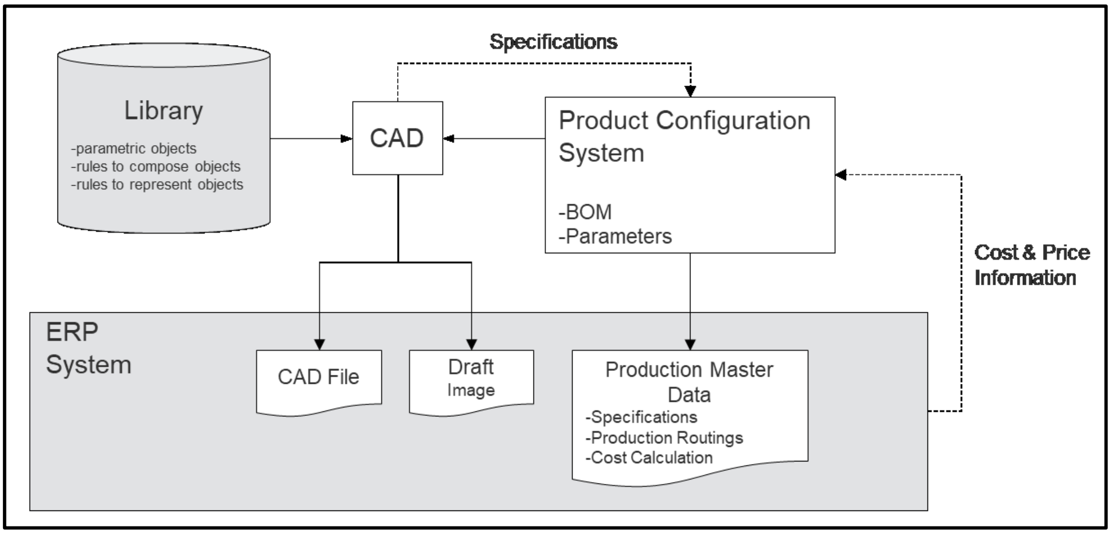

Figure 27: Using the parametric design data.

As already mentioned briefly, the rule-based design only has been implemented as part of a feasibility study. The purpose was to proof the feasibility of the concept, which has been successful.

4.1.4.2 Production Routing

For standard component the production routings are already available in the ERP system. That is the reason why there are ERP material numbers linked to the configuration software (SAP-number). To automate the generation of production routings for parametric components, parametric templates for each type of component need to be established. Those templates can be associated with the stereotypes from the technical model. They serve a similar purpose acting as a template for the configurable components.

The assembly time is calculated for each assembly according to the number and kind of the different components in the assembly. Therefore, standard times need to be determined for the assembly step of each specific component. According to the BOM of each assembly the required time can be computed.

Using material, cutting length and number of starting holes for sheet metal panels the operating time can be determined. The time is an important indicator for the calculation of the costs and for production scheduling.

4.1.4.3 Cost Calculation

The automated calculation of costs improves the accuracy of the determined costs. Currently, the type and number of the used components is estimated by the product managers. Using this estimation, the costs and in the next step the price for a specific hot zone is calculated. In contrast, the product configuration system in combination with the CAD system allow a more precise determination of the BOM. That includes the type and number of standard components as well as the number and dimensions of the parametric components.

Analog to the production routings the costs can be directly retrieved from the ERP system for standard components. Those costs are regularly updated according to changes in material price and machine rates. For the cost calculation of the parametric sheet metal panels material, weight, cutting length, number of starting points and sheet thickness are important. Using those parameters, the material costs and machine rates from the ERP system, the production costs of the parametric components can be determined. To determine the assembly costs the required time from the production routing can be used in combination with the rate for the specific production unit.

For the calculation of the product costs the individual costs of the components and assemblies are summed up. Like stated in Section 3.2.2.3 the product price can be computed by adding customer specific costs and a mark-up.

Regarding the customer value, introduced in Section 2.3, the factor cost is not affected since only the way of the cost determination is changed. The factor service though is improved by providing the information about the product price earlier due to the automated calculation.

4.1.5 Software Implementation

For the software implementation of the product configuration system the proprietary application 'EASYConfig 1.41' from Fraunhofer IPA[4] is used. This is a database application using Microsoft Access. 'EASYConfig 1.41' works according to the commercial and technical models introduced in the previous chapters ([OKH14], p. 20).

The basic functions of the software are performed in three steps. First, the commercial model is created using features (questions) important and easy to understand for the customer. Second, the technical model is implemented using the maximum BOM represented in the VACD. During this step, the components are deliberately constrained using the features previously defined in the commercial description. The final step relates to the configuration of products by selecting certain characteristics according to the customer requirements. The software compares the required characteristics and the defined constraints for selecting suitable components for the current application.

Figure 28 shows the graphical user interface (GUI) in 'EASYConfig 1.41' for the commercial description. On the left the features are added to describe the product. The right side shows the possible characteristics for the features which are in this case the selectable characteristics for 'Maximum Temperature'.

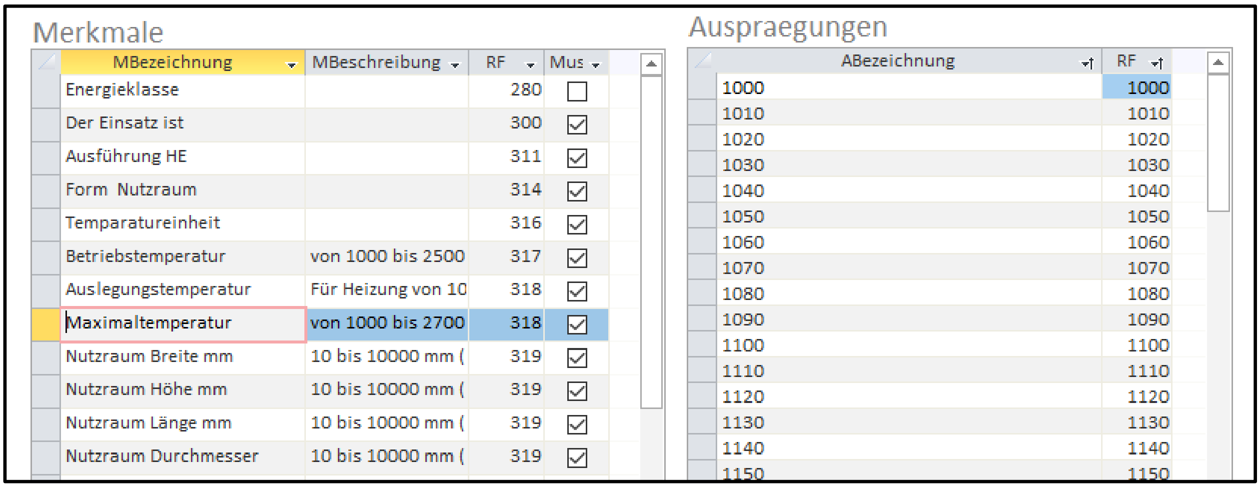

Figure 28: The commercial description in 'EASYConfig 1.41'.

[4] Institut für Produktionstechnik und Automatisierung https://www.ipa.fraunhofer.de/

Figure 29 illustrates the technical description in 'EASYConfig 1.41'. On the lower left side, the components are added. The relevant features for the current component can be selected on the upper right side. The constraints to each component are edited on the lower right side by adding certain characteristics to the selected features.

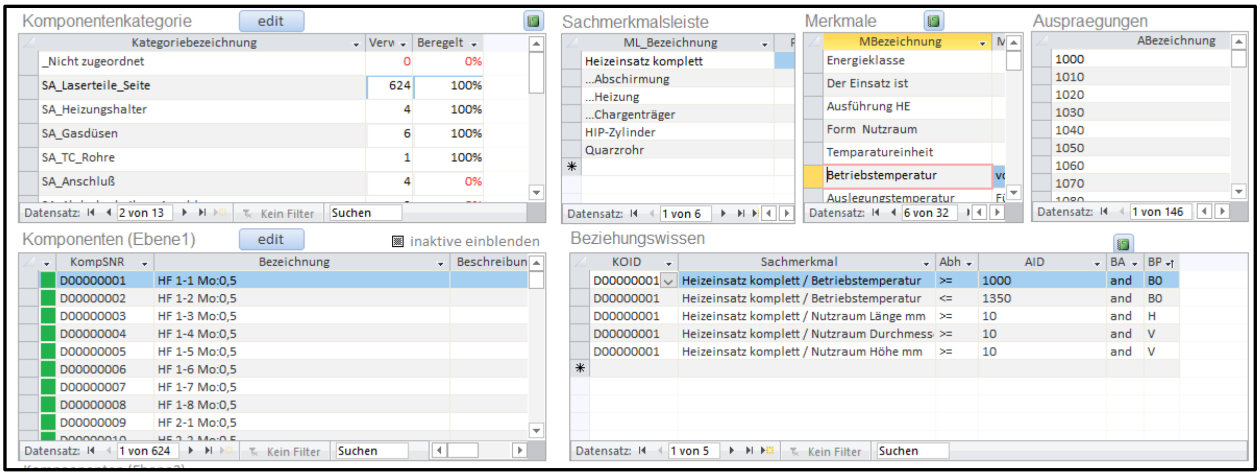

Figure 29: The technical description in 'EASYConfig 1.41'.

Figure 30 shows the interface for the configuration of components. First, the required features are selected on the upper left side. Then, for each of the features the corresponding characteristics are added. The sequence of the features is determined according to the commercial description. For mandatory features characteristics need to be selected for the configuration to work.

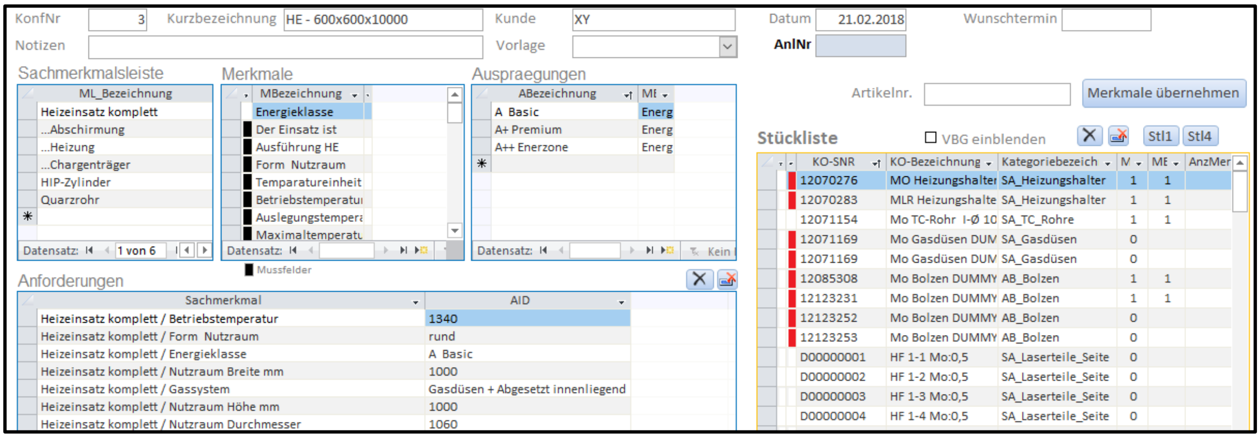

Figure 30: The configuration interface in 'EASYConfig 1.41'.

After selecting all features and characteristics according to the customer requirements the BOM is generated on the right side. This BOM can then be used in the CAD package and for further calculations of production routings, costs and price.

As already mentioned, the configuration software 'EASYConfig 1.41' has been developed by Fraunhofer IPA. The software is currently under development. Originally the software did not support parametric components. This function has been implemented due to the requirements of the configurable product design (Section 4.1.2) by Fraunhofer IPA. This enables the computation of dimensions for the parametric components directly in the configuration software (Section 4.1.4.1), which is a precondition for the rule-based design model. Although Fraunhofer IPA implemented the functions in the software, the concepts regarding rule-based design and parametric components have been developed within this thesis.

4.1.6 Organizational Redesign

As mentioned in Section 3.2.2.4 there is also a change in the organization necessary to support the new configuration system. This originates from the change in the roles of the different departments. No change of responsibilities is necessary but a shift in the anticipated workload and the type of work is inevitable.

Starting with the sales department, the time spent on calculating product prices and finding similar existing products can be drastically reduced. This enables the sales department to increase their customer focus. Using the design drafts in the proposal should supplementary help in the clarification process with the customer.

The engineering department should be able to reduce the time required for designing the products. The design draft should only be further customized and adapted to the customer's needs by the design engineers. The time saved in the design process can be used to improve the design templates. This involves the improvement of product performance and the manufacturability. Due to the standardized design the engineers are better able to react to customer feedback and improve the product design building.

The same is true for the production planning department. Because plenty of the production master data should be generated automatically, the planning engineers have more time to maintain the existing data. As described in the Section 2.1 the existing production master data is often created by copy and paste. Therefore, the additional time can be used to review the data created this way. This improves the data quality and therefore mitigates failures in the manufacturing process.

There are not only time savings coming with the product configuration system but like for every technical system maintenance is needed. This should be done by a team involving the three departments sales, engineering and production planning. The selected team is responsible for all changes regarding the product configuration system. Those changes involve the configuration process itself, the product design and the manufacturing process.

Figure 31 shows how the configuration process affects the different departments. Starting with the customer the sales department receives a RFP from the customer. Subsequently the sales department performs a basic product configuration according to the customer's requirements. If the information given in the RFP is not sufficient, the sales department collaborates with the customer to gather the additional information needed. Next, the sales department prepares the proposal using the product information from the configuration system. This involves a design draft and a preliminary price. Having a detailed proposal, the customer is able to further refine the requirements in collaboration with the sales department. As soon as all the customer requirements are available, the engineering department starts with the detailed configuration process. The generated draft from the configuration process is refined and modified to meet the customer's needs. At the same time the product planning department gets already informed about the basic components of the product and their preliminary quantities. This enables them to check the stocked components and plan purchasing and capacity ahead. After the engineering department finalizes the drawings and the BOM the product planning department reviews the production master data and schedules the manufacturing process.

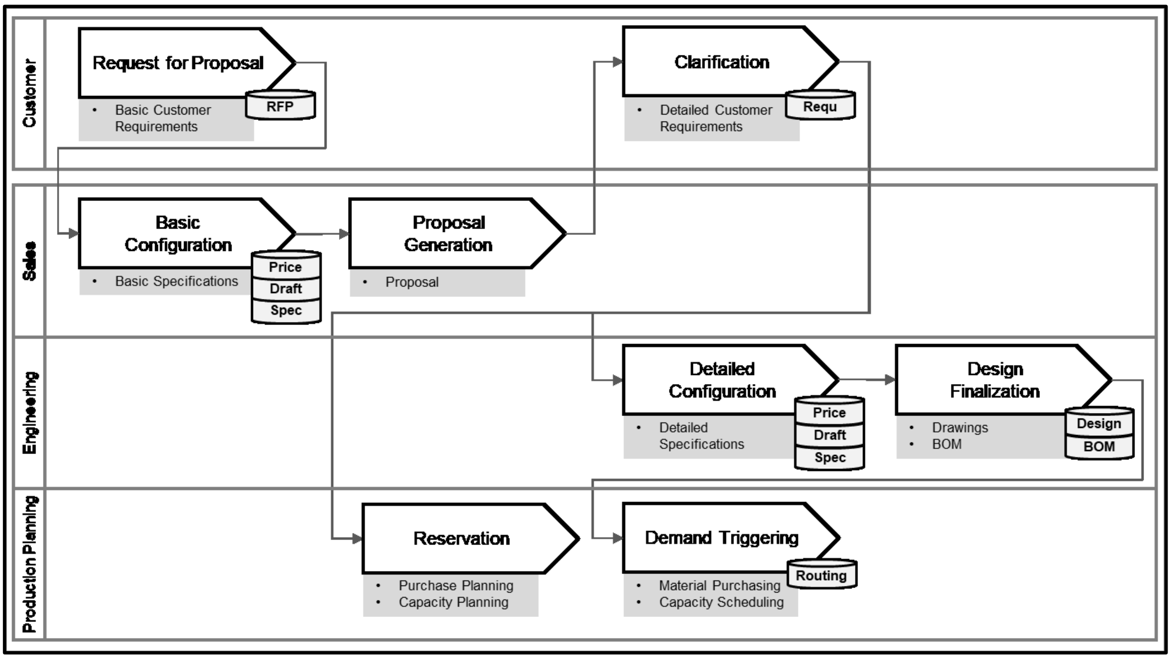

Figure 31: The product configuration process overview.

The standard procedure should look like outlined above for the order fulfillment process using the configuration system. Beside the standard procedure the already mentioned team continuously works to improve the process.

4.1.7 Estimated Time Savings

Figure 32 illustrates the time savings in the upstream processes in a qualitative way. Using this illustration, the possible time savings are explained and estimated. The estimated time savings refer to the lead time analysis in Section 2.

At the point of RFP, the customer usually already has a certain date for the demanded product. The configuration-enriched proposal provides the customer with a better impression of the offered product, which can for example lead to an earlier purchasing decision. The date of demand is, however, not affected by that decision. Therefore, the available time for delivering the product is increased. Using the example of the hot zone, the customer usually has a date for the demand. The date can either originate from a scheduled replacement or from the planned installation date. Those dates are usually fixed. In the case of the replacement the customer wants to complete the life cycle of the old hot zone. In the case of the new hot zone, the customer cannot start the assembly without the remaining components like the vessel and the electric installations. Unfortunately, the time gained for delivering the product cannot be estimated ([OKH14], p. 5).

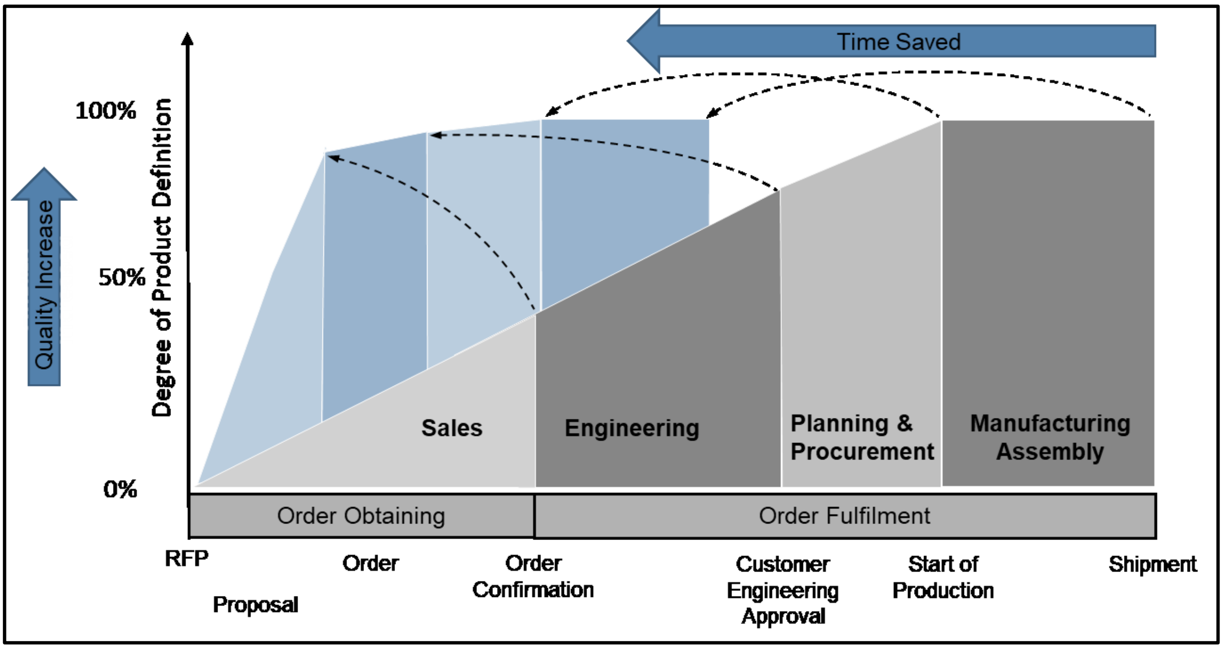

Figure 32: Time savings in the upstream processes ([OKH14], p. 5).

Overall, the time for the sales process might not change a lot. Yet, the effort for the proposal generation is decreased by the configuration process. In turn, the transition to the engineering department only happens when the complete product information, necessary for the design process, is available. This change in the procedure extends the sales process but helps during the engineering process. The two counteractive effects might neutralize each other. However, the effort in the sales process is decreased due to the automated calculation of the product prices.

The availability of the necessary product information has the biggest impact on the engineering process. According to the problem analysis in Section 2, 37% of the lead time in the engineering process is unproductive due to missing information. The configuration process should be able to eliminate this period. Additionally, every time a process is stopped and restarted again a mental setup time is involved. Therefore, the whole unproductive time is estimated to 40% of the engineering lead time. Additionally, the increased use of standard components and the use of parametric CAD templates reduces design efforts. Creating holes and adjust them to the thermal expansion accounts for 20% of the productive time in the engineering process. Due to that, the time saved by automation of the design process is estimated to 20% of the productive time ([ERL10], p. 290f.).

Due to the parallelization of production planning and engineering there is no data available to determine the time required for the planning process. This also makes it hard to estimate the time savings in the planning process. The increased use of standard components and templates should show significant benefits as well. Because of parallelization the time savings cannot be leveraged in the lead time reduction.

Summarizing the effects of product configuration on the lead time in the upstream processes, the available time should be prolonged, and the time savings are estimated to at least 52%. Those 52% include 40% from eliminating the unproductive time and 12% from automation in the engineering process. Those 12% are resulting from 20% of potential automation of the remaining 60% productive engineering time.

4.2 Manufacturing Organization

This section deals with the implementation of the findings in 3.3. First, the requirements for the improved space situation are determined. Subject are the space requirements for additional machines and additional buffering spaces as well as the distribution of workload on the different workstations. In the second part, the idea of performing specific operations outside the IFT facility to gain more space are elaborated. Therefore, the manufacturing space is analyzed, and suitable technologies are assessed. Finally, the sourcing process of the support structures for the hot zone is reviewed.

4.2.1 Requirements for an Improved Shop Floor

There are two main requirements for an improved manufacturing shop floor (section 2.3). First, there is more space required. This additional space is needed for two reasons. On the one hand, more buffering space to leverage the standardization from the configuration process by pre-commissioning of assembly material and on the other hand, additional machines are needed. Second, the segmentation of the workstations should be changed to more dedicated workstations which optimally enable improved utilization of learning curve effects.

The following paragraphs outline the estimation of the additionally required spaces on the shop floor at IFT. The calculation method depends on the type of space.

Buffering Space

Referring to Section 3.3.1.1, the manufacturing strategy for parts, standardized by the configuration process, changes. A MTS strategy for standard products enables the postponement of the decoupling point for the standardized products. The advantages of the postponement of the decoupling point are discussed in Section 3.3.1.1. Prerequisite for such an approach is sufficient space for the commissioning of the standard products.

Section 3.3.1.2 recommends the separation of logistics and assembly. Such a step provides an increasing efficiency on the shop floor by separation of value adding and non-value adding activities. Like for the postponement of the decoupling point, dedicated areas for the buffering and commissioning of goods is required. The implementation of such a commissioning buffer is outlined in the next paragraphs.

Assembly carts should be introduced to enable pre-commissioning of all the necessary products for the assembly process (Section 3.3.1.2). The outer measurements (length x width) should be the same as a DIN-pallet 1,200x800mm. There are more reasons for that. First, DIN-pallets are compatible with standardized boxes for storing small parts for the assembly process. Second, the existing carts at IFT already have that dimension. For that reason, both, the existing and new carts fit in the same buffering spots ([MAR16], p. 67, [MAR16], p. 64).

To utilize the space above the buffering area a pallet rack installed above this area. The arrangement of the pallets and the pillars of the pallet rack as well as the required space for logistics is illustrated in Figure 33. For each of the assembly workstations there should be at least two material supply carts. The reason for that is: If parts, that inhibit the further assembly of the product, are damaged during the assembly process, there is a second cart. The frequency of failures, due to the specific behavior of refractory alloys (Section 1.4) justifies two carts. The second cart enables the employees at the assembly workstations to work on a different product in the meantime. There are 3 dedicated workstations for HIP-cylinders, quartz glass melting crucibles and hot zones. There is an additional general assembly station with 3 more work places. The workstation rolling and bending requires also buffering space for2 additional carts.

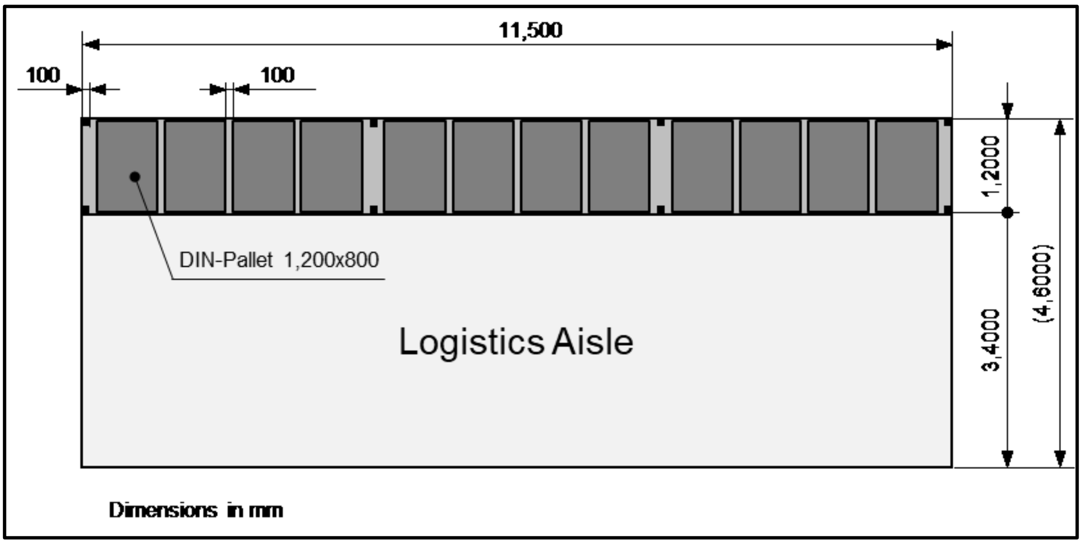

Figure 33: Sketch of the required buffering space.

The calculation of the buffering space is done as illustrated in Figure 33. Leaving 100mm of clearance between the carts and 100mm for the pillars of the rack the total length of the buffering space accounts to 11,500mm for 12 carts in a row. For the determination of the width of the buffering space, the length of the pallets and a leeway for the access of forklifts need to be considered. The material carts require only around 900mm – 1,200mm of leeway but the forklift to for the pallet rack requires 3,400mm. Therefore, the total width accounts to 4,600mm. The total required are for buffering and accessing the material carts and the pallet rack account to 52.9m^2 ([MAR16], p. 253, [MAR16], p. 378ff., [MAR16], p. 360.).

Space for Additional Machinery

As already mentioned there are additional machines required at IFT. Those machines are a CNC press brake, a deburring machine, a coating system and a substitution for the existing water jet cutting machine. To determine the gross required floor space the requirements of the specific machines need to be considered (Section 3.3.2).

Table 5 shows the calculation of the required gross floor space for the CNC press brake, the deburring machine and the coating system. The water jet cutting machine is a replacement for the current water jet cutting machine and requires 10m^2 more space than the existing machine. Because the only space requirement that changes for the new water jet cutting machine is the net floor space, there is no detailed calculation done for this machine. Since, the existing machine is already in the existing layout, only the difference of 10m^2 needs to be considered.

Table 5: Calculation of the required floor space.

	CNC Press Brake	Deburring Machine	Coating System
Net Floor Space	$7.8m^2$	$4.2m^2$	$8.4m^2$
Auxiliary Equipment	$2m^2$	$0.8m^2$	$9.6m^2$
WIP Buffer	-	$2.4m^2$	$2.4m^2$
Working Space	$11.4m^2$	$17.8m^2$	$8.0m^2$
Maintenance Space	$5.2m^2$	Work Sp.	Aux. Equ.
Gross Floor Space	**$26.6m^2$**	**$25.2m^2$**	**$28.4m^2$**

In Table 6 the total required floor space is calculated. All the additional required spaces are considered in this calculation. As mentioned already the water jet cutting machine only accounts for $10m^2$. That is the difference between the existing machine and the new one.

Table 6: Calculation of the total required floor space.

Buffering Space	$52.9m^2$
CNC Press Brake	$26.6m^2$
Deburring Machine	$25.2m^2$
Coating System	$28.4m^2$
Water Jet Cutting Machine	$10m^2$
Total Required Floor Space	**$143.1m^2$**

4.2.2 Manufacturing Situation

Because there are additional spaces required at the IFT shop floor that are currently not available, the current manufacturing situation is analyzed in this section. There are evaluations concerning the shop floor space, productivity and product mix integration. The results of these evaluations are used as basis for the assessment of the manufacturing technologies in the subsequent step. Therefore, the conducted analyses provide the necessary objectiveness. The assessment allows an estimation of the importance of the different production units for IFT. Consequently, production units are selected to be performed outside the IFT shop floor. This measure provides enough space for the additionally required equipment and buffering spaces at IFT.

4.2.2.1 Space Analysis

For the space analysis CAD construction plans and layout charts are used as a basis (section 3.3.2). Figure 34 shows the results of the space analysis. The different colors show the different purpose of the areas. The production spaces are divided once more into logistics areas necessary for materials handling and production areas indicated by either a P for production or a L for logistics and handling. There are no general buffering spaces available in the IFT layout. Therefore, the WIP is buffered directly at the workstation in the handling and logistics space (L) or in the logistics aisles.

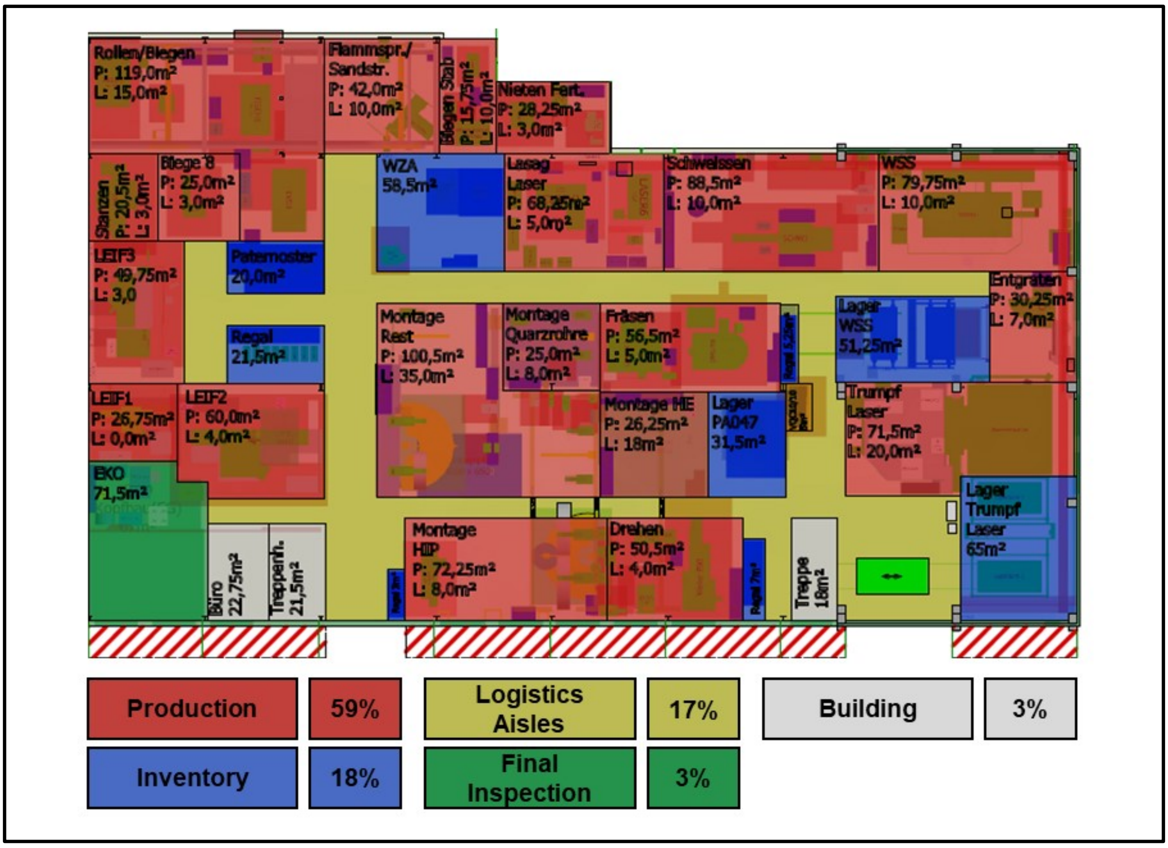

Figure 34: The space analysis.

In contrast to the standard values introduced in Section 3.3.2 the logistics aisle space is relatively low. As already mentioned, the used literature does not distinguish between the different manufacturing strategies. Therefore, those values can only be a rough guideline. The standard value ranges between 20% and 28% including dock areas. The logistics aisle space in this analysis only accounts for 17% including dock areas.

As already mentioned, the production space is split once more into net production area (P) and materials handling area (L). The materials handling area accounts for 15% of the production area. This raises the total logistics space including materials handling at the workstation and aisle space to 26% of the total manufacturing floor space.

The inventory area accounting for 18% of the total space, ranges between the standard values of 10% and 20%. This storage area also includes the red hatched area in front of the building. There are no finished goods stored at IFT. The storage units mainly store components, semi-finished goods (especially sheet metal), tools, jigs and fixtures.

The space analysis shows that logistics aisle space is scarce. The situation is even deteriorated by storing WIP in logistics aisles. The space for inventory is within the standard values. For those reasons the production space should be reviewed in greater detail. This type of space accounts for the largest part and the remaining spaces are either to low or within the standard values.

4.2.2.2 Productivity of Production Units

After reviewing the shop floor areas according to their function (e.g. production, logistics, inventory), especially the production space should be analyzed in greater detail. The analysis is based on the working hours form the PDA in the ERP system and the gross floor space of the particular production units. The gross floor space includes the net production space and all necessary areas to operate the production unit (Section 3.3.2).

The productivity analysis in Figure 35 shows the normalized rating of the production units. This rating results from dividing the gross floor space by the working hours spent on the particular production unit in the year 2016. This measure has been chosen as the productivity of the specific unit. It should be an indicator for how much they contribute to products produced by IFT and therefore how important the production units are for IFT.

According to this analysis some production units show a relatively low performance. Especially the stamping unit with a value of 0.08 and the metal spinning units with ratings between 0.12 and 0.2. Additionally, the rating of the production unit welding, with a value of 0.19, is low.

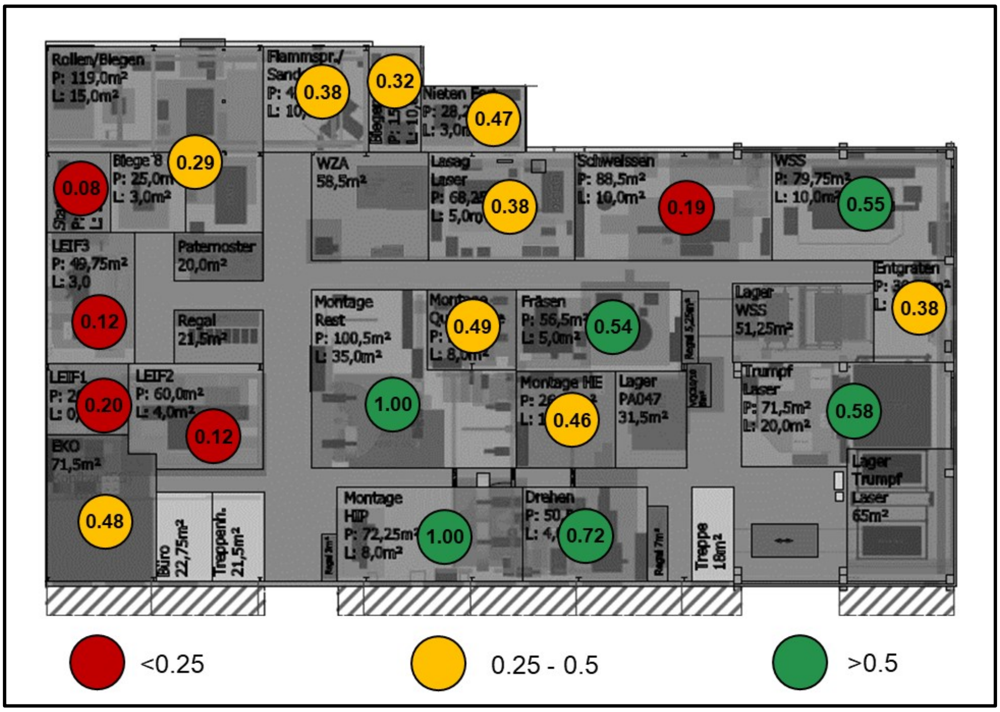

Figure 35: Productivity analysis of the IFT production units.

Due to the productivity analysis of the shop floor space the production units stamping, metal spinning, welding and precision laser should be reviewed in greater detail. The precision laser is reviewed because of a low integration into the IFT product spectrum according to the shop floor personnel and the shift leaders.

4.2.2.3 Product Mix Integration

The production technologies found in the previous analysis are further evaluated concerning their contribution to IFT core products. Therefore, a volume-variety analysis is conducted first, to determine the core products at IFT. For the volume-variety analysis the PDA data of the year 2016 is used once more. Using the data, the hours spent on the specific product groups at IFT are determined. The 14 product groups illustrated in Figure 36 together account for 80% of the annual working hours spent at IFT. The core products described in Section 1.2 rank beyond the top 5 products. Shieldings and heating elements are the main subassemblies for the product hot zone (Section 1.2.1). This analysis provides an insight which products are most important for IFT. This information is a precondition for the analysis of the integration of the production units into the IFT product mix.

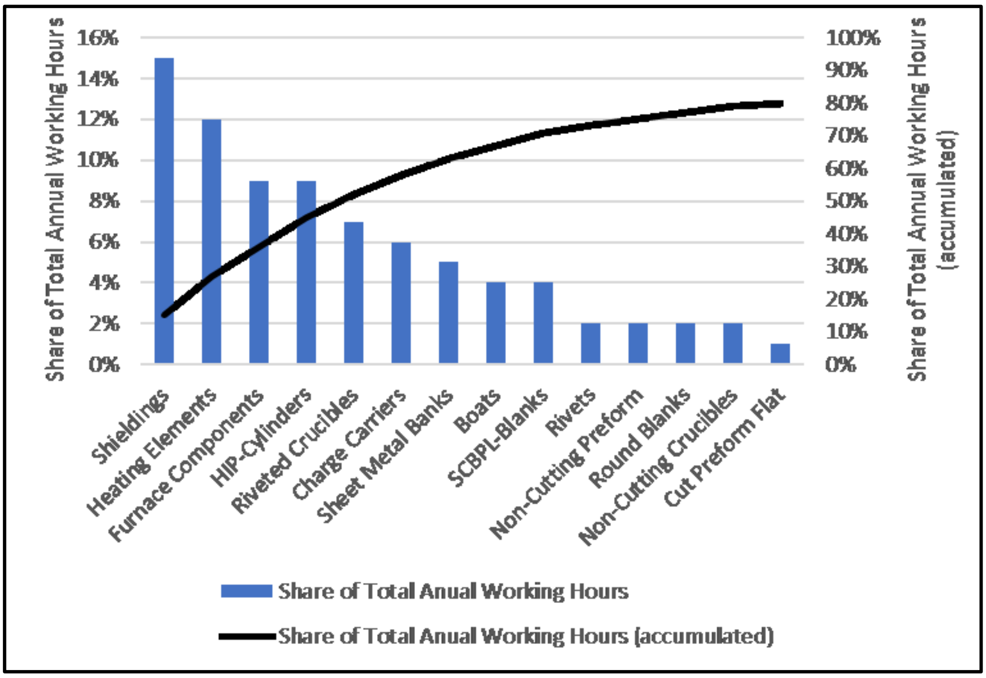

Figure 36: The volume-variety analysis.

Building on the volume-variety analysis, Table 7 shows the analysis of the product mix integration of the production units found in Section 4.2.2.2. The analysis shows much time the specific production units contribute to the product groups selected in the volume-variety analysis. More specifically the working hours of the different production units from the PDA in the year of 2016 have been analyzed regarding their contribution to the different IFT product families. Additionally, the importance of the specific product group is indicated in the column 'Share', using the shares of the previously conducted volume variety analysis.

The working hours are expressed as share of total working hours of a single workstation working two shifts per year. That improves the readability of the table. The hours of two shifts per year are chosen since IFT works in two shifts.

Table 7: Analysis of product mix integration.

	Share	Stamping	Metal Spinning	Welding	Precision Laser
Shieldings	**15%**	4%	-	-	1%
Heating Elements	**12%**	-	-	14%	-
Furnace Components	**9%**	-	-	12%	2%
HIP-Cylinders	**9%**	-	4%	-	-
Riveted Crucibles	**7%**	-	-	-	-
Charge Carriers	**6%**	-	-	-	-
Sheet Metal Banks	**5%**	-	-	-	1%
Boats	**4%**	-	-	8%	-
SCBPL-Blanks	**4%**	-	-	-	-
Rivets	**2%**	-	-	-	-
Non-Cutting Preform	**2%**	-	22%	-	6%
Round Blanks	**2%**	-	-	-	35%
Non-Cutting Crucibles	**2%**	-	24%	-	2%
Cut Preform Flat	**1%**	-	-	-	11%

The analysis in Table 7 clearly shows that the production unit stamping has a very low integration into the product mix manufactured at IFT. Metal spinning contributes only minor to the production of HIP-cylinders (4%). The main contribution of the metal spinning process can be seen for products ranging in the volume-variety analysis at 2% respectively. The welding process overall shows only little integration. But, welding contributes to IFT core products, namely heating elements and furnace components. The precision laser has a low integration with IFT core products but shows notable contribution to product groups at around 2% in the volume-variety analysis.

Since some of the production units need to leave the IFT shop floor to provide additional space, this analysis provided insight into the importance of the concerned production units. The knowledge about the importance of the specific production units for IFT product groups is utilized in the next steps, for the definition of alternatives and the assessment of those alternatives.

4.2.2.4 Definition of Alternatives

Knowing about the manufacturing situation at IFT from the previous evaluations, packages are defined with technologies to leave the IFT manufacturing facility. For those technologies another facility inside the Plansee SE plant in Reutte should be found. The different packages are listed in Table 8. Due to the neglectable working hours of the production unit stamping and the weak integration of the metal spinning process into the IFT manufacturing process, those two technologies are combined to 'Package 1'. This alternative is out of question. That is why all the remaining alternatives contain this scenario.

Table 8: Alternative packages for the weighted factor analysis.

Alternative	Space	Production Units
Package 1	167m^2	Stamping, Metal Spinning
Package 1&2	265m^2	Stamping, Metal Spinning, Welding
Package 1&3	240m^2	Stamping, Metal Spinning, Precision Laser
Package 1&4	605m^2	Stamping, Metal Spinning, all Cutting Technologies incl. Storages & Deburring

4.2.2.5 Assessment of Production Technologies

Based on the previously conducted evaluations the results now are used in a weighted factor analysis (section 3.3.2). The weighting and rating of the factors have been done by the IFT management personnel including the head of the production line, two production supervisors and two shift leaders. For the analysis four factors are being used. Those are the gained space, flexibility, efficiency and the included risk. The factors will be explained in greater detail in the next paragraphs. In addition, an insight into the driving reasons is given. For the weighted factor analysis in this section, the procedure introduced in Section 3.3.2 is used.

The gained space is the first factor, meaning the additional space available for production equipment. The weight of this factor is 35%. This results on one hand from the requirement to gain space, which is why all the analyses have been conducted. On the other hand, all the alternatives provide sufficient space for the additional machinery and buffer. Although, preferably more space than necessary is gained to meet future demands.

The second factor is the flexibility of the IFT production line. The more technologies are directly at the IFT facility the more flexible is the production line. This factor has been influenced by recent experiences of the IFT personnel regarding flexibility. Due to current difficulties caused by recently transferred production units, the weight of this factor is relatively high. Additionally, this factor also affects the lead time. Performing the operations inside the production line is less time consuming than performing operations externally. Performing operations inevitably involves transport and wait times. Since the reduction of lead time is the main target of this thesis, this is another reason why this factor is rated relatively high.
The third factor is the efficiency. This factor describes the increased effort in inbound and outbound logistics due to the absence of the production units from IFT. The efficiency contains the necessary coordination between the production sites. The efficiency addresses the monetary aspects of running the operations in a facility other than IFT. The weight of 17% results from concerns about higher production costs while accepting higher costs for the reduction of lead time due to additional machines and buffer spaces.

The last factor considers the realization effort and risk. That means the estimated costs for transferring the production unit and the availability during the repositioning process. The weight of this factor is the lowest of all factors. This is because IFT wants to improve the operations in the long run and the risk and costs are only occurring once.

The rating concerning the capacity gain has been done using the areas gained through removing the different production units from the IFT facility. The more additional space available the better the rating of the alternative.

For the rating of the alternatives regarding flexibility, the number and kind of transferred technologies has been decisive. For example, the alternative involving all cutting technologies has been rated very low due to the fear of greater dependency on third parties.

The rating of the efficiency is based on the product mix integration. Since both, 'P1' and 'P 1&2' contribute only little to IFT core products the ratings of those alternatives are the highest.

The rating of the realization effort and risk is very similar for 'P1', 'P 1&2' 'P 1&3'. This is because those production units are similar in size and effort to transfer. 'P 1&4' in turn, involves all the cutting technologies including the laser, water jet cutting machine and associated sheet metal storage units. This alternative involves significantly more risk and is therefore also rated very low.

Table 9: The weighted factor analysis.

		Rating				Weighted Rating			
Criteria	**Weight**	**P 1**	**P 1&2**	**P 1&3**	**P 1&4**	**P 1**	**P 1&2**	**P 1&3**	**P 1&4**
Capacity Gain (Space)	**35%**	3.0	4.5	3.9	8.5	**1.0**	**1.6**	**1.4**	**3.0**
Flexibility	**42%**	9.8	8.5	7.0	2.0	**4.1**	**3.5**	**2.9**	**0.8**
Efficiency	**17%**	10.0	9.0	8.0	3.0	**1.7**	**1.5**	**1.3**	**0.5**
Realization Effort/Risk	**7%**	6.0	5.8	5.8	1.0	**0.4**	**0.4**	**0.4**	**0.1**
					Result	**7.2**	**7.0**	**6.0**	**4.4**

The variants 'P 1' and 'P 1&2' score significantly better than the remaining options. Therefore, 'P 1' is selected for implementation at IFT. That means the production units stamping and metal spinning are removed from the shop floor at IFT. Because the variant 'P 1&2' did not score much worse than 'Package 1' this variant can be implemented if the need for more space arises in the future.

4.2.2.6 Improved Shop Floor Situation

After assessment and selection of the technologies to be performed outside IFT a new layout is designed using the newly available spaces. Since alternative 'P1' has been selected in the previously conducted weighted factor analysis, the metal spinning and stamping production units have been removed from the IFT shop floor. Figure 37 shows the new layout.

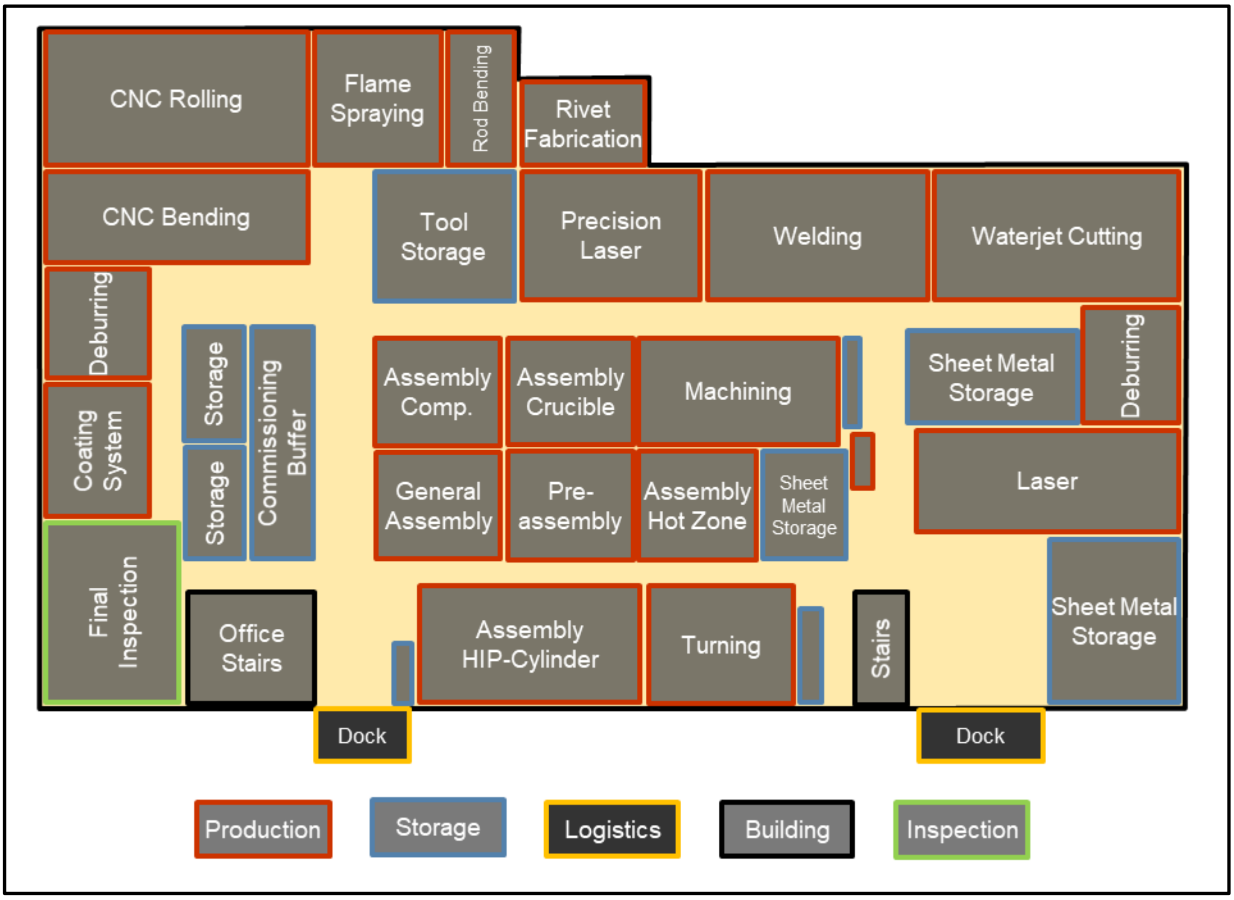

Figure 37: The improved manufacturing situation at IFT.

To prevent major changes the 10m² additionally required space for the substitution of the water jet cutting machine can be taken from the welding space. Due to the low utilization found in the analysis in Section 4.2.2.2 this is not a problem.

The additional CNC press brake fits at the former space of the stamping machine. The position perfectly fits since the current bending machine is adjacent to this position. Therefore, sharing of personnel, tools and equipment (e.g. welding torch) is enabled. The space of the metal spinning production units can be used for the coating system, the additional deburring machine and the commissioning buffer. The deburring machine is placed close to the main logistics aisle. That is because the production orders for this machine are usually small and frequent. Therefore, the material flow is important and a decisive factor. The coating system usually serves a low number of production orders with long processing times. For this reason, the access to the main aisle is of minor importance for the coating system. The existing storage units for components need to be rearranged. Regarding the commissioning of components, the position of the storage units next to the buffer is important. Because of the high interaction between the commissioning buffer and the component storage proximity is required. Therefore, the storage units are positioned adjacent to the commissioning buffer.

To enable learning curve effects (Section 3.3.1) the general assembly production unit is split into three different, dedicated production units. The same is true for the production unit rolling/bending. This unit is also split into two separate production units with the arrival of the new press brake. The only drawback of this solution is the necessary split of the two deburring machines.

4.2.3 Sourcing Process

Since, according to the problem analysis in Section 2.2, 40% of the supplied support structures do not meet the quality standards of Plansee SE, the sourcing process needs to be improved. The first step to improve the sourcing process of the support structures is to conduct the final inspection at the manufacturing site of the supplier. That does not shorten the lead time for the 60% of the support structures that meet the quality demands but improves the situation for the remaining 40% of the cases. Performing the final inspection prior delivery should also train the suppliers to deliver better quality themselves. This short-term action can be implemented immediately.

As a long-term solution, blanket orders can be issued to selected suppliers. Such blanket orders are long-term contracts and generally improve the bond between customer and supplier. Doing so, the lead times for the sourcing process of the support structures should be reduced. There is an alternative option, if the anticipated lead time reduction of the supplier cannot be achieved. In this case, the establishment of internal fabrication abilities should be reviewed.

5 Reflection

This thesis deals with the whole order fulfillment process from the proposal and order acquisition process to the manufacturing and delivery process. That holistic approach highlights one prevailing requirement in the whole order fulfillment process, namely the requirement for a higher degree of information and data integrity. Starting from the sales process downstream, information increases the productivity and predictability of all processes.

The literature review concerning the product configuration provided good insight into the topic. Especially the described challenges helped to avoid common pitfalls. Unfortunately, no standard modeling language for this field has been found. Due to that, the model in this thesis uses a combination of different modeling languages using standard UML expressions. Also, the terminology in different scientific papers differs. Although the main ideas found in literature are matching.

Due to the recommendations in the literature to reduce the scope in the beginning of configuration projects, the configuration has been implemented for the 'Vertical Side Shielding' only. That is a rather complicated sub-assembly of the product hot zone. The implementation of this example has been chosen to demonstrate the capabilities and benefits of product configuration. This configuration additionally serves as a template for the further integration of more assemblies into the configuration system.

In the field of manufacturing organization there is a lot of literature available for planning of manufacturing layouts and facilities. This literature has been adopted for selecting suitable processes that can be performed outside the IFT shop floor. Such an approach has been necessary, because no literature has been found for the assessment of production units.

The new layout at IFT is tuned to shorter lead times and provides space for the additional equipment required at IFT. The alternatives assessed in the weighted factor analysis also provide a plan if there is another shortage of space on the IFT shop floor in future. In this case the alternative 'P 1&2' can be implemented, which additionally contains the welding production unit. Therefore, the layout plans at IFT are robust and fit for the future.

6 Conclusion and Outlook

The current section summarizes the results of this thesis and highlights the next steps to further improve the processes concerning the order fulfillment process at Plansee SE, especially IFT. First, the upstream processes using the configuration system are discussed. Subsequently, the changes in the manufacturing organization are elaborated. Finally, a conclusion including both topics is drawn.

6.1 Market Oriented Product Configuration

Until now, the only subject for the product configuration has been the 'Vertical Side Shielding' of the product hot zone. To restrict the scope to one sub-assembly only has been necessary to enable fast project progress and establish a template for similar products. This increases the probability of success and proliferation of the configuration concept (Section 3.2.2.6).

The next step is to standardize the generation of production drawings and to develop standard text blocks for the generation of proposals. Those two tasks are tedious and repetitive. A standardization would justify more detailed documents because of the automation.

Another opportunity to improve the proposal and increase the customer service is to calculate the delivery date. This improves the accuracy of the proposed delivery date by far. Currently, the lead time is estimated by the product managers based on experience. With the configuration system the calculation of the delivery date can be done using the estimated lead time form the production routings. The estimated lead time is determined on basis of the production routings and the BOM in combination with the scheduled idle capacities from the ERP system. This data driven approach allows more accurate estimations.

After the complete implementation of the configuration system for the side shielding the process should be reviewed and tested. The intention behind was to highlight possible improvements for the proliferation of the configuration system for more sub-assemblies and products. Additionally, the proliferation of the configuration system should increase the use of standard components.

Furthermore, the purpose of the product configuration project has been to free up time, design engineers can use to focus on the product design. This time can be used pursuing other ideas found in the literature review, like the improvement of the manufacturability of the products and developing modular components supporting the configuration idea.

6.2 Manufacturing Organization

The new buffering and commissioning space should improve the manufacturing situation at IFT. The pre-commissioned material carts reduce the unproductive time of the employees in the assembly processes. This enables them to focus on their assembly tasks and shortens the lead time.

Transferring the stamping and metal spinning production units away from the IFT shop floor enables all necessary machines to fit in the new layout. Anyway, if there are additional machines required in the future there is still the option to transfer the production unit welding as well. This step is required because there is no space left for additional machines in the new layout.

The short-term improvements in the sourcing process of the support structures can shorten the lead times in 40% of the cases. Unfortunately, the lead time reduction cannot be determined in the manufacturing process.

Furthermore, Plansee SE is thinking of consolidating the cutting technologies of the whole plant in Reutte in a cutting center. Such a step would also involve the laser cutting and water jet cutting machines at IFT. Due to this fact, the scenario was part of the weighted-factor analysis.

6.3 Conclusion

Both, the measures concerning the product information management as well as the manufacturing organization are significant for achieving the prevailing goal of shorter lead times. Those measures have been:

Product configuration enabling automation in design, production routing generation and cost calculation. Additionally, the increasing standardization of components provides benefits in the production process.

Creation of additional spaces on the IFT shop floor to fit additionally require equipment and a commissioning buffer. The commissioning buffer allows to leverage the increasing standardization of components.

Improvement of the customer supplier relationship to increase the quality and shorten the lead time of the supplied support structures.

The potential for time savings is much greater than in the upstream processes. This not only originates from the lead time analysis, but the configuration system can be seen as an enabling technology for automation in the upstream processes. Especially the potential for improvement in the generation of sales and manufacturing documents can be exploited.

Additionally, the increasing standardization through the product configuration process improves the efficiency on the shop floor. The increased use of standard components allows a MTS strategy for a higher number of components. This fact postpones the decoupling point and therefore causes a shift towards an ATO strategy for the final product.

The prerequisite for such a shift in the production strategy is provided through the product configuration and the increased buffer spaces on the shop floor.

7 Directories

7.1 Literaturverzeichnis

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8 List of Figures

8.1 List of Tables

8.2 List of Abbreviations

ATO	Assemble-to-Order
B2B	Business-to-business
BOM	Bill of Materials
BTF	Build-to-Forecast
CAD	Computer Aided Design
CSV	Comma-separated values
ERP	Enterprise Resource Planning
ETO	Engineering-to-Order
GUI	Graphical user interface
HIP	Hot Isostatic Pressing
IFT	Industrial Fabrication Thermal Processes, Plansee SE
IPA	Institut für Produktionstechnik und Automatisierung
KPI	Key Performance Indicator
ML	Molybdenum-Lanthanum Oxide
MTO	Make-to-Order
MTS	Make-to-Stock
PDA	Production Data Acquisition
PDF	Portable Document Format
PPC	Production Planning and Control
PVM	Product Variant Master
RFP	Request for Proposal
SE	Societas Europaea
SLP	Systematic Layout Planning
TZM	Titanium-Zirconium-Molybdenum
UML	Unified Modelling Language
VACD	Vertically Aligned Class Diagram
VDI	Verein Deutscher Ingenieure
WIP	Work-in-Process