MSc Program
Engineering Management

Efficient Production Planning at the Franz Barta GmbH

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
Dr. Ing Thomas Duda

Oliver Valenta, BSc

01425624

Vienna, 12.03.2021

CONTINUING EDUCATION CENTER

Affidavit

I, **OLIVER VALENTA, BSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "EFFICIENT PRODUCTION PLANNING AT THE FRANZ BARTA GMBH", 81 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

Vienna, 12.03.2021

Signature

Abstract

Every manufacturing process has the necessity for an optimal production schedule. The scheduling though depends on a diverse range of internal and external parameters. These have to be defined and optimised to best queue orders accordingly. In this thesis the planning process of a transfer producing company, the Franz Barta Gmbh, is analysed and optimisations implemented, to reduce the required know-how and time needed to conduct the process. Due to pending retirements, in the planning division, the threat of losing knowledge and hence not being able to efficiently schedule grows.

Methods used to simulate the influencing factors are analysed if suited to aid the process. Generally, the more precise and accurate methods are the better they incorporate all influences, terminating in complex models. Due to the high interdependencies of the different parameters at the company the digitally visualisation approach was chosen to reach the goal. Consequentially, the different workstations needed to have a thorough information flow implemented and where analysed and adapted according to the Lean and JIT philosophy. All resulting in reduced planning times, through distributing responsibilities and tasks to the separate division.

Table of Content

1 INTRODUCTION

This master thesis was executed in collaboration with the Franz Barta Gmbh. The company is specialised in producing transfers in screen printing and operates for more than 70 years in the field branding and labelling of different materials. In the area it is considered as the quality leader and the company which provides products to decorate difficult materials. It established its name and reputation with suppling first class service and a huge flexibility towards the customer. Further the company adapted to a wide range of customers, each requiring different procedure and products.

The thesis was conducted to help establish a new and more efficient planning process. At the moment the planning is dependent on two employees, the lead planner who has work experience, at the company, of 42 years and the deputy with another 39 years. The lead planner started in the printing department, than grew into the pre-printing process, and finally ended in the planning division. In this journey a lot of knowledge and experience was build up. This is now incorporated into all decisions and plans. The second member is the deputy planner who also advanced from the shop floor. Both operators will retire within the next five years. The skills and experience required to carry out the process at the moment, are not present with any other employee. Further, the method used is outdated and circuitous. Many tasks can be automated and incorporated into the ERP system[1].

This thesis will therefore, mainly focus on the analysis of the current production planning process. It will evaluated how to change the process with keeping the machinery utilisation high, best plan at shop floor level with reducing external or manual interventions, and visualise the production plan. All this should benefit the new planning staff, modernise the process, and make it more efficient. Ultimately, the goal of this work is to develop a process by which the planning can be done to the same quality, however more process stable and faster, by any ordinary skilled worker. Therefore, the process has to be broken down and some tasks have to be incorporated into different departments. With this method, it is not necessary for the members in the planning division to hold all knowledge. The workflow has to be digitalised to enable different division working on the scheduling at the same time.

[1] ERP – Enterprise Resource Planning systems are used to manage and automate all kinds of enterprise processes (Scheer & Habermann, 2000)

Further, responsibilities have to be divided so that the planning at the shop floor level regulates itself. For this purpose, every workplace needs a specially design work cockpit to have all essential information available in a visualised and responsive manner.

The new process will be monitored to evaluate the performance. To assess the changes and especially the efficiency a new PI[2] for the process has to be designed and implemented. The existing KPI[3] and PI's of the process stay untouched, so that the changes can be controlled and it can be verified that the planning quality stays high.

Picture 1 Logo of the collaboration company

[2] PI – Performance Indicator of a process to better analyse process performance (Biedermann, 2016)

[3] KPI – Key Performance Indicator of a process defined by efficiency and effectiveness (Biedermann, 2016)

2 BACKGROUND

2.1 Products

To understand production planning at Barta and why the process has such a complex structure, it is vital to first look at the product portfolio. In the following passages the product portfolio will be investigated with regards to the delivery form, the different products, and the artwork.

First, it is essential to know how the product is build up. The sold label consists of a carrier which is either coated paper or foil. The carrier is important for the later application process and is crucial for the appearance. After the application the carrier is removed from the printed film and releases the transfer (label). Depending on the carrier the label can be applied with heat, with pressure, or with solvents. Further, it is responsible for the degree of gloss or if the label is reflective. Onto the carrier, layer for layer of the product is printed. Depending on the layers and in which sequence printed, the products will have different attributes.

The amount of layers each artwork product mutation is made of depends on the product, the different colours of the artwork, and the motive. Generally, the first printed layer of the product is a clear lacquer which protects the printed motive. The second layer can either be another clear lacquer or the first colour depending on the product. The following layers are the different colours of the artwork. Since the printed colours are very thin and quite translucent an opaque white layer is printed on top. The white layer is needed so that the colours do not change when applied onto a dark or coloured material. Different products have special layers either before or after the white. The last layer is subsequently the adhesive. Some products have two adhesive layers.

All together the product portfolio holds 60 product variations, each with unique characteristics. Further, the company offers two ways of delivery either in reels or as separate cut labels (single cut), this depends on the application process of the customer and the product. All products can be delivered in single cut but not all in reel. Single and reel cut items can be printed in one batch, but have different post printing processes.

Before an order is placed the customer material is sampled to find the product best fitting to the requirements. After the internal and/ or external trials a product is chosen. Depending on the product the required artwork is reworked so that it can be produced. To make it clear: A customer does not buy or order a standard product, each product has to be customized. The acquisition is the customer's artwork as one of the 60 products.

Those 60 products can be grouped into around ten sub groups, depending on the carrier, adhesive, and technology used. At the moment eight different carriers are in use at Barta. The adhesive is split into two groups, one which requires a protective paper due to tackiness and one which does not need the protective paper since it is dry after printing. Lastly the technology of the product is also a dividing factor, since different chemicals need different handling, printing, and drying. Technology means the used chemistry. Some products are air dried, others heat dried, and others need UV light.

In total, there are more than 65 000 active customer items available at Barta. Since the product, the artwork is delivered in, may vary depending on the material the customer wants to apply the label on, it is possible that the same artwork is available in up to ten different product variations. Further, the form of delivery may be varying for the different production facilities of a customer. Each customer item is therefore a distinct combination of artwork, product and delivery form.

Some of the products further have different special attributes, which have to be incorporated into the planning. Those attributes range from special drying times to the necessity of finishing the print in a specific time period. The drying times, or the so called resting times, can vary from sixteen to forty-eight hours. During this time a polymerisation of some of the layers take place. If the layers would not have the time to fully crosslink before being further printed on, some product properties change. Other products have to be finished within a specific time period of sixteen hours, so that the layers do not fully dry out before being further printed on. If some layers are too dry during over printing they create wrinkles in the label which leads to visible defects. Further, some products are only able to be produced on one machine type. In chapter “2.3 Production” the different printing machine types are outlined and it is discussed why some products cannot be printed.

Overall, it can be concluded that every item sold at Barta is a customer specific piece. In the planning department those items are subsequently clustered by product, product groups, and further by colour. Why colour is so important for the planning department is explained in more detail in the chapter “2.3 Production” in the section Lithography and Printing.

2.2 Customers and Requirements

Customers of Franz Barta are separated in 4 segments; automotive, sports and outdoor, health care and industrial apps. The automotive sector is the most significant segment whereas sports and outdoor the least. Figure 1 shows the percentile distribution according to revenue.

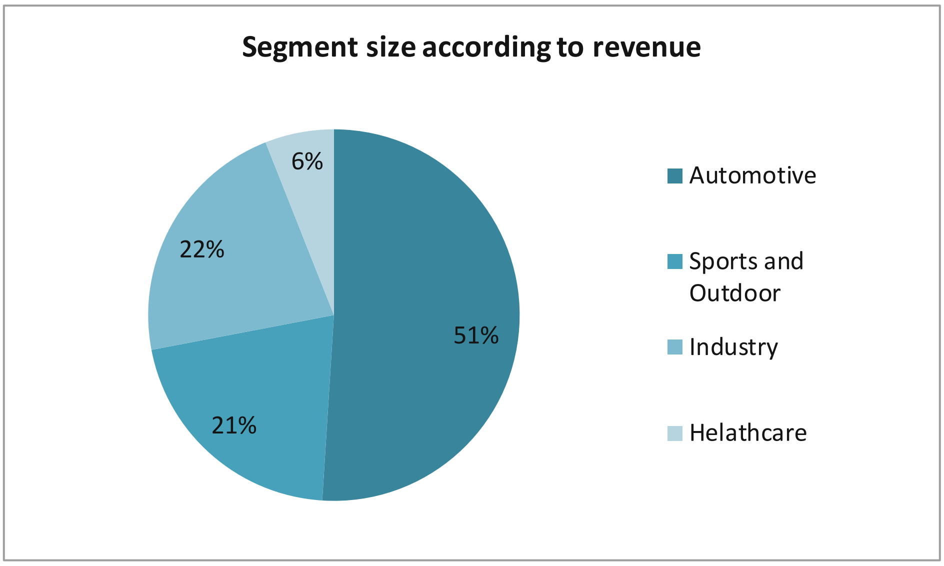


Figure 1 Segment size according to revenue

Each customer group has totally different ordering procedures and requirements which creates the necessity for a flexible planning process. To analyse the difference, requirements are broken down into: Demand- order quantity, lead time between order and delivery, artwork mutations, and amount of different items ordered. The demand quantity at Barta is divided into three shades; small orders (1 000 - 10 000 pieces), medium sized orders (10 000 – 50 000 pieces), and large/ bulk orders of >50 000 pieces. The standard delivery time of orders is four to six weeks.

The most important information when an order is placed is the required quantity per artwork. Generally, Barta only supplies quantities starting at 1 000 piece per order per artwork product mutation. However, sometimes a customer has a master agreement where an order of, say, 6 000 pieces in total is placed and called off as 500 pieces per month. Setting the minimum order quantity to 1 000 pieces per artwork, has to do with the way of production at the company. Why the minimum order quantity is set to 1 000 pieces is discussed in the production subchapter. Following, portrays the differences in the above stated fragments according to customer segment.

Automotive

When analysing the customer segments in regard to the demands and artworks, it can be seen that the automotive industry requires large amounts of the same artwork. For example, one of the produced artworks, for the automotive industry, is an airbag warning label, which is fitted on the passenger seats sun visor. Each car has one on the outside and one on the inside of the sun visor, adding up to the total of two exactly the same label per vehicle.

Furthermore, due to logistical and cost reasons, the OEMs[4] and Tiers[5] would like to receive only one artwork product mutation for different models and regions. For this reason, many labels have been converted into the same pictogram so that they can be used in different countries, thus reducing the amount of different graphics. All this leads to a need for a large amount, of the same artwork product mutation. In addition the automotive industry also forecasts the demand and call of orders at the start of a project. With this information a frame contract is negotiated, which enables the planning department to create a yearly production plan. Lead times therefore are very short since the call orders can be supplied from stock.

All contracts have a runtime of more than one year and are mostly linked to specific model series in a particular region. Since, some orders can be bombined, synergies are created and most production surplus can be sold even after the respective order has expired. The following is an example of how such synergies are used to sell production surplus. A tier in Europe orders an airbag label (pictogram) for a specific model series which is build and will be sold in Germany. The contract is set for three years and it is targeted to 500 000 pieces. After all production runs in total 600 000 pieces where produced and therefore there are still 100 000 pieces on stock. Since the same label is also supplied to a tier in the US who produces a different model series of the same OEM, those labels can be used to supply this demand.

Sports and Outdoor

The sports and outdoor segment includes the sport fashion, sport equipment, and general fashion industries. In comparison, to the automotive industry the sports and outdoor segment works completely different. Firstly, the apparel industry only knows the required demand of the labels after presenting the new product line at fairs or sales calls. This happens twice a year, in the first quarter the winter collection of this

[4] OEM - Original Equipment Manufacturer mostly referred to as the actual car manufacturer (Lambert & Kareta, 2021)

[5] Tiers are referred to as suppliers in the OEM Supply Chain. Tier 1 are the first suppliers, Tier 2 the second and so on. (Lambert & Kareta, 2021)

year is presented and in fall the summer collection of the following year. After those events the stores are provided time to order. Only after receiving the amounts which the retailers require the purchase is place at the suppliers. Leaving the supplier with a short lead time to produce and send the products. Continuing the first demands are tiny quantities of 20 – 100 pieces, to produce the collection samples which are presented at the fairs and sales calls. This trend is also increasingly observed in the sport equipment industry, especially in the bike segment with yearly new equipment presentations.

In the fashion segment it is besides common to have a variety of artworks and divers materials which all require different products. For instance a brand orders back neck labels for five different garments which each require a different product. This would mean one artwork for the each of the seven sizes XXS, XS, S, M, L, XL, and XXL and that for each of the five products is needed. In total, this would add up to thirty five artwork and product mutations.

On top of that the sizes, colours, and demands of each of the artworks differ. The indicated complicates the planning and sheet setting further. In total, the order value is significant but when breaking it down into the mutations some create more expenses than generating revenue. Taking out and analysing the XXL mutation for an outdoor sports raining jacket this may have a demand of as less as fifty pieces.

Since, the collections are changed twice a year, it is dangerous to build up stock. All transfers kept on stock will only be valid until the next collection when new mutations are ordered. Often observed the fashion industry places an order and notices that the sale of specific apparel is better than expected. To meet the demand, a reorder is placed, but it must be delivered within one to two weeks.

Industry

The industry segment consists of all customers which create products for industrial or heavy duty work. It contains clients which produce working equipment such as axes, chainsaws, and knives. But also manufacturers of machineries like tractor or drilling equipment. Coincidently this segment also includes working apparel producers and retailer especially for footwear. Other than it may be expected the working apparel customers have entirely different requirements than the fashion and sporting industry. This segment holds also a lot of smaller retailers of the industrial equipment. In total it is the division holding the most customers.

First of all, when looking at the general requirements and ordering behaviour of this segment, it is recognisable that most industrial customers have fixed product lines that are on the market for a few years in a row. Therefore there is a valid forecast relying on the past years and a long term production plan. Unfortunately most of the customers in this segment refuse signing a frame contract. Nevertheless the regular order behaviour and forecast generates the possibility to produce a batch sizes best fitting into the production schedule.

This conclusion can be underlined with the example of a working equipment supplier, who produces amongst other things axes, shovels, and picks. Most products are branded on the shaft with the logo. All shafts are made from the same material and therefore require just one product. The logo is the same on all of the different equipment and only varies in three different sizes. Altogether only five different artworks are ordered in one product form. These mutations only vary in size but have the same colour and layout. The same amount is ordered quarterly, which causes the situation that the lead times can be kept short and the best lot size can be produced.

The way the working apparel producers require the transfers is as follows. Each wearable is attached with one transfer, this means with the same product and a distinct artwork for each different wearable (one for the shoes, one for the shirts, one for the jackets, etc.). The particular specification is that transfers must be conspicuous just before or just after application (either laser or pen), as each wearable requires specific data that is not known until after or just before the transfer is applied to the wearable. This data may contain size, colour, or might go as far as engraving the name of the company or person using the wearable. This technique makes it possible to keep the artwork mutations low. Since most wearables are made of strong absorbent fabrics which have the necessity of a lot of adhesive, this favours one product type for all the different wearables.

One special customer group, inside the industrial segment, orders inspection stickers which are attached onto some equipment as a seal and/or as information about the last check. The transfers are used for instance as inspection stickers for fire extinguishers, which reveal the year and date of inspection and seal the security splint. This group again requires a fixed yearly amount and have regular call off orders. Since the transfers can only be used in one year it is necessary to have no surplus production since those transfers can only be used in a specific time range.

Altogether this group has smaller to medium sized orders between 2 000 and 15 000 pieces.

Health Care

The Health Care segment comprises all customers who manufacture or sell equipment intended for the use in medical therapy. This includes among other manufacturers of bandages, prosthesis, walking aids, and orthopaedic shoes. Members of this segment can be classified into two smaller sub groups. One group demands bulks and the other minor quantities.

The conglomerate, which purchases large quantities, has the characteristic of ordering individual work of art in a product for a variety of goods. These are all medium sized enterprises focused on a specific market and supplying great amounts of the products. These purchasers have low change in layout and content of the requested transfers and therefore have a long run time per mutation. On average an artwork mutation is ordered for five years.

Following the order behaviour for the customers considered in the bulk group is illustrated with a producer of reusable bandages. In the case of this specific client the transfer contains the washing and handling information and is used as the cutting mark of the endless bandage. Bandages are woven endless and winded on reels. After a specific distance one of the Barta transfers is applied and the bandage is cut exactly at this mark. The adhesive of the label is used to keep the cut threads in place and stopping the bandage from unweaving. Those bandages are then supplied to nursing homes, hospitals, and for private use. The bandages can be used around 60 times before having to be replaced. Here there is a highly predictable situation of the demand and therefore the order behaviour is very constant. There is also the willingness for long term ordering contracts.

The second subgroup has the same requirements as the bulk group but only demand considerably small amounts. This unit generally only consists of orthopaedic shoe suppliers. Simply one product is needed and consequently one artwork, but with a mean demand of low as 1 500 pieces per annum. These labels solely contain the name and logo and are applied just before selling the shoes or insoles. Therefore the artworks are not changed often. Orders are irregularly and in small portions. No long term contracts can be negotiated and surplus production often expires before it can be sold. The ordering interval is on average eighteen months. The labels have an expiring date of 24 months after production and are to be sold until 6 months before the expiration date.

Customer Requirements Conclusion

To sum up, this subchapter following the key elements stated in the previous passages. The greatest customer segment (automotive) has a very predictable ordering behaviour and a low number of mutations which favours synergies between projects. The industry segment, which is the second largest, group when ranking in terms of revenue, consists of very many customers which in total are unwilling to sign frame contracts. Nevertheless orders are predictable and surplus production can be mostly sold. The sports and outdoor clients require the opposite of all other customers. The industry requires short lead times, fast changing and very many artwork/ product mutations. Further, forecast are only for a short period and seen from the past, are unsecure which creates unexpected reorders. The health care customers can be split into two subgroups in terms of demand, but overall have a small variety of items and predictable amounts. The surplus production for the orthopaedic shoe manufactures is long on stock and with an uncertainty that it will be sold before reaching the expiration date.

The conclusion that can be drawn from the last paragraph is that the diversity of customers can be divided into four different ordering behaviours. One is very predictable, has low mutations, and has agreed upon quantities. The second is as well predictable but the quantities are not fixed, still there are low mutations and orders are in bulks. The third scenario is the same as the second but the demand is small to medium. The last behaviour is unpredictable therefore short lead times, has many variations and small to large quantities.

2.3 Production

The production is solely performed at the head quarter in the 15th district of Vienna. All other locations are only sale subsidiaries. At the production plant all tools for the printing process are completed, which creates a great in-house production depth. To illustrate the vertical range of manufacture, sixty nine employees work in the operations department of whom only fifteen work in the printing division. The printing division is the only value adding process for the customer in the company.

General Production

The production site has 4 self-build reel to reel screen printing machines, two large format (720 x 475 mm) with each five printing units and two small format (432 x 395 mm) where one has five and the other one three printing units. The units are set in series and can each generally print one layer. One print run contains one sheet arrangement, which is printed a specific number of times, the amount determines the batch size.

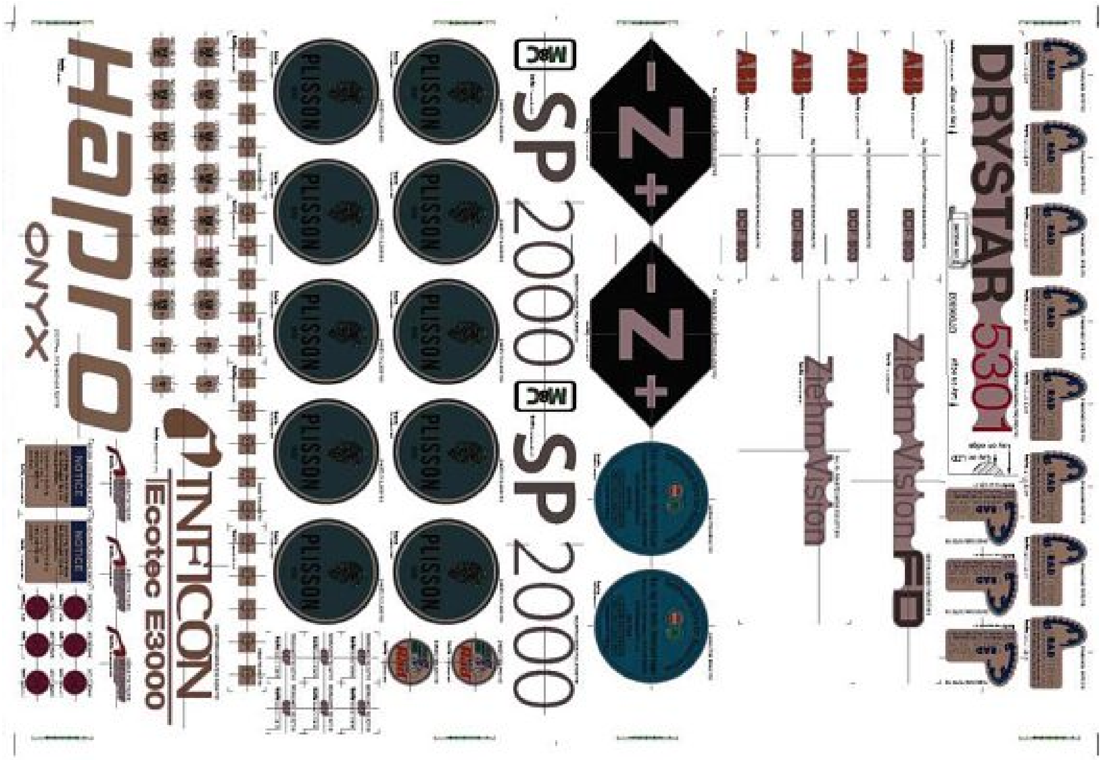
There are two types of printing runs/ batches at the company. One contains only one customer and is referred to as separate run and is used for the production of medium to bulk size orders. The other carries different customers and is referred to as collection run and hence used for small to medium quantity orders. This production type was developed to serve lower quantity orders for a reasonable price.

In separate production runs, in general, there is only one artwork product mutation printed. These batches have between 1000 – 9000 sheets printed. One sheet contains the motive multiple times. On average one sheet in a separate run holds around forty multiples of the artwork. The sheet arrangement is done by the lithography considering the item size, delivery form, product, and some internal specifications of different divisions. Picture 2, illustrates how the sheet arrangement of a separate batch may look.

Picture 2 Graphic of a separate batch sheet arrangement

Orders from different customers are gathered in the collection runs. This leads to the fact that there are a large number of artwork product mutations on one sheet. As stated in the product section, attention has to be paid that only specific artwork product mutations can be printed in the same run. The arrangement underlies the same specifications as the sheet setup of a separate run. In addition there is the needfulness to organize the sheet such, that the artworks with the same colours are next to each other. Furthermore, if same products are placed on the sheet, it is required to set these near to one another. The sheets for these runs contain up to twenty five different items. Some items can be arranged multiple times others only once, always depending on the order quantity. These runs print between 800 – 2 500 sheets.

Why specific orders are placed on one printing sheet and how they are arranged will be discussed in the planning section. Generally, it has to do with the batch size and amount of labels demanded. The goal is to best utilise one sheet to reduce the amount of prints. Following Picture 3, shows how such a previously described collection batch can look.



Picture 3 Graphic of a collection batch sheet arrangement

The printing department works on a two or three shift module depending on the workload and schedule. Conditionally the surrounding processes work on a one or two shift module. If the printing department works the two shift module the surrounding processes work on a one shift. If it works on a three shift the others work a two or three shift module depending on the department.

Process description

As this thesis discusses the planning division at the company all workstations requiring a plan from the division will be portrait. In the following, all the different stations are outlined in regards to the input and output, process steps, and shifts the department works in.

The input is meant to indicate the necessary raw materials and information needed for the process. In addition the output displays the tools and information which are created and handed to the next station. With this depiction the linkage between the different stations will be defined. The process steps are important to discuss, to see how the scheduling can be broken down. This will in addition provide the possibility to identify which tasks are already excluded from the planning department. Furthermore, additional functions should be found which can be integrated into the individual areas.

Figure 2 illustrates the overall production setup with regards to the inputs and outputs of each process. Missing workflow in this visualisation is the screen post treatment, after printing. This is an additional division which maintains the screens and cleans them such that they can be reused as stencils. This process is not scheduled by the planning department and is therefore not included in the analysis.

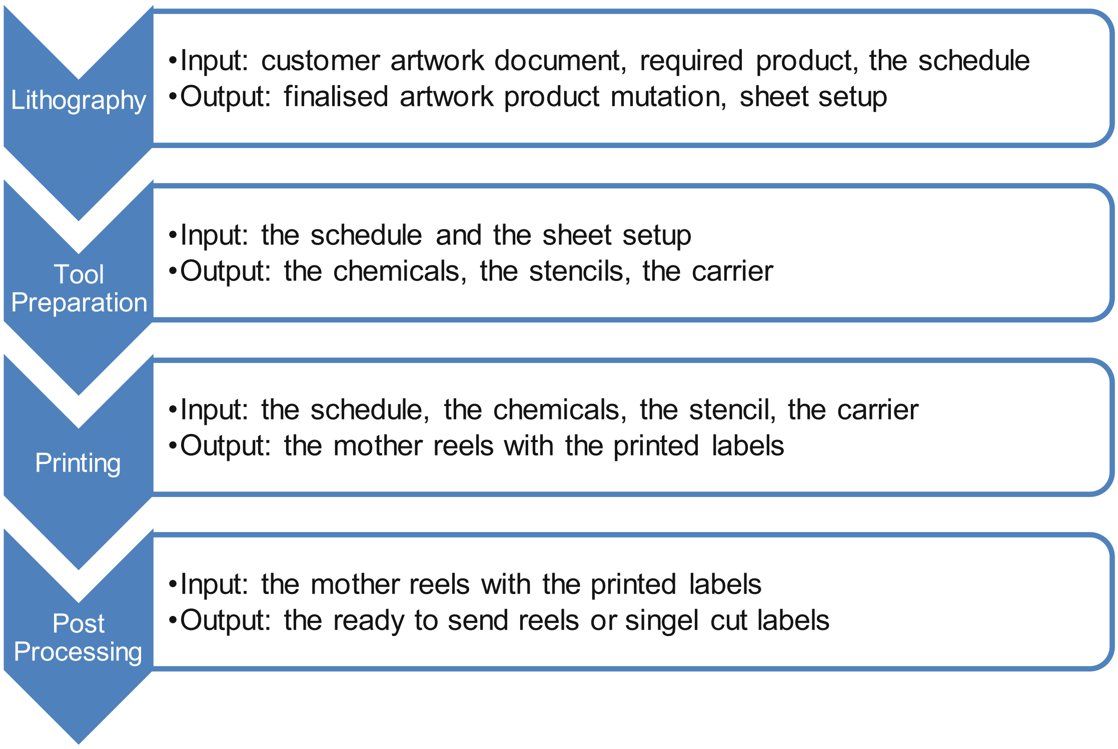


Figure 2 General overview of the production flow in regards to input and output

Demonstrated in figure 2, the process outcomes are the inputs for the following workstations. In order to better identify the process steps of the tool preparation section, this is further divided into the stencil, carrier and chemical production. Moreover, the post processing will be split into the cutting, reel, and single cut processing tasks. In the following section, the different workstations are presented and evaluated based on the four previously mentioned attributes earlier.

Lithography Department

The Lithography department is the first step where the production process starts. The required input, as mentioned in figure 2, is the customer's artwork, the information created during the sampling phase (which product is required), and the scheduling information.

The first step in this process is editing the artwork. If the document supplied by the customer is no vector graphic, it has to be redrawn. After having a vector graphic on hand the artwork is edited, such that it can be produced in screen printing and as the desired product. Some products have limiting traits such as line thickness, element sizes, overall sizes and motive arrangements. When the motive is adapted it is farther split into the different layers of the requested product. Subsequently a proof is created and handed over to the customer for approval of the changes. A proof is the technical drawing for a transfer. It contains all information regarding tolerances, sizes, colours, characteristics and fulfilled standards.

When the customer confirms the sent proof the artwork product mutation is placed on the printing sheet. Having two printing formats there are two printing sheet sizes on which the artwork can be arranged. The information on which format, batch type, and how often the artwork is placed on the printing sheet, is supplied from the planning department. Since the arrangement is one of the main planning topics, it will be further discussed in subchapter "4.3 Printing Sheets". Subsequently speaking, the more different items are placed on one sheet the harder it gets to arrange. The arranged sheet is further divided into the layers. These so called Tiff[6] documents are supplied to the stencil production division.

Figure 3 exemplifies the steps of this process. Farther it ties up the entire outline which was discussed in the previous passages. Typically the department works in a one shift module. The process steps as outlined are not limited by any working equipment, machines or other scenarios. Further the department has no reason to be attendant whilst the printing is done. The sheet layout is delivered to the stencil

[6] Tiff – Tag image File Format is a way to store raster image data so that these can be exchanged between machines (Parson & Rafferty, 1998)

creating division when finalised. Since this department works two weeks ahead the impact on a delay is not noticed in the printing department.

Adapting the artwork	Preparing the artwork for printing	Proofing	Sheet Planning
• **Input:** Artwork • **Task:** If necessary creating a vector grafik and eddditing the artwork • **Output:** Printable motive	• **Input:** Printable motive • **Task:** Adding the product specific layers and splitting it into colour layers • **Output:** exact item layers	• **Input:** Mutation • **Task:** Creating and sending the technical drawing to the customer • **Output:** Customer approval	• **Input:** Schedule and artwork product mutation • **Task:** arrange the items on a sheet • **Output:** Tiffs for the stencil creation

Figure 3 Lithography overview; input, output, the process steps, and who plans the tasks

Stencil Production

The stencil production is the only tool preparation process which is depending on a previous process. Only when received the tiff documents the stencils can be created. This input triggers the workflow of this workstation. Each printed layer requires a separate screen.

In the stencil creation there are also four process steps in which it can be broken down. The first task is the coating of the screen. At the company there are ten different screen types. A screen type is defined by the amounts of strings per centimetre and the thickness of the strings. Depending on which layer is printed, specific screens are used. The impacts the different screens have on the printed layers are the thickness of the layer and its resolution. In this step the screen is coated with a photosensitive emulsion and dried in an oven.

In the second stage the coated screen receives the motives by exposing it to light. A special laser draws the previously created tiff onto the coated screen. The emulsion reacts wherever the laser passed. The third step requires putting the screen into a special washout machine. In this machine the screen is rinsed with water pressure. The areas where the emulsion did not react are water soluble and washed off the screen. All coated areas of the screen are impermeable to the layer chemistry. All uncoated areas release the lacquer, colours or varnishes. After these three steps the screen contains the image which it is supposed to print. Lastly it is placed in a drying chamber.

The final step in this process is making the screen ready for printing. It will have to be masked with sticky tape to keep the frame clean during printing. Further the thickness and roughness is measured. Both values indicate if the screen is adequate for printing. Additionally, it is visually controlled for any pinholes. Pinholes are tiny holes which form in the washing process step and have to be covered. (Scheer, 2007) Otherwise there would be unwanted marks on the printing sheet.

The outputs of this process are all screens required for printing the planned batch. Further the department always works a two shift module to best utilise the machinery. Since the laser is the bottle neck in this department the longer it can be run the more stencils can be created. Further there is the possibility of having a problem with the screens during printing. Screens could tear when handled or have a defect which would both require a new screen. This additionally creates situations in which personnel of the screen department need to be attendant. Since there are only two employees in this division the third shift always contains a printing member who can operate the laser and washout machine. The screens are picked up by the printing staff and other than the chemicals not delivered. Figure 4 illustrates and combines the information discussed in this section.

Screen Coating	Laser of Stencil	Washing	Making ready for Printing
• **Input:** Tiffs • **Task:** Coating the screens with photosensitive emulsion • **Output:** Coated screens	• **Input:** coated screens • **Task:** drawing of the tiff with laser onto the coated screen • **Output:** coated and lasered screens	• **Input:** coated and lasered screens • **Task:** removing unreacted emulsion • **Output:** Screen with stencil	• **Input:** screen with stencil • **Task:** applying tape and checking screen and stencil • **Output:** printable screens

Figure 4 Stencil creation overview; input, output, the process steps, and who plans the tasks

Chemical Production

The chemical production is split into two special divisions. One is responsible for the production of the base compositions and named mixing department. This would be the seventeen colours essential for colour tinting, the ten base compositions of which the different lacquers and adhesives are formulated, and the compositions which have a consumption of more than 150 kg per week. Chemicals with the large consumption are the different whites, the standard lacquers, and adhesives. The second part supplies the tinted colours and the two component mixtures which have a usage time of three to eight hours and is named colour department. These mixtures include white, lacquers, adhesives and all colours.

Altogether there are around 150 recipes for mixtures excluding all colours. Since the colour formulas are not incorporated into the ERP system the sum is not detectable. At Barta full tone colours are printed rather than halftone. This was decided so that a greater colour spectrum can be produced. Drawback in this way of production is that each colour is a separate layer. In comparison the halftone CMYK[7] prints consists of only four colours and depending on the spot size, arrangement, and overlapping the different colours are formed. In total the company stores 353 different components, all needed to create the mixtures for the distinct products.

Although the division is split into two different departments the overall process steps and responsibilities are the same. The course of actions is as follows; managing the warehouse, mixing the different compounds, and issuing the required mixtures to the printing machines.

The mixing department is taking care of the chemical raw material warehouse (the 353 components) and the colour department manages the colour depot. Supplying the compounds to the printing machine is done on a shift basis. If the printing department works a two shift module the compounds are delivered at the start of the shift. At the end the leftovers are collected and the new mixtures for the second shift are brought. If a three shift is worked the first shift does the same as in the two shift module. The second shift then collects the mixture at the end of the second shift and delivers the mixtures for the third shift.

The colour mixing division delivers the colours when required. Since these mixtures need to be done short before printing they can only be mixed when needed. The two component compounds would react and hence not be printable. The colours can be mixed ahead but have to be stirred up shortly before being issued. Otherwise the particles may sink to the bottom and the colour tone would change. Therefore the division has to always be available when the printing machines are producing.

Further the colour tinting is not as straight forward as mixing the base compounds or the standard mixtures. These all have formulated recipes which are compounded on a logging scale. This calculates the exact amounts required of each component added to the mixture when entering a desired amount of the compound. When tinting the colours it is a trial and error. There is a backbone of which base colours to mix, than the mixture is printed with a manual screen printing table and measured. This method is repeatedly used to finalise the colour tone. Once a mixture is

[7] CMYK – Cyan Magenta Yellow and Key (Black) the four base colours of which a specific colour spectrum can be formed (Has, 2008)

established it is reported for the next time. Still it has to be controlled and it is likely that it has to be nuanced. It is therefore more complex and time consuming than the production of the standard mixtures.

The last task both sub divisions have is to resolve problems when the chemicals produce difficulties at the machines. These difficulties may be conglomerates in the lacquers, adhesives, or wrong colour tones from the tinted colours. The first issue is rather negligible and happens twice a year. The colour tone variance happens on a regular base. This has to do with fact of the colour tolerances. This specifies that the colour tone can have the value of dE4 CIELAB76[8]. This also underlines the significance of having a representative of the colouring department available at any time when the printing is performed.

Carrier Production

The carrier production is performed on a stock based manner. As mentioned earlier there are eight different carriers, of which three are paper based and the rest foil. The base of the carrier is important to understand the different process steps which each have to undergo. Paper carriers are sensitive to humidity and temperature other than foils which are not.

Therefore the first step when receiving the paper carriers is to acclimatise these. To do so the carriers are transported through a special construction. During the acclimatising phase the paper fibres adapt to the humidity and temperature adjustment in the production facilities of Barta. This process leads to size changes of the carrier. The foils do not change dimension according to the humidity and temperature and therefore do not have to experience this treatment.

The second process task is to cut the carriers to the right format, punch the transportation holes and wind it onto the internal coils. Barta uses vertical coils for transporting reels through the different production stages. This enables a fast manoeuvring and space saving storage. All this is done with a special stamping machine. For the large format there are two punchers and for the small format one. This correlates with the amount of printing machines.

Other than the chemical department the carrier division is not responsible for the raw carrier warehouse management. This task is performed by the purchase and inventory management staff. A soon as the carriers are processed the responsibility

[8] dE stands for Delta E which is a calculated value of how big the colour difference is to the original colour (delta = difference). CIELAB76 stands for the arithmetic calculations used to define the colour difference. (Has, 2008)

is handed to the carrier division. Therefore the department is responsible for the stock of the processed carriers.

Further the carriers are not supplied to the machinery when needed but rather placed in specific areas for the printing staff to collect. The production facility has three printing rooms and each has a special area for the processed carriers. Due to the correlating amount of punching machines the carrier department is not required to work in a shift module. Furthermore no problems can occur which would request the attendance of the carrier department employees.

Printing Production

Eventually the printing process, which is in terms of the costumer, the value adding production step at Barta, is performed. Inputs for this process are all the tools produced in the pre-processing departments. Further there is equipment which the printing staffs prepare ahead of printing. This includes the squeegees which are needed to in the first step fill the open mesh of the screen with colour and in the second step, create contact between the screen and the substrate such that the colour can be released (Scheer, 2007).

As mentioned in the previous sections there are different shift modules performed. This has to do with the availability of the different machineries, the human resources and the ordering situation. In the ideal case the two big format and small format machines could be run each on a three shift module (24h five days a week). Per printing machine a minimum team of three employees is required. At the moment this would mean that there are five printing teams at the company, with no one having a sick leave or holiday. This creates the possibility of running the two big format machines with each a two shift module and further the two small format machines on a one shift, because both are in one room and can be handled by one team. Therefore at the moment in total use of capacity either five shifts can be worked on the big format machinery and nun on the small format. Since there are always orders for the small format the best split is having the big format machines running on each a two shift module and the small machines on a one shift. Further limiting the total use of capacity of the machines is that they require maintenance and repair and therefore sometimes one machine is taken out. In addition the printing staff has to perform side tasks such as fetching the screens/ carriers and preparing the squeegees. This further reduces the available employees per machine. With the current amount of people employed in the printing department the best plans that proved are either working one big format on a three shift and the small on a one shift or one big format on a two shift, the other on a one shift and the small format also on a one shift. So all together working four shifts no matter on which machines.

One printing unit generally prints one layer. One layer is represented by one tiff document. However, for a better utilisation Barta developed a technique with which one printing unit can print up to five different colours. Imagine a batch containing the same product thirty times. Six labels are red, six blue, six green, six yellow, and six orange. The label build up is exactly the same (one lacquer and one adhesive) only the colours vary. This leads to a situation where the batch would require seven printing units. With the technique of arranging the colours next to each other on the sheet layout and splitting the screen appropriately all of the five colours can be printed on one unit. The technique is internally referred to as an iris print. This is the reason why clustering artworks according to colour is necessary in the Lithography department.

The process steps of the printing department are described in the following paragraph. First step is the mounting of the equipment to the different printing units. The first unit is mounted with the screen and squeegee of the first layer, the second unit for the second layer continuing to the last unit of the printing press. The carrier is loaded at the first printing unit and continuously forwarded from one printing unit to the next. There are 150 sheets required to reach the first unit and 350 sheets from one unit to the next, including the drying stations. Altogether 2000 sheets are fitted into the printing presses, no matter if big or small format. Therefore it takes on average around fifteen minutes for a sheet to travel from one printing unit to the next.

The second step is to align the print with the carrier at the first unit. On the second unit the second printed layer has to be aligned with the first printed layer. If a batch contains twenty layers this step has to be repeated twenty times. In the third step the printed layers have to be visually okay. This means having no defects such as holes, wavy surface appearance, and/ or unclear edges. All these defects can be prevented with adjusting the setup.

The fourth step is the adjustment of the print, so that the printed layer fulfils the requirements. Lacquers and adhesives are required to have a minimum and maximum layer thickness which has to be pre-set. Therefore special foils are stuck to the carrier before the printing unit, removed afterwards, dried, and finally measured in regards to the thickness. If the thickness is out of range changes have to be performed. The colours are specified as mentioned in the colour department section. Therefore a different foil is applied and the colour tone measured. Adjustments have to be done such that the tone is in the tolerance range. The white is also measured with the same method but here it is checked in regards to the opacity[9]. All those parameters have to be controlled throughout the runtime of the batch and if applicable measures have to be taken. However, since the printing units are in series a stop for adjusting the print on one unit causes all of the other units to stop as well. If the machine stops for more than thirty seconds the screens have to be washed up, since the solvent based colours start to dry and close the open mesh. This leads to a lot of downtime and further the next five sheets after the screen was cleaned are considered defect and have to be marked such that they can be removed later on.

After the last printing and drying unit the batch is coiled up onto a reel. Depending if the last printed layer needs resting time the reel is either put aside or recoiled such that the beginning can be feed into the first unit. As soon as the resting time is over the batch will be recoiled and further printed. Some layers have the characteristic that they cannot be overprinted on the next unit because they are not fully dry. This demands to leave the next unit free to use only its drying chamber. After the last layer is printed the reel is also recoiled to have the beginning with all the setup sheets up front, such that the following department (cutting) can use these to adjust the machinery and not sacrifice good sheets. This is considered as the output of the printing process.

Altogether the printing department is determining the flow in all the other departments, pre- or post-printing. Therefore the main scheduling has to do with best utilising the printing, but incorporating the drawbacks of the other departments, consider the limitations, and take in account the availability of the staff.

Cutting

The cutting department is the last division in which both delivery forms are still present. The main goal of the process is to refine the big reels into either smaller reels which can be further processed or into sheets. The input is the coiled up reel from the printing department. A batch which contains both reel and single cut items will be cut on a specially designed cutter. This cutting device slices the reel part onto a smaller reel and the sheet part will be cut with a guillotine. Just reel delivery items

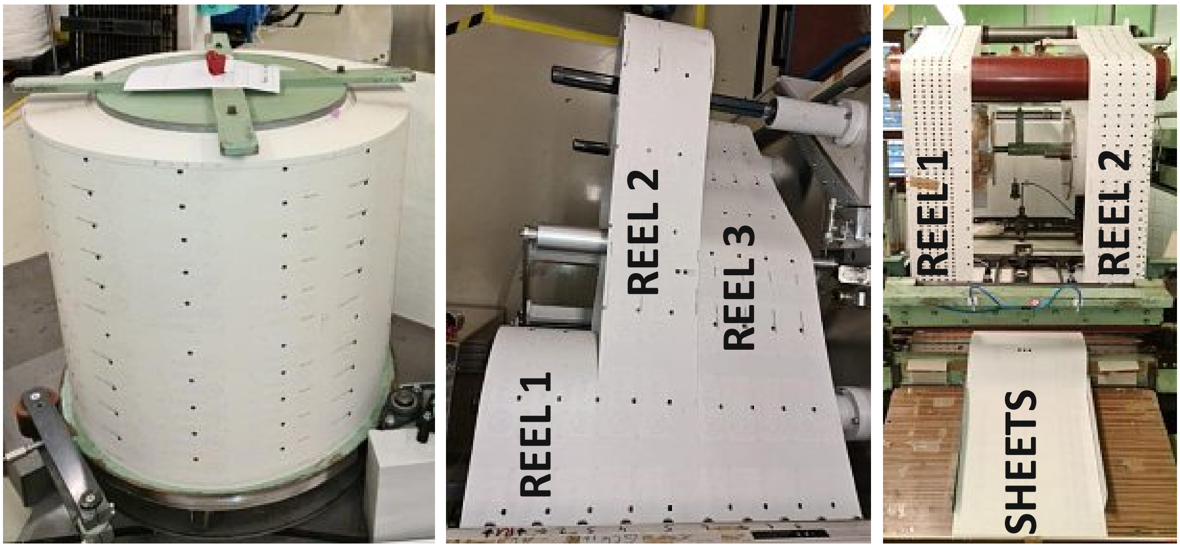
[9] Opacity – the opacity is a measurement of the impenetrability of the underground. 100% opacity measurement would mean no underground colour is detectable. (Scheer, 2007)

are processed on a different machine, which cuts the big reel into three equal smaller ones. The last machine only processes single cut items and cuts the mother reel into sheets.

The tasks of this department are solely adjusting the machine, cutting the batches, controlling the machines, and delivering the cut batches to the corresponding departments. Adjustment means to set the machines to the right lengths and or widths. Controlling during the cutting step is to monitor any malfunctioning which cause wrong cuts. The delivery is done with special carts for the smaller reels and some for the sheets. These outputs are than forwarded to the following departments.

This department is not required to work on shift based modules. Since there are enough machines to cope with the workload the bottleneck are rather the employees. Overall this division is triggered by the outcome of the printing department and works on the basis of the delivery dates. This is other than the pre-processing division which focus on supplying the printing schedule.

Picture 4 illustrates the previously described cutting department. The first picture on the left side shows a vertical coiled reel which is used to transport the finished printed batch to the cutting department. The middle picture represents how the mother reel is cut into three parts for further post processing. Finally the last picture demonstrated a mixed single and reel batch, reels one and two are coiled up and the sheets are stacked in the basket. If a batch contains no reels the whole length would be cut lateral and the whole sheet width would be stacked in the basket.



Picture 4 Illustrations of the cutting department (from left to right): vertical mother reel, cutting mother reel into three parts, and a mixed reel sheet cut batch

Post Processing Reel Labels

As mentioned earlier there are the two different delivery forms in which customers can order the transfers. Generally the reel cut labels are mainly for European companies which have enormous order quantities. Those companies have semi- or fully-automated application presses to keep the labour cost low. The automated presses are triggered by a so called stop mark which is printed next to the label. A sensor detects the black mark and sparks the press.

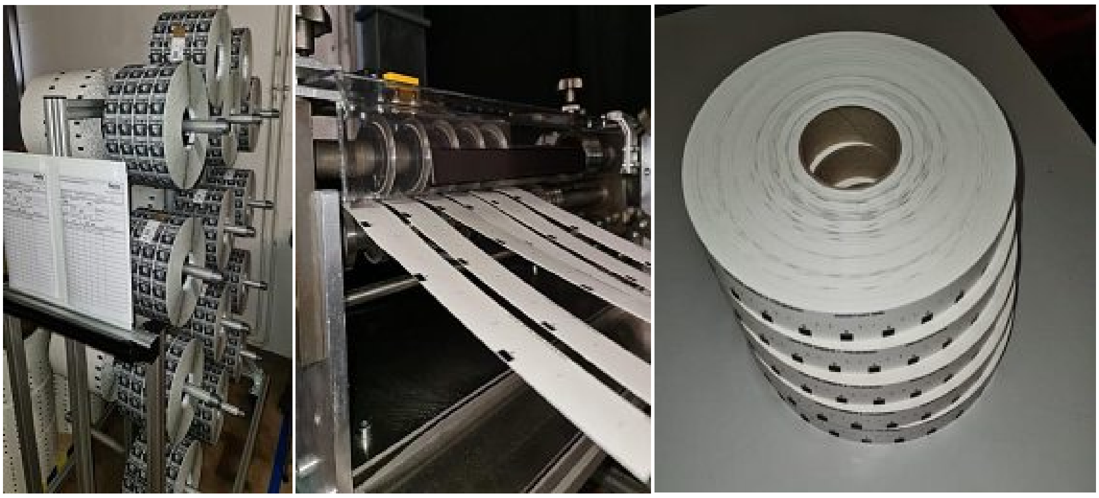
The cut mother reels are delivered to the department. Here the reels are inspected visually by employees, defect labels are marked, some are cut out, and the reels are trimmed into the final form and packaged. The inspection works on special tables with either two inspection runs or one depending on the product and customer. The first inspection run detects defects in the adhesive layer and lacquer. The second run is performed to identify defects in the visible transfer (colours). Two runs are needed since two different lightning settings are required to ensure that the different defects are detected. Some customers have a lower quality standard or artwork design where only one run is sufficient to detect the defects. Additionally with some products there is the possibility to detect the mistakes in the lacquer, adhesive and colours in one run.

Depending on the fact if one or two runs are required the time for inspection differs. Other than it may be expected the time does not half. Inspecting the lacquer and adhesive takes around one third of the time, the colours take two thirds and the setup times are negligible. The reason for the difference in time is that the colour layers have far more visible defect than the transparent layers. Defect labels are marked such that the stop mark is covered with a white sticker. This leads to a situation where the sensor on the press would not detect the mark and hence not apply the defect label. If too many bad labels are in one reel or in a row these have to be cut out. Defined as too many are if there are more than one third faulty labels on the length of one printing sheet or contained on the final reel. The defect labels which are on the length of a printing sheet are cut out during the inspection. The final reel is evaluated after it was cut into its final format and during the finalising task.

After the inspection, the mother reel cut offs are further cut into the final format. Since the cut offs are one third of the mother reel they can consist, depending on the label size, of between two and five final reels. These are than brought to the finalising station where the reels are coiled up the way the customer requires them, counts the amount of good labels, if too many defect labels are contained removes these, and packages the reels.

Same as the cutting department the post processing of the reels are not printing schedule driven but operate according to the delivery date. Some batches therefore take months to post process since there is no fixed delivery date yet appointed. Further a shift module is not required since there are enough inspection tables, cutting, and finalising machinery available.

Picture 5 reveals the finalisation of the reels. The left picture shows the delivery from the cutting department. After theses are inspected they are cut into the single reel which is seen on the middle picture. The last picture illustrates the finished reels.



Picture 5 Illustration of how the reel changes throughout the processing (from left to right): transport of the 1/3 mother reel, cutting these further into the single reels, and the finalised reels

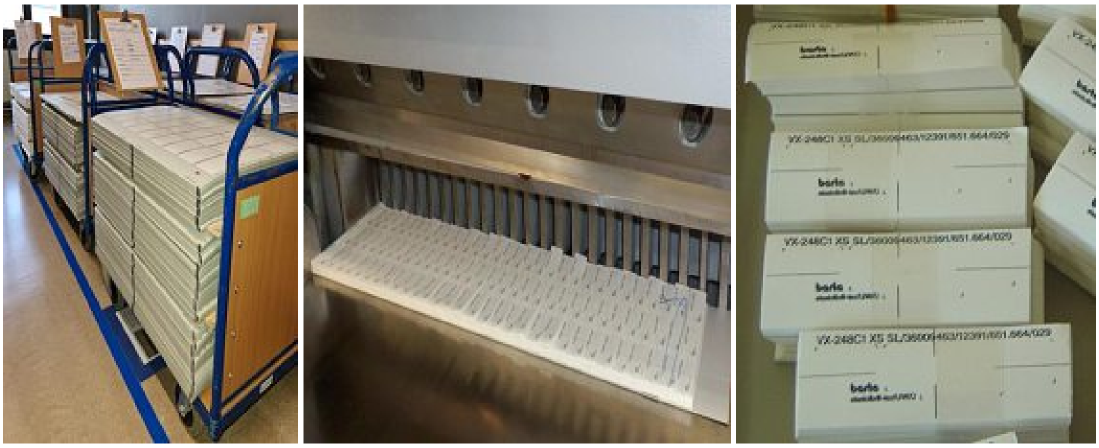
Post Processing Single Cut Labels

This division deals with the items which are delivered as single cut stacks. Generally one stack contains 100 labels. Sixty five percent of all deliveries are single cut. Customer ordering this delivery form are either small quantity customers or apply these in low labour cost economies. There is only one OEM ordering single cut items in bulk, which are applied all over the world. This is due to a special development with Barta, to create a full automated single cut item application press.

The inspection process works similar to the one described in the reel post processing paragraph. There is also a dependency on the mentioned attributes if one or two inspection rounds are required. A difference to the before illustrated workflow, is that the labels are not marked with covering a stop mark, but rather with a red line across the label. Single cut labels do not carry a stop mark since they are mounted single into the press and the machine is triggered manually.

After the sheets have been controlled and the defect labels are marked piles of fifty sheets are collected. These are handed into a cutting machine which chops the pile of sheets into the final format. When the sheets have been cut, stacks of 100 items are piled. During this process step all marked labels are removed, such that the customers only get good labels. Depending on the size of the transfers, the product, and the lot size, this step can be either done manually or with a machine. Transfers with a size starting of 50 x 40 mm can be processed automatically. Only products containing no or hard to remove protective paper, can have the defect labels removed and be stacked with a machine. Furthermore, it is important that the lot size is greater than 10 000 pieces such that it is economical to processes it with the machine. Once the stacks of 100 deliverable transfers are formed they are banded, packed, and either stored or delivered. Generally, all production surpluses, in both reel and single cut form are stored until further notice. Overall, the inputs are the sheets and the delivery dates and the output are bundled stacks of 100 deliverable items.

This process again contains no limitations of machinery and therefore a one shift module is fully applicable. Furthermore, it is also planned according to the delivery date. The inspection personnel are interchangeable between both processes, depending on the workload. Picture 6 illustrates the previously explained single cut process. The left picture shows the transportation wagons, the middle one the sheet during the cutting process, and the right picture demonstrates the bundled and bandaged stacks of 100 pieces each.



Picture 6 Single cut finalising (left to right): transport with special wagons, cut items, sorted and bandaged items

Conclusion Production

To conclude the information portrait in this section, all departments require a separate schedule. On one side the pre-processing departments are tied to the printing schedule, since these deliver the equipment to produce. The printing and post-processing departments on the other side require a schedule based on the delivery dates. Some departments require shift work to support the printing divisions and to overcome bottlenecks caused by machinery others do not.

Generally speaking, large quantities of the same artwork and product are best to produce at Barta. The particular reason for this circumstance is that the machinery was built for printing the same sheet setup many times in a row. If a setup on a printing unit is changed often more stops occur which leads to more waste and hence a less effective production. To cope with this circumstance and still be able to supply small order customers the collection batch module was designed. This also explains the minimum order quantity of around 1000 pieces. Since the smallest produced batch size consists of 800 sheets, an item placed on the sheet one time will deliver, in the case of no waste, 800 pieces. As mentioned earlier the bigger the batch the better the overall workflow and smaller the produced waste. The ideal batch size was found to be greater 2 500 sheets.

2.4 Background Conclusion

At the company there are many different influencing factors which have to be considered when talking about the production planning. In the previous chapter all customer ordering behaviours and processes where demonstrated in regards to how they influence the planning. Overall it can be concluded that the customers have an influence on how orders have to be processed and on special implemented techniques to cope with the different ordering behaviours. Further, it can be determined that special processes require more knowledge during the planning stages. Therefore, the optimum lot sizes at Barta are high quantities of the same item. The item is considered as the product, artwork, and delivery form mutation.

It is important to point out that the special techniques such as the collected batch production in combination with the full tone colour printing leads to further exceptions. One leads to the iris prints which require a lot of time in the sheet arrangement and knowledge about the divers processes. When combining reel and single cut labels also special rules apply such that the mother reel can be processed in the cutting department on the special machinery. All this will be further investigated in the subchapter “4.3 Printing Sheets”.

3 PRODUCTION PLANNING

Production planning is defined as the planning of acquisitions of resources and raw materials. Further, it is viewed as the planning of the production activities, necessary to manufacture finished products out of the raw materials. All this is performed such that the customer demand is met in the most efficient and/ or economical manner. (Pochet & Wolsey, 2006)

The problems that arise in the industrial field require decision in regards to the production lot sizes of different products, the time in which these lots have to be finalised, and further on which machinery these productions have to take place and in which sequence. Generally, all these problems serve the purpose of fulfilling the forecasted demands at minimum costs. The planning is considered to cover a short to medium term time frame. (Pochet & Wolsey, 2006)

The overall goal of production planning is to create a schedule that compromises the economic objectives such as maximisation of the contribution margin or cost minimisation and the satisfaction of the customer. To fulfil this objective, manufacturing scheduling systems are becoming more complex, to increase the productivity but also the flexibility of the operations. The trend goes to incorporating more and more departments into the planning system. These departments include procurement, distribution, sales, and planning. The faster demand changes seen with customers create the need of quick market responses, without losing overall productivity, hence leading to more flexible production planning processes. (Shiroma, 2013)

Others define production planning as the process of setting a time frame of manufacturing to meet customer orders. These time frames include the material availability, the availability of resources, and the knowledge of the future demand. Overall it is defining the planning department responsible for all the material flows inside and partially outside the company. (Bertrand & Rutten, 1998)

In assisting the production planning different management tools and systems where developed to keep enterprises compatible on the market. One of the famous systems is the Just in Time (JIT) management tool. JIT consists of eight basic elements, incorporating smaller tools such as: *"(…) focused factory, group technology, reduced setup times, total preventive maintenance, cross-trained employees, uniform work load, JIT delivery of purchased parts, and Kanban (…)"*

(Nellemann & Smith, 1982). Generally, JIT was developed for medium to large size firms which had the bargaining power over their suppliers, the possibility to pay higher wages for cross-training of the employees, have enough capital to make major plant changes, and hence reduce setup times. (Abdul-Nour, et al., 1998)

A second system which developed during the time, to keep an enterprise productive and hence enabling the possibility of growth or simply survival in international competitive and growing markets, was the Lean method. The method was concluded after an analysis of the development and manufacturing conditions at different automotive production companies. It was seen that Toyota developed a waste reduction model better than all the competitors. Through different publications the Toyota system was introduced to the different industries and today is used in all kinds of productions, but also other business segments such as maintenance and administration. Especially two authors James P. Womack and Daniel T. Jones thoroughly described the Lean model in their books "The Machine That Changed The World" and "Lean Thinking", which helped introduced the systems. The main focus in the Lean module lies on reducing waste throughout all processes during manufacturing and further in all kinds of business sectors. (Kister & Hawkins, 2006) Other than JIT, Lean is built on ten principles: (Kister & Hawkins, 2006)

1. Levelled Production – to produce what is needed and in optimal batch size
2. Continuous Improvement – many small improvements lead to a bigger goal
3. Customer First Approach – understand what the customer really needs
4. Total Productive Maintenance – planning maintenance to avoid unexpected downtime or have losses through maintenance
5. Streamlining Processes – to deliver products on time in an efficient manner
6. Develop Failure Proof Processes – also known as Poka-Yoke solutions, such that no mistake can happen
7. Focus on Quality – the quality is defined by the customer and needs to be out of reach
8. One Piece Flow – finish the work at each station before handing it over
9. Value Stream Mapping – analyse each process step according to the value added and eliminating those that do not add value
10. Respecting Humanity – respect the working hours, have a reasonable failure resolution, and create motivation

Evidently the eight basic elements of JIT and the ten principles of Lean, are highly overlapping. Lean breaks down some of the points included in the JIT system just into a higher level of detail. Since both systems either include parts or are fully based on the Toyota Production System (TPS) this is comprehensive.

Strictly speaking, Kanban is a subsystem of the TPS, and incorporated into the JIT management. As Lean is mainly based on the TPS it also includes the Kanban system. This leads to the fact that both of the modules which are used to best utilise and efficiently produce advanced and build up on the TPS and hence include the Kanban methodology. To understand the significance of Kanban, it will be further defined and analysed. "*Kanban is defined as a Material Flow Control Mechanism (MFC) and it controls the proper quantity and proper time of the production of necessary products."* (Graves, et al., 1995)

In the direct translation from Japanese to English Kanban would mean card system, thus nearly all companies could be said to use such a system, since all shop floors work with some kind of sheets, plans, or lists. Yet, just using cards is not the only idea behind the method. Since the original concept advanced from an automotive company the technique was fully tailored to fit the corresponding processes. Over time the tool was implemented into various industry segments and hence adapted to further fit the needs of the specific process flows. The general goal of Kanban systems is to signalise the process state of a specific workstation, stating the progress, and the demand requested. Mostly this is achieved by a type of board which minimally consists of three areas: To do, in progress, and done. More complex processes may require a greater variety of the different sections. (Ansari & Modarress, 1995) The system is limited if a process has unstable demands, unclear or varying processing times, non-standardised process flows, long setup times, a range of different items, and uncertainty in the raw material supply. (Grünwald, et al., 1989)

In all of the studied literature the production planning was indicated as the responsible department for the raw material management, the demand planning including the optimisation of the produced batch sizes and the flexibility in the ordering process. Furthermore, it was stated that the production planning is growing into different departments and is also considered being responsible for the supply chain management, total productive management (TPM), and the human resource management, rather than an exclusive planning and scheduling department. (Pochet & Wolsey, 2006) The following chapter will therefore analyse these points further, and examine the status quo in different industries and enterprises, focusing on how the tools of the Lean respectively JIT systems aid the different responsibilities of the planning department.

3.1 Resource Planning

As the resource planning was defined as one of the major elements in the production planning process it will be further split into the raw materials planning (supply chain), the human resource planning, and machine resource planning (TPM). Without the previous mentioned resources, no product manufacturing can take place. Therefore, these elements are essential to be provided to the right time, in the right amount, and further to the right station, such that a fluent production process can be performed. (Shiroma, 2013)

Raw Material Planning/ Supply Chain Management

The raw material section in this thesis will not just incorporate purchased materials for the process, but also the needed equipment which is prepared at the company. This will create the possibility to better relate to the analysed problem the thesis is discussing.

On one hand, digging deeper into the forecasting of the customer orders it can be seen that they are only valid and plannable over a short period of time. On the other hand raw material ordering process and delivery take far longer than the expected lead times of the customers. Thus, the necessity of a raw material safety stock is required. Holding safety stock, though, bonds working capital and requires storage space. Further, the risk of broken stock after hazards and reaching the expiration date of the raw material rises. (Bertrand & Rutten, 1998)

To reduce the storage cost and the hence bond capital, the JIT delivery of purchased parts tool can be applied. This would require the delivery to the specific workstation of the raw material at the exact right time coordinated with the customers ordering behaviour. Furthermore, the JIT philosophy can be applied to the needed equipment at a specific workstation. Just in time when the equipment is required to further process the production step it is delivered to the station. The same risks, threats and costs are created by storing equipment. In addition, the costs of manufacturing the tool are bound, which is, depending on the time required to produce often higher than the used raw materials. (Vollmann, et al., 2005)

Receiving the raw materials just in the time they are required raises the risk of downtime if the components are not supplied in the needed quality or at the needed time. A delay may be caused due to difficulties during the delivery such as traffic jams or accidents, the supplier had production difficulties or high default rates, the order by the supplier was placed too late, or the delivered component does not fulfil the quality standards. The only issue in control of the company is the ordering process all others are commanded by the supplier or the logistic contractor. Nevertheless, enterprises have figured out solutions to overcome these issues in implementing a supply chain management which incorporates the suppliers into the planning. This was made possible by the rapid development in the communication systems between the different members in the supply chain, which enable a fast triggering if and when material is needed. Further, it can give information to how and where the materials are in the suppliers' process to better schedule the machinery and avoid the downtimes. This goes as far as that when a customer of the company places an order the all suppliers will immediately receive the order amounts required for them to produce and his suppliers will receive their amounts and this throughout the whole supply chain. The further back in the supply chain the cheaper the raw materials. Since each supplier adds value to the component the further upfront in the supply chain the more capital will be bond if the components are put to stock. In addition, it is harder for producers at the back of the supply chain to control their stock in the same manner as the ones upfront. Raw materials from mining, agriculture or large chemical industries are traded in huge amounts. Prices can be negotiated far better when purchasing in big amounts, especially in respect to primary raw material deliveries. (Abdel-Malek & Das, 2003) In the automotive industry the JIT delivery goes as far as indicating that the storage of the OEM, which is the last member in the supply chain before the customer, is the lorries moving on the motorways.

To achieve such good deals there is the desire for long term relations with the supplier. This includes audits in which the production capability, work conditions, and quality standards are thoroughly investigated. Overall the goal is to reduce the raw material stock and minimise the risk of downtime due to bad or late deliveries. (Vollmann, et al., 2005)

Figure 5 illustrates how the supply chain ties up the different information between the customer and the suppliers. It is observable that there is not just the link of material flow between the suppler and manufacturer but also a supply contract and information link. The contract is the legal framework for the collaboration of the two parties and is defining the key elements in the business structure. It is necessary to protect each party within the parameters which are defined in the contract. In the best case this contract is finalised before the business starts to succeed in the case of disagreement in any supply scenario. Such contracts hold general terms and conditions of delivery time, quality, overall order amounts, and business data required to plan the orders and deliveries. Opposite to the contract the information link is the previously mentioned linkage between the two parties. This transports information in real time such that each enterprise can best regulate according to the actual situation. This automated interlinking information tool is the key technology which enabled the possibility of holding low storage and applying the Lean respectively JIT models.

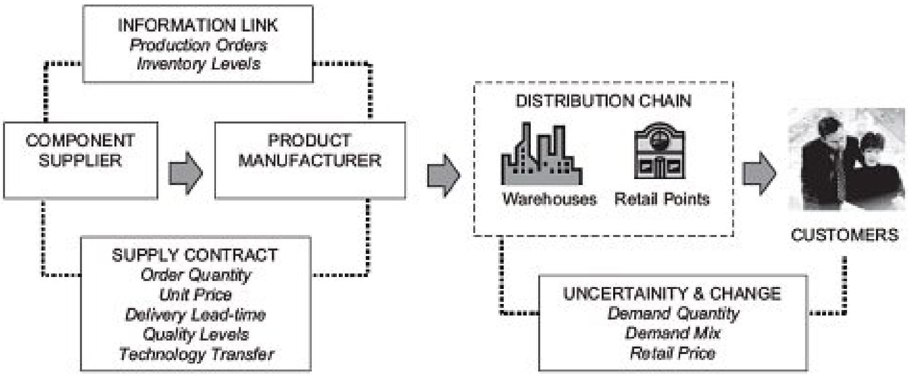


Figure 5 Supply Chain with product and information flow, contracts, and uncertainties

To organise the internal deliveries according to the JIT system, means providing internal manufactured equipment or raw materials to the following stations exactly when required. This can be best achieved with the Kanban model. In this model the next of each station is seen as the customer and pulls the components similar to the supply chain. What is far easier in this model, is that the information which regarding process status, quality, production time, and error rate is within the company. The distribution of this information to the planning department is therefore far easier, than having to link up with the supplier ERP system.

The original Kanban system can be described by four main characteristics: (Lage Junior & Filho, 2010)

1. Having two communication signals, one is gives the information to produce a fixed amount of products and the other to transport a fixed amount of product to the following station
2. The production is pulled by the last station, either by the inventory or the schedule
3. The stations control themselves visually to perform a decentralised control

4. The work in progress (WIP) is limited which respectively limits the inventory level and hence creates only a finite buffer.

The original system though adapted to be also usable in less strict production environment, in which the lot sizes change, where there is a vast item variety, and machine breakdowns happen on regular basis. In the Kanban review from the Authors M. Lage Junior and M. Godinho Filho thirty two different system adaptions where analysed to conclude how this system was integrated so thoroughly into the different industries. The evaluation included systems with only small adaption such as the E-Kanban, where the only change was that the information was transported via electronical signals, rather than cards or sheet. This enabled the possibility to trigger different station at the same time with less effort and to increase the distance between the workstations. Further, systems which had far more vital changes such as the Critical Path Method where portrayed. In this adaption one of the original characteristics, the pull factor, was changed to a push method between the productive departments and the final assembly. (Lage Junior & Filho, 2010)

All these different models eventually concluded that the main idea behind using a Kanban system is to adapt the use of viewing each individual workstation as the customer of the station before and itself as the supplier of the following and regulating the signals which identify the requested demand. Therefore, each station requires its own plan, raw material, and final stock inventory, whereas some can be planned either stricter or loosely depending on the item variety, flexibility, demand, and amount of performing tasks per station. (Lage Junior & Filho, 2010) Eventually, the different workstations within a company are viewed as the internal supply chain, exactly like the one to the company suppliers, over seen by the planning department but generally organising themselves in regards to resources and WIP. This created the possibility to have different systems at different workstations since not all processes flows can be handled efficiently with one system and by one department. (Ansari & Modarress, 1995)

Overall, in respect to the production planning the goal of a Lean raw material management is to create a situation, in which the material flow organises itself, in the best case according to the companies ordering intake. To achieve this standard a high degree of digitalisation has to be available at the company. This would relieve the planning department of having to readjust or take into account the raw material inventory during scheduling. In the ideal case the planning department can freely schedule without incorporating the material flow because this can be assumed to be available and present whenever needed. This would reduce the planning by one variable.

Human Resource Planning

The next stage in the planning of the resources required to produce is the workforce, hence the human resources. The same issue as previously described in the raw material management, the growing international competition, requested a change in how human resources can and should be manged. In this section the problems and competition, but also solutions and adaptions of the Lean respectively JIT modules are applied and demonstrate how to overcome some of the issues.

Major costs for manufacturing enterprises are not the raw materials, especially when having high vertical production integration, but the labour costs. Especially the western world struggles to compete with low labour cost economies in which the social standards are low, the corporate social responsibility not regulated by the government, and workers' rights are not present or taken serious. Many companies setup new production plants in developing economies to stay competitive and increase the contribution margin. These transitions where further driven by political factors and decisions. Companies which did not have the financial resources, size, and/ or will to relocate their production site faced major struggles. These relocations generated a competitive advantage for of the moved companies compared to the ones that did not. Creating a market situation in which the production plants in the high labour cost economies had to readjust their production. (Goldberg & Harik, 1995)

A solution for staying competitive is to invest into automation and hence reduce the production staff. Since the capital for investing is limited and not the whole production can be automated at once different solutions had to be incorporated to use the advantages of the high technical advanced location. Being in regions with in generally higher educated, more creative, and skilled workforce these attributes have to be incorporated into the production. One approach was to specialise on niche products which require these attributes of the employees. These products would require a higher level of expertise than the low cost big batch products, whereof the production could be easily implemented in the developing countries. In addition the availability of the trained workforce could be used to further stream line the processes according to the Lean approach and decentralise the control. (Goldberg & Harik, 1995)

A different resolution attempt was to further streamline different process steps and reduce the time taken for the completion of specific tasks. Now labour cannot be viewed and managed in the same way other productive factors such as materials and machine can. The human resource is not just defined by an amount of available staff and will not always perform in the same manner, but dependent on its motivation, eager, and as described in the previous passage skills and preferences. To give an example, a work team of five skilled and motivated people can produce exponentially more than a team of double the size and no as skills or motivation present. Therefore stated in the Lean concept there should be the goal of cross training, investing into the skills, and motivation of the employees. Cross training further creates the possibility of not having to fill each job with a deputy, to cope with sickness leaves or vacations, but if more employees can do the same job these can make up for the absent person. Additionally, the more each employee can do the different jobs the less work it is for the production planning to schedule according to the available teams. (Shiroma, 2013)

Keeping a motivated and high skilled workforce is not essentially the responsibility of the production planning department but rather a companywide endeavour. Nevertheless, these factors aid the planning and reduce waste, downtime, and other difficulties. Furthermore, the planning has effects on the motivation and skills of the available labour. If for example, a worker is only placed at one machine it will not help diversify the skills and further may lead to motivation loss due to repetitive work day in and day out. On a different perspective wishes of employees can be incorporated into the production schedule, some enjoy working night shifts due to personal routine and wage reasons, other do not. In the end it is necessary to identify the potentials, qualities, and preferences to specific processes and other members to effectively gather a team and support the previously mentioned qualities. (Shiroma, 2013)

Planning the human resources is further a difficult venture since the output, mistakes, and generally the behaviour is not or only hardly predictable. Humans tend to perform differently than it may be logically expected. Different research had shown that the more employers are overseen and controlled the slower some tasks are performed. The Hawthorne Effect further proved that only the knowledge of participating in a study influences the behaviour of the participant in some cases positive if it aids their reputation or negative. The more complex a task, the less effective the monitoring and controlling is, but the better the praise and selfactualisation helps in reducing errors. Further the stress performed on the employees has a direct influence on how they perform. Table 1 represents how the queue size and amount of control or supervision effects the throughput time of the products. (Goldberg & Harik, 1995)

Case	Queue Size	Time	Jobs/unit time
Base	5 55	39415 33056	0.761 0.907
Unsupervised ($f = 0.98$)	5 55	39934 44614	0.751 0.672
Lax Supervision ($f = 0.9$)	5 55	39960 39861	0.750 0.753
Tight Supervision ($f = 0.8$)	5 55	40018 38326	0.749 0.782

Table 1 Comparison of how the queue size and control influences the throughput times (Goldberg & Harik, 1995)

Table 1 illustrates how queue sizes and supervision influence the workforce and reduce or raise the output. The case with the fastest time per unit was the unsupervised and high queued one. One factor excluded in this analysis was the quality output. When supervised the stress of making mistakes and sticking to the process plan is disrupting the well-rehearsed routine. Again proving the Hawthorne Effect, without mentioning the participation at a trial, in the base case, and queueing the worst results where gained. These results underline that the human behaviour is difficult to predict. (Goldberg & Harik, 1995)

To better predict and plan the human resources, people started to time specific tasks to create a list with average values for specific movements. This is called the Methods-Time Measurement (MTM) and was established in the beginning of the nineteenth century and further adapted and developed throughout the years. The employees can be compared to this list and the tasks can be planed according to the average time they take to be handled. The limitation is that not every task of every production could be timed and analysed in this overview, but it explains how the times of different movements can be combined to result in the preformed task. Further, it describes the measurement methodology and hence enables the company to create their own average times, required for different tasks. (Kargar & Bayha, 1987) This further helps to recognise the non-value added or wasted times that takes place in a process and can hence be used to streamline it according to the Lean system.

Overall the human resource management depends to a great amount on the performable job. Low skilled operations generally require less thought during the scheduling and planning. These jobs can easily be learned and hence conducted by different people and require low training, further these jobs can be easily overseen and controlled. (Kargar & Bayha, 1987) As though mentioned the production landscape changed such that the low skilled work tasks are either outsourced to or done in developing countries. More developed countries therefore have to deal with a situation of planning high skilled tasks and hence leading to the necessity of thoroughly planned schedules in respect to the human resources. The long term concept should foresee a high degree of automation and reduce the required skills of the single employee, with decreasing the amount of employees needed to produce or finish a task, and further to simplify them to such that they are streamlined, wasted time is reduced, and the to perform tasks are predictable with MTM. (Goldberg & Harik, 1995)

Machine Resource Planning

In this section the thesis will focus on the theoretical background on how machinery behaves in a production environment, problems that arise and destroys the schedule, and how these issues have been addressed and solved in manufacturing processes. Machinery is required to complete all production tasks, especially in the production environment of economically more developed countries.

The amount of machinery used on the shop floor increased exponentially during the first industrial revolution around eighteen hundred. Handcraft was reduced and replaced by better predictable, steady working and quality delivering, and in addition often faster working machine. This trend increased further to create full automated production sites. This change brought many advantages, especially in regards to the planning, since a machine could be utilised with a specific amount and that every day, the unpredictable human behaviour and hence performance was reduced. (Al-Radhi & Kamiske, 2002)

Problems which this change incorporated was that machinery is good in a specific task but flexibility is lost, breakdowns can occur and lead to long down times if the defect is hard to detect, and/ or repair and further maintenance of the machinery is a direct loss of production capacity. The more the machinery established on the shop floors the higher the need for a system to cope with these rising issues, hence the Total Productive Maintenance/ Management was developed. The issues this tool deals with are maintenance management to reduce breakdowns, spare parts management to reduce repair times, risk management of the machinery, and to hence increase the Overall Equipment Effectiveness (OEE). (Biedermann, 2016)

The TPM is build up on several pillars and a basis element at the bottom. Depending on the literature these are portrayed in different detail grades. The base element though generally consists of the 5S: (Kletti & Schumacher , 2011)

1. **Sort** – all equipment and materials to have an overview
2. **Straighten** – layout all machinery, equipment and material to reduce unnecessary movements
3. **Shine** – keep a clean working area
4. **Standardise** – processes to have systematically approached flows
5. **Sustain** – the process and principles such that they can be used for a long term

The pillars building up on this basement consist of: (Reichel, et al., 2009)

1. **Autonomous Maintenance** – employees should make small maintenance tasks to relieve the maintenance team which can focus on the specialised tasks
2. **Continuous Improvement** – in the TPS it is referred to as Kaizen and should aid to create a zero defect and loss production. Incremental optimisations continuously improve the effectiveness and efficiency of the process
3. **Planned Maintenance** – these tasks proactively repairs and maintenance machinery and equipment and is crucial to prevent unexpected breakdowns
4. **Quality Maintenance** – this part takes care of identifying parts which may cause qualitative defects or caused these previously
5. **Training** – each member in the production needs to know their work and tasks to help aid the goals, therefore training of the tasks is important
6. **Office/ Administration TPM** – not just the shop floor employees but also the management is incorporated by TPM, controls, scheduling, and planning also need to have improvement to further raise productivity.
7. **Safety, Health, and Environment** – the workplace needs to be safe for the employees and special disposal of hazardous material is required.

TPM is in total one aspect of the Lean module, which sets the main focus on streamlining the maintenance and general machine technical side of the production. The risk of a machinery breakdown and hence a production stop grew with the complexity of the used machines. More automated advanced processes consist of more complicated machines which even interact and thus the bigger the threat if one fails. These machine and especially as a group are often specially produced. Since the more automated a process the more expensive the machinery, it is not possible to reduce the risk with providing spare machines in case of break downs. Although TPM does not include the evaluation of this risk it provides the solutions. (Al-Radhi & Kamiske, 2002)

As in the Human Resource section, the planning department is not solely responsible for the TPM, but it aids that the planning has clear guidelines regarding maintenance times and the developments, trainings of employees, 5S techniques, and other pillars help to reduce unexpected breakdowns which cause production delays or even stops. With these advantages the planning can better utilise the machinery to have a high OEE and hence reducing the throughput time.

Conclusion Resource Planning

In conclusion the three different resources discussed in this chapter need to be optimised internally with the different techniques which developed from the Toyota Production Systems and matured in the Lean, JIT, and TPM models. In addition, the three resources need to be examined in combination to one another to eventually reach the desired optimum resource planning. Evidently, the further developed and optimised the management of the resources is, the easier it is to create correlations to each other.

With the increase growth of the digitalisation in enterprises the information distribution channels develop from printed sheets to electronical triggered signals, which are in despite of environmental and time issues also valuable in delivering the exact right information, to the right department, at the right time. All this information can be used to create decisions during the scheduling phase and improve the efficiency of the production planning. Further, displaying the information reduces the overall know-how of the individual working with them. This is only possible once the necessary information has been clarified and the process completely setup. All these tools encourage a fast and efficient production planning and the possibility to automate some of the decisions and tasks. Figure 6 demonstrates the different departments working together to create such an environment in which the planning process can be partly automated or easily executed. It incorporates the Computer

Integrated Management[10] (CIM), Computer Aided Manufacturing[11] (CAM), and the Computer Aided Design[12] (CAD).

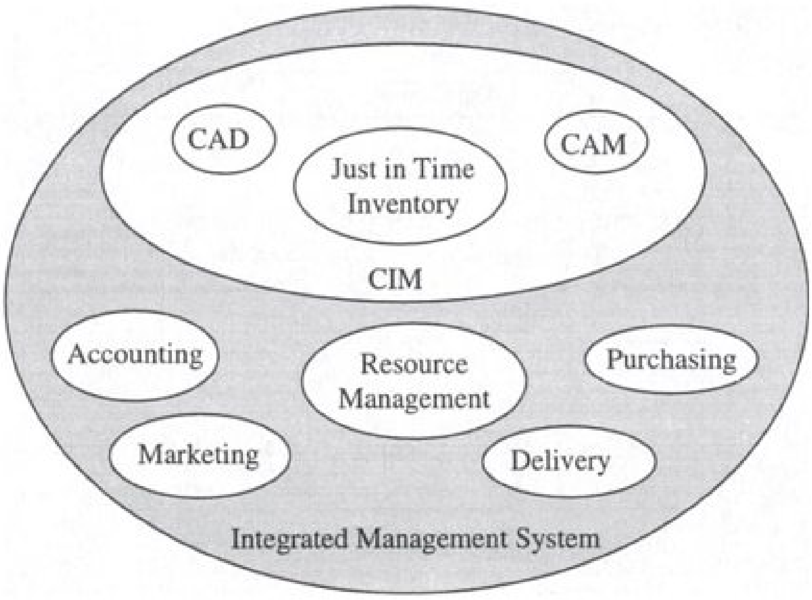


Figure 6 Computer integrated management systems aiding the production planning

3.2 Demand Planning

The demand planning is other than the resource planning the main task of the planning department. All the others should be managed according to the previous subchapter, that the required demand is producible, with the best utilised machinery, and hence in the most effective and efficient manner. Most important in the demand planning is the information about the required amount, the delivery date and the number of pieces which have to be delivered at that date. (Shiroma, 2013) This data is often hard to get, wherefore, in specific industries complex forecasting modules have been created to calculate the demands according to various external influencing factors. Since all these linear or even polynomic regression modules in the end just represent a better educated guess, the demand planning carries a huge uncertainty factor which creates two major risks. On one side there is a risk of not being able to deliver the customer desired demand and product when required, since the production started only with the final call off or order, or is at the moment fully utilised. On the other side it holds the risk of producing to stock and not being able to sell the items. Over the years different modules such as production to stock

[10] CIM – organises the resources at the start of the manufacturing process (Shiroma, 2013)
[11] CAM – Automated manufacturing, less human resources (Shiroma, 2013)
[12] CAD – aids the design with parts list and assembly plan (Shiroma, 2013)

or production to order have been developed, but again depending on the product, market, and customer no one universal method is applicable. (Pochet & Wolsey, 2006)

Following section will therefore analyse the difficulties which may arise when the demand planning has various uncertainties and is not conducted in a reasonable manner. Further, concepts of how these difficulties can be overcome are discussed. First though, the main factors which have to be incorporated into the planning are exemplary illustrated, since these often lead to adaptions in the scheduling that cause difficulties further down the road. (Abdel-Malek & Das, 2003)

The first and most important factor was already mentioned in the first paragraph of this section, the order quantities and delivery conditions. Another factor which has to be incorporated during planning and scheduling of a batch are the setup costs. A batch production costs a specific amount during the setup phase, no matter how high the produced lot size is. This is best illustrated by Figure 7 which represents the economies of scale. (Pochet & Wolsey, 2006) A larger batch will in total have fewer costs per unit, since there are only the unit costs, marginal costs, added per further produced unit and this is by far less than the setup cost upfront.

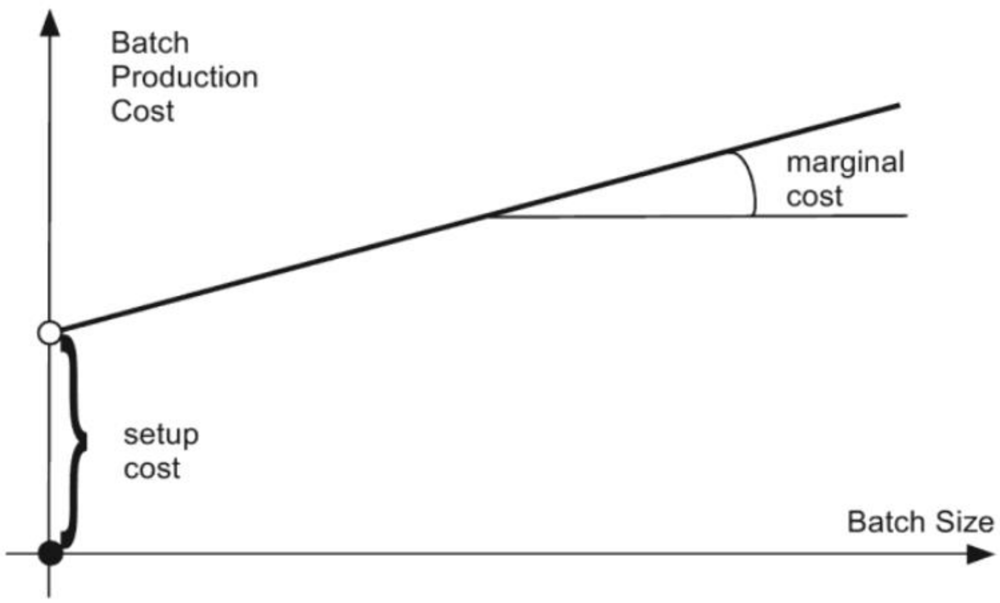


Figure 7 Economies of scale- setup and fixed charge costs in relation to batch sizes (Pochet & Wolsey, 2006)

Breaking down the setup costs clarifies which factors are decisive. Influencing the setup costs is the time needed to mount, adapt, and change the machine settings. Further, depending on the industry the first produced items are generally not deliverable, since the machine produces waste products during the setup phase, which in addition creates extra costs. To reduce these setup costs the Lean/ JIT techniques have to be applied accordingly, but in the end, although the costs have been decreased by streamlining the processes, they will never be zero. (Shiroma, 2013)

A third factor which influences the planning is as previously discussed the resources. In the ideal case these are supplied and available in such a way that the planning does not have to incorporate them separately, since these organise themselves. In reality though such fully automated and functioning systems are the exception, in general these factors have to be included. Repeating the outcome of the last section, the easier the information is displayed and the better these factors have been optimised, the easier they can be incorporated into the demand planning. Issues that may cause the planning to reschedule are not having the necessary raw materials on stock, a machine which is out of order, or to little employees due to sickness or vacations.

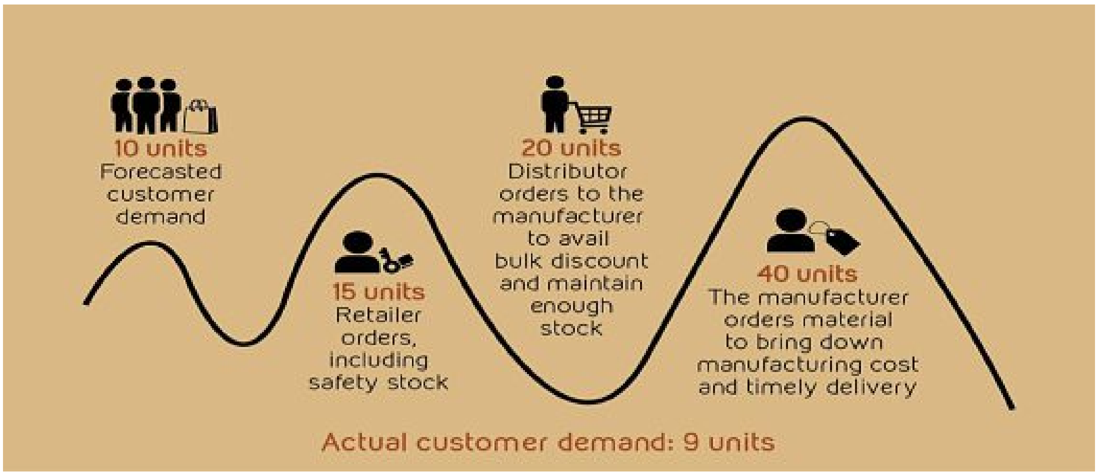
A fourth factor is that there is a limit in how big a batch can be made according to the finished product inventory. Not represented in Figure 7 is that there is a boundary for the curve to grow linear, after it the production of each further unit will exponentially increase. The reasons why the costs per unit increases include the rising cost of stock, the loss of other business, labour costs if the normal working hours are exceeded and growing cost of raw materials in the warehouse. It is therefore important to find the sweet spot in lot size, which is best produced in the corresponding environment. (Shiroma, 2013)

Another factor which has to be incorporated into the planning is the product specific manufacturing. Some products require a special sequence of tasks which others do not. To create the best utilisation all these factors have to be known and accordingly ordered in the schedule such that the costs of production are as low as possible. Over the years special models have been formed to gather the different products and hence jobs together into one schedule. In section “3.3 Production Plan Simulations ” different ways to best gather the different jobs will be discussed. (Abdel-Malek & Das, 2003)

Problems that are caused by an inaccurate or defective demand planning, are as mentioned earlier, not being able to supply the customer or creating unnecessary surplus production. A phenomenon which describes some factors of manufacturing to many products is called to Bullwhip Effect. The further down in the supply chain the bigger the uncertainty of the final customer demand, in addition, all stages before include safety and hence excess stock to reduce the risk of not being able to supply the demand. Therefore, more stock is build up than initially demanded such that the product can always be provided to the supply chain. (Pastore, et al., 2020)

Following abstracted and simplified an illustration of the Bullwhip Effect. One item is sold only at one store and this store holds the article once. When it is sold, the store reorders by his supplier, wholesaler. This supplier delivers the item within two days and holds two items on stock for safety reasons and reorders directly by the manufacturer. This item requires one week of production and on average one item is sold every week. The manufacturer requires only one raw material to create the item. This material is solely used in the production of this specific item. The manufacturer holds enough stock of raw material to be able to produce four items and always has two finished items on stock. The supplier of the raw material delivers the required amount for two items every second week and produces, due to setup costs enough for the next ten weeks. Imagining, the store receives an order of ten pieces, if these can be supplied within ten days. The store places the order at the wholesaler, which further places it at the manufacturer. Each station will further increase their safety stock and place a proportionate higher order, since apparently the demand for this item grows, leading to a massive over production at the raw material supplier or even already at the manufacturer. Picture 7 illustrates how this affects the single stations in the supply chain. (Pastore, et al., 2020)

Once the amount is produced it would be no issue if all could be sold, but since the demand was artificially blown up, due to the extras in safety stocks at each station in the supply chain, the produced parts will take far longer than expected to be sold. The manufacturer and raw material supplier would therefore have a real fluctuation in the ordering behaviour, since all the stock at the vendor and wholesaler will be sold first. In addition, the manufacturer and supplier had to fully reschedule their production plan, to fulfil the order, and hence losses the continuity in the schedule. All these increased orders lead to the situation that the manufacturer and finally the raw material supplier produced a large amount on stock and are uncertain when they will or if they can sell it, in case it has an expiration date, and further lose a stable production plan, leading to uneven plant utilisation. (Pastore, et al., 2020)



Picture 7 The Bullwhip Effect (01.03.21, https://medium.com/@stitchdiary/the-bullwhip-effect-c40751d768ba)

Generally, the effect can be explained due to unknown demand forecasts of the single stations in the supply chain, the further back the lower the information about the real demand. Overall it can be concluded that not enough information was exchanged along the chain. Interestingly, it was overserved that only increasing the demand information flow is not the final solution to overcome the bullwhip effect fully. Since generally a safety stock by the individual stations is required and advised, more than just the customer demand variable has to be included in the forecasting models. All these approximations and calculation, in the end are just theoretical approaches to help, but have to always be applied to the actual situation and brought into the real world. (Pastore, et al., 2020)

Overall the demand planning holds major risks for an enterprise if it is done inaccurately or contains flawed assumptions. In the end the better the demand can be forecasted the easier it is to organise the resources and schedule the production plan. Concluding, a master contract with the customers is in this case the best way to reduce the risk for the individual supplier throughout the supply chain, since the possibility is not given by the majority of customers, input simulating forecast models are created to best guess the required demand.

3.3 Production Plan Simulations

The previous subchapter discussed the parameters which have to be evaluated when creating a production schedule. This chapter will now evaluate how these variables and factors interlink with each other and how these have to be incorporated during the scheduling phase.

Simulations can be used to increase efficiency in the production planning when combining different job runs. Numerous different approaches where developed in the past years, for all different kind of productions. If an enterprise decides to use such models the one best fitting should be chosen and generally has to be adapted. Following subchapter will therefore focus on eight such models and analyse how they word, where they are best applied, advantages, and disadvantages.

Simple Heuristics

These models are the quickest, cheapest, and least difficult to apply in the production planning process. Generally they work by gathering jobs accordingly to one major feature, which may be to start with the job which takes longest or first produce the job with the earliest delivery date. These models can be applied to all productions but are very weak in regard to efficient planning. Just because the job has the earliest delivery date, or takes longest to produce, does not mean that the job is most efficiently scheduled as the first job, since interdependencies such as setup times which may be overall lower if a different job was produced first are not incorporated. These simulations can produce adequate solutions for abstracted and simplified examples, they often deliver inefficient schedules in realistic business applications.

Nearest Neighbour

A different model which only incorporates one influencing parameter or factor is the nearest neighbour. Unlike the simple heuristic which only considers factors within one job, this model examines the setup costs of every queued job. The goal of the model is to minimize the setup costs between the different jobs. To better understand this model it is often explained with a salesman planning the customer visits. The starting point is chosen randomly and then the customer who is nearest is chosen next. Analog the model works such that the job closest and hence with the lowest change in setup is produced next. This will be continued until all the jobs have been finished.

The disadvantage of this method is that the job with the lowest setup cost of the latest finished job may be a job which was already done and the next have disproportional high costs. In other words, the method only includes two jobs the predecessor and successor in the sequence. This may work out well for the first few jobs but has a high possibility that the fourth or fifth forced placements at the end of the sequence generate such high costs that the overall setup cost of the sequence is not optimal. Due to often creating not favourable sequences this model not commonly used in the industry. (Pastore, et al., 2020)

Balancing Machine Load

This model is used to improve the scheduling and hence production plan by limiting the amount of jobs allowed entering the queue on the work floor. This idea was based on empirical observations, showing that many queued jobs waiting for a machine or process the time to process each job increased. The calculations of when the next job can enter are determined by the estimated waiting times of the historically queued jobs. Finally, the daily load for a machine is calculated and the next job can only enter if sufficient capacity is available at the time. The jobs are processed according to the First In First Out (FiFo) concept, not incorporating any delivery dates, production specific parameters (processing time), or setup costs. This also leads to the major disadvantage of this model. First, it only works on linear production systems where only one item is produced sequentially, but as soon as parallel worked production take place the historical values the calculations are based on are not sufficient. Eventually, the model levels the machine load but does not lead to the optimal production plan, since again only one factor is incorporated into the planning. (Wiendahl, 1992)

Expert Systems

This production planning model tries to mirror the choices of the human expert which incorporates all the different factors. These systems function on a real time updating knowledge base, which record the actual situation in regards to the resources within the enterprise and the different currently executed or to be processed jobs. On the basis of this knowledge pool informed, intelligent, and efficient sequences can be arranged. Since the pool constantly updates and each changes are tracked more and more knowledge is gained, which can in the future help to schedule. This systems analyses on the basis of this knowledge pool, which portrays the resources as currently available, in use, to be in use, and will be available at the right time, and hence choses which job can be best processed next. This is referred to as forward chaining logic of the resource availability, all with the goal to reduce waiting times and best placing an order fitting to the current resource situation. In addition rules are implemented into the system, which is the basis of decisions. (Shiroma, 2013)

Overall, the system works very well, if it was programmed and built up by an expert. The disadvantage is that the expert systems require a broad knowledge base on which it can be coded. This expert knowledge has to be programmed into the system which is an expensive and time consuming endeavour. Further, the maintenance of the system is difficult if the expert knowledge within the planning department was lost. In addition, expert choices are often intuitive and hard to explain, which creates the difficulty to gather the right tools. The experts which have the knowledge are further often not able to provide the information in a way that it can be programmed. (Biethahn & Schmidt, 1987)

Another problem encountered in the system is that although the program works fluent and generates efficient sequences, the user interfaces are often not user friendly and especially hard to operate by experts which have little to no knowledge on programming. This leads to a situation where new information and rules are often hard to include into the system. (Biethahn & Schmidt, 1987)

Generally, the systems outperform all the other algorithms, if they there is a broad domain specific knowledge incorporated into them and the users are able to adapt the system in the daily use. Further, it is costly to install and requires a lot of specific knowledge. (Biethahn & Schmidt, 1987)

Enumeration

In the enumeration the goal is to analyse all the different possible sequences and evaluate which would best fit. This always delivers the optimal solutions, since all schedule plans are simulated and the one with the least time, costs, or whatever value is desired to be the lowest can be chosen. Since, this method does not need the entire knowledge, but only the production times, costs, or other desired values it is far easier to implement. The main restriction is that the system can only be used in an environment where only a few jobs have to be evaluated. As an example, a production plan of five jobs needs to be created. The possible permutations that the sequence can have are (n-1)!, with n representing the number of jobs. Therefore there exist 4! possible mutations of the production plan. Equation 1 represents the calculation, leading to twenty four different production schedule solutions of which the best according to a desired value can be chosen. (Shiroma, 2013)

$$4 * 3 * 2 * 1 = 24 \tag{1}$$

In this case all possible sequences could be analysed within a few seconds. As soon as the different jobs increase the amount of permutations grow exponentially leading to a situation where the different constellations cannot be analysed within a reasonable time period. If 20 different jobs have to be scheduled there would be according to equation 2 one hundred and twenty trillion solutions which would need to be analysed. This can no longer be executed in a restrained time frame. (Shiroma, 2013)

$$19 * 18 * 17 * 16 * 15 * 14 * 13 * 12 * 11 * 10 * 9 * 8 * 7 * 6 * 5 * 4 * 3 * 2 * 1 = 120.000.000.000.000.000 \quad (2)$$

Concluding, this method is very efficient if low number of jobs have to be compared but rapidly grows into to many mutations which cannot be further analysed in a reasonable time frame and hence not useable in many industries. Although the schedule at the end might be the best in terms of the analysed values, the time required for planning is far too long such that it is not efficient.

Dynamic Programming

This is a model based on the enumerative technique which also leads to the best schedule after a specific amount of iterations. Rather than analysing all possibilities it breaks the analyses into multiple parts. Therefore only parts are optimised and further used in the following iterations. The idea is that an overall solution can only be good if the single parts are optimal. It therefore breaks the production into specific parts and analyses them according to the costs, time, or a different value of interest. Those values are than traced from the end to the start to see which job cumulative would have the lowest amount and hence is the optimal solution to produce at that moment. The different decisions are represented by nodes which contain the cumulative value of the, to be executed processes. (Bellman, 1961)

Branch and Bound Algorithms

There are different branching models, but all advance from the same idea, similar to the dynamic programming model, to break the jobs into subsets and lead to combinatorial optimal solutions with only a few steps. Therefore branches at each decision are created and the process below analysed to take the job which best fits accordingly to the following process values. Each decision therefore creates a branch. Therefore the tree grows many branches on the way to the finalised product and the route of branch which is the optimal solution can be chosen. Since many decisions can be necessary during a production flow, these systems can rapidly turn into complex, often confusing, and unclear large trees which lead to a difficulty in implementing the algorithms. In practice these systems are therefore generally not used. (Shiroma, 2013)

Simulation Conclusion

Overall simulations theoretically are very useful in portraying different routes of how jobs should be sequenced according to a specific factor. In the real world applications, with all the different factors interlinking and interfering, most of the simulations reach a limit. In production with only a very spare amount of items, no resource issues, no external influencing factors other than the delivery time, or with only a hand full of production jobs a day, most simulations are easily overstrained. The first three methods only incorporated one factor of each job and only in comparison to one other job. The enumeration although also only analysed one factor but this was analysed for all queued jobs. The branching and dynamic programming would create a tree in which the different branch routes would be analysed, but also only according to one specific value. The model which could best represent the actual situation was the expert simulation, which though has the restrain that the specific knowledge has to be available in the company during the setup and when changes have to be conducted.

3.4 Essential for Planning

The general opinion on production planning, in all the studied literature tends to advice flexibility, automation, and reducing the stock of raw and finalised products. The flexibility is needed to meet the fluctuating demands of the markets. These short term changes of demand and the requirement for fast deliveries grew throughout the industries. The automation of processes should aid the production planning with information from the different stations or supply chain members to create the optimal schedule. Decreasing the both raw material and finished product stock should help keep working capital unbound and reduce storage costs.

To create the optimal production plans different simulation models have been developed, but are all limited when applied to real world problems. Further, the development of a company own system is very complex, time consuming, and hence expensive to implement. The optimal schedule can only be created when either all the influencing factors are taken into account.

3.5 Planning Systems in the Printing Industry

Since this thesis focuses on the planning system at a printing company, the following section will focus on how the general scheduling method of production runs works in this industry. To do so different tools which are used for planning are illustrated and their functions, advantages, and disadvantages are examined.

First off the printing industry is very broad, containing commodity products such as flyers, stickers, and business cards but also very specialised and niche products as the transfer. Since there is a huge difference in the production of the various products and the requirements in the planning are very diverse, it is necessary to choose a commodity product which is comparable to the transfer. When analysing the different products, it can be observed that a transfer and sticker generally have the same intentions and batch sizes. Their aim is to mark, label, or brand specific items and often they compete against each other in projects. The differences lie in the appearance and characteristics, but in general they have a very similar production setup. Since the sticker industry is far bigger than that of the transfer, different systems have been created to assist the production planning.

Stickers where always produced with offset printing. A printing technique where the printing plate and to be printed material do not get in touch, but the colour is exchanged with special cloths, this is therefore also referred to as indirect printing. (Engelmann, 1950) As the printing techniques developed further, the digital printing took over and is at the moment the widest spread method in the sticker production. (Brekalo & Knok, 2010) Printing stickers can be done in two ways; either they are printed in reel to reel or as sheet production. No matter which method they are printed in, the smallest unit is a sheet which has to be arranged. This is exactly the same with the transfers. The sheet arrangement of the transfer prints was discussed briefly in subchapter “2.3 Production” section “Lithography” and will be examined in more detail in subchapter “4.3 Printing Sheets”. The major difference between the stickers and transfers is that the stickers do not contain any printed lacquer or adhesive layers. Stickers are printed onto an already produced body, consisting of coated foil or paper which contains adhesive. Therefore, the only to be printed layers are the colours. The standard digital printers print the colours in halftone as described earlier. The combinations of those four colours cannot represent the whole colour spectrum and therefore more professional printers use up to eighteen different single colour tones. (Has, 2008)

There are two ways of digital printing either inkjet or toner prints. Both do not require any preliminary work such as stencil or printing plate creation. The printing sheets are designed and in the inkjet technique sprayed accordingly with piezo electric controlled jets. The digital toner printers work such that a cylinder is loaded electrostatically according to the print layout and the toner sticks to the negative loaded areas. During the printing the toner is then pulled with an electrostatic discharge onto the printed media. No matter which method is used and how many colours a digital printer contains, all colours are printed in one machine run. In addition, how the colours have to overlap, be arranged, and which size each colour spot requires is calculated and done by the printer. (Brekalo & Knok, 2010)

In the sticker production therefore the manual process or interventions during the print sheet setup and arrangement is tending to zero. Systems exist which can automatically arrange a printing sheet and calculate the costs behind each of the different arranged sheet setups, such that the only task is to choose the batch setup which best fits into the program and is cost efficient. Up to five different setups are presented at the end all having a different value in focus. One represents the sheet arrangement which produces the least costs in production, the others which use the least of a specific resource such as colours, carriers, equipment, and human resource. Since the overall costs are a combination of all these factors, it can create situations where the lowest of one resource consumption is required and not the overall cost efficient. Generally, the one representing the lowest costs is preferable, but if there is for example a machine bottleneck, it can is useful to know which sheet arrangement has the lowest throughput time at the particular machine. These types of software are called ganging software and originally developed for planning the optimal cutting layout of material sheets (leather, metals, cloth). (Shekhar, 2017)

This software incorporates the cost of production in regards to raw materials, time, and amount of prints. These values have to be clarified and defined first. In addition, rules can be implemented how the different motives can be arranged. The arrangement can be affected by the printing and post processes or be influenced by customer regulations. Since the modern digital printers have no more setup regulation these rules are further negligible. Due to the increasing development in the laser technology the post processing, more specifically the cutting, further has no more influences. The customer requirements and motive are the only limiting variables and these can be easily analysed and incorporated by the software. The software is limited by the amount of rules and variables, in particular with factors which interfere with one another.

Overall, the software is very good in arranging different jobs with little influencing factors and visualising different setups depending on the interested lowest value. They work very well with halftone prints since these are fully explored, programmed, and defined according to the digital printing machine. The disadvantages lie in the amount of variables, such as rules and on one another depending factors, which can be considered for the arrangement.

4 ANALYSIS

In this chapter the current planning situation of the collaborated company, Barta, will be analysed in respect to the information that was defined in chapter "2 BACKGROUND" and with the tools which were defined in chapter "PRODUCTION PLANNING". Therefore, the whole production is split into the previous defined production steps and each analysed according to the three resources: Raw Materials, Machinery, and Human. The demand planning influencing factors will be defined according to the previously evaluated customer situation and finally the sheet and hence job arrangement will be examined.

To analyse the resources required for the production, a value stream map was created (attached in Appendix A). The information which was gained due to this value stream map where; which raw materials are required at which station, what is the throughput time of this station, and which are the waste creating process steps which have to be optimised. All this should lead to the desired outcome of subchapter "3.4 Essential for Planning"- it creates a situation such that no resource limits the optimal production schedule. The resources required by the single departments were defined in subchapter "2.3 Production". In this subchapter it was defined which machinery is limiting, if the department has to work in a shift model, and which resources are required. For a better overview view the table in Appendix B, this illustrates all the information.

The forecasting and customer specific requirements where defined in subchapter "2.2 Customers and Requirements". The outcome was that there are four different situations which the planning has to deal with. Overall it was found that the flexibility has to be available such that smaller not forecasted production runs can be set into the schedule, without breaking the large runs into smaller parts.

The scheduling is therefore performed on a medium range time period and has to be adapted on a daily basis such that the unforeseen runs can be incorporated. All in all the system relies on a great amount of expert knowledge. How this is managed will be described in the following subchapter.

4.1 Current Process

At the moment the process at Barta works such that the orders are divided into two different sets. On one side there is the small to medium order which will be placed on a collection run and on the other side there are the medium to big size orders which can be performed on a separate run. Medium sized orders can be either produced as separate or as a collection batch, always depending where they can be best fitted, and if the product and motive design can be combined with different orders. This split is done in an expert round which meets daily and evaluates all orders. The members of this group contain the head of sales, one sales employee, the planning department, one employee from the lithography department, and the head of the post processing workstations. In this expert round the items are assigned to a batch. Collection batches are filled within three weeks and after that the following week the batch will be printed. Factors on which the decision is based are; order size, product, the amount of open collection batches, the filling grade of the open collection batches, the requested delivery date, present stock, and the motive (size and layout). The filling grade of a collection batch is considered as the percentage amount of area covered by motives. This expert round generally sets the planning for in six to eight weeks, which is then detail planned in the planning department.

After the general decisions have been made the planning department opens the batches in the ERP system and enters the first information. This so called "Drucktasche" will carry all the information required for the other departments to conduct their work. In addition, all created information is stored in this tool such that every step that was done during the production is retraceable. The first information entered into the ERP system, which was generated in the expert round is:

1. Minimum amount of carrier (by separate batches the amount of printed sheet is calculated by dividing the order amount by the multiples of the items placed on a batch/ collection batches consist in three different sizes 800, 1500, & 2500 sheets)
2. Which items are placed on the batch and the multiples which need to be placed such that the order amount can be supplied (on a 800 sheet collection batch an item requested 1600 times needs to be placed twice)
3. Which product group is produced (this defines the required carrier, base chemicals, and the screens for the basic layers)
4. Week of production
5. Delivery date of the earliest to deliver item on the batch

In the next step the lithography department needs to finalise the artworks if changes or new ones are placed on a batch. Afterwards, the sheet arrangement has to be done, since this is the essential step for the other departments to know the exact amounts of materials and equipment needed to be prepared.

The planning department can only start with the detailed planning once a batch was finally arranged, since only than the amount of print runs (required printing stations) and requested resources are given. After the sheets are finalised, the stencils creation, the carrier preparation, and the amount of lacquer, adhesive, and colours required can be planned. The required resources are than entered into the "Drucktasche" by the planning department. The amount of carrier needed is calculated by a formula which adds the setup prints and other printing sheet losses throughout the production to the final required sheet amount. During the sheet arrangement it is possible that through a very efficient arrangement the sheet amount can be reduced or has to be increased if the rough planning in the expert round was not realizable. The amount of base chemicals required is estimated according to previous batch runs and experience. The screens do not need further planning since the department receives the tiff documents which contain all information. The detailed plan consists of a weekly overview and a daily plan. The rough plan is contained in the ERP system, yet both detailed plans, weekly and daily are separate word or excel files which have to be delivered to each station and printing machine.

Once all data is entered into the ERP system the planning department schedules the weekly plan. This is in general finalised Wednesday for the next week. Typically, the detailed plan for ninety percent of the next two weeks, solely missing is the closing collection batch for that week. For the detail plan the factors, amount of printing sheets, printing machine availability, raw material availability, stock information, resting times, drying units required for the layers, amount of printing units required by the produced product, queued batches, requested delivery time, setup times, and human resources are considered. The human resource plan is done by the head of the printing department and is settled for the next two weeks.

The post processing plan is created once the finalised printing plan is set. All post processes queue the batches according to the one containing the item with the earliest delivery date. This process is monitored by again an efficiency and effectiveness KPI. The efficiency is defined as the sheets per hour, which can be processed in the department per worker. In the last three years this KPI increased slightly from ninety nine to one hundred and three sheets per hours. The effectiveness is defined if they are able to hand all necessary items to the next station, the packaging and sending department.

Generally, it is planned that a batch requires on week in the pre-printing departments, one week in the printing department and one week in the post processing departments. Therefore three weeks are a realistic throughput time. The reason why six weeks delivery time is given, are the collection batches which require up to three weeks until they are filled with items. When adding these three weeks to the three weeks of production it leads to the six weeks. Therefore separate production runs can be easier manoeuvred and scheduled. Most separate productions are further produced to stock, since the storage costs of the small transfers are negligible. Further, the company has enough available self-owned storage capacity leading to no costly impacts.

To better access the system the time for planning a daily, weekly, and rough plan was taken. The rough plan takes fifteen minutes per day of the five members in the expert round, equalling to seventy five minutes. The weekly plan requires in total five hours and the daily two hours. These times do not incorporate any changes done in the week or day of the schedule. Further, the KPI's of the process where monitored intensively to notice any changes. The efficiency KPI equals the average printing machine utilisation. In the past three years it was constant at around eighty percent. The effectiveness KPI represents if the amount of batches planned could also be produced. The percentage value here for lies at one hundred in the past three years. These values will be analysed after changes have been made to the system, to access if the process performance is maintained or positively or negatively influenced.

4.2 Restrictions of the Current System

The current system works due to the enormous knowledge contained in the planning department, which already intuitively plans incorporating all the factors. The main difficulty is that the influencing factors are not all reported and entered into the ERP system and therefore unknown to the other entities. Following section will therefore analyse which of the input information is not accessible and which problems arise when the lead planner is not available.

The first rough plan is conducted as mentioned earlier in the expert round. The decisions are based on printouts of the orders and so called item cards which are printed cardboard sheets containing among others the necessary motive information (size, colours, product, etc…). Each item has one card and this is passed through the entire process flow until the next order when it comes back to the expert round. This leads to a situation in which the necessary information has to be searched on different printed documents (item card and printed order), which can lead to confusions and an inefficient workflow if this process is not conducted on a regular basis. In addition, the information about the filling grade of the open collection batches is not available in this meeting but have to be memorised before. It further requires that all orders and item cards have to be reviewed first by each individual member which takes part in the meeting and prevents the ability to compare the items directly to each other. A direct comparison could lead to a better decision of which items should be gathered in a collection batch. The decisions are noted into special order books and later this information is transferred to the ERP system.

Once the rough schedule was created, this is currently not presented to the other stations. This could though already supply some beneficial information for their rough planning for the future weeks. The rough plan is set for the next six to eight weeks and contains seventy percent of the printed batches. If this information was provided to the pre-printing departments the resource planning could be handed to the department and one responsibility taken away from the planning department. The data about the resources are now provided by the divisions but the overview if sufficient resources are given is done by the lead planner. If the special information for each department which the rough plan contains could be displayed to the division the resources could be planned appropriately and not the schedule according to the resources.

Since the plan of the following week is only finalised on Wednesday, the preparation time for each station is respectively short. Since some steps require more time to be a relatively large safety stock has to be held. As an example, the stencil creation department needs to coat the screens before being able to laser them. Only once a coated screen contains the stencil it is unique for the batch. Therefore, the coated screens are not yet assigned to a batch and taken from stock. As mentioned earlier after coating the screens should be lasered as soon as possible. If the department would have more thorough information earlier of which screens will be needed for the next week these could be put in stalk rather than producing on expectations and lead to situations in which coated screens are stored for up to three weeks.

Further, having the detailed plans as separate documents time is wasted for the distribution and no meaningful examination can be done. The information can further not be broken down into parts which are required for the single departments, but each department needs to work and rely on these printed forms. Small adaptions and changes in the plan lead to a lot of new printouts and there is a risk of old schedule being used.

Since there is no valuable information other than the delivery date, all post processed jobs are solely regulated with this parameter. In addition, the delivery date of a collection batch is defined by one item, which has the earliest. This could lead to a situation that a batch is processed due to one item and a different batch put aside although the overall priority would be higher. Furthermore, assigned delivery dates are not always requested from the customer but defined in expert round. The determined date is given to the customer causing situation that the items would not need to that date, but internally it is still scheduled correspondingly. In these cases it would be misleading to rank according to the date. The KPIs of this process are represented by the delivery rate and the amount of sheets which are controlled per hour per worker. The delivery rate is on average ninety nine percent and one hundred and three sheets are controlled per worker, per hour.

4.3 Printing Sheets

The printing sheet arrangement is the most vital factor in all of the planning processes. Therefore, the process will be separately illustrated and examined in this subchapter. Especially the focus will be set on which rules the arrangement is based on, how these interfere with each other, and finally comparing it to the automatic ganging software.

The first step is to compare each of the item cards and arrange these according to the products and colours. The same colours and products should be gathered in special areas on the printing sheet, such that these can be printed together on one printing unit with an iris setup. According to that gathered piles the sheet is arranged such that the desired multiples of each item can be placed. The placement has to follow some very strict rules, which were established over the years originated from the different processes. Following the rules are listed:

1. Each motive requires a minimum boarder of 10 mm (25 mm for the reflective product) on each side
2. Some customers define exact carrier sizes which dominate the setup

3. All cut lines have to be in a straight line, this constrain comes from the cutting department since discontinuous lines would require more cuts and movements of the fifty sheets stacks
4. When having an iris print, the distance between two different layers needs to be minimum 5 cm
5. Each iris print needs to contain control marks
6. Control marks need to be set 5 cm from the sheet edge
7. The positioning marks, to align the different layers need to be placed on the sheet
8. Special items need to be always placed vertically to the printing direction others horizontally
9. When placing reel items onto the sheets the alignment punching holes of the sheet is not allowed to be in the same lane as a stop mark
10. When mixing single cut and reel items, maximum 240 mm from both sides can be used to place reels and the rest can be filled with single cut items.

The arrangement setup is done either digitally or manually with older staff members who are not technically affine. All in all the process works very well and creates, on average, over all the batches ninety percent of the sheet is utilised. The most difficult part while arranging is the interferences of the different rules. For example the colours of five items would perfectly fit into one iris print setup but due to the issue that four items are single cut and one is a reel, they cannot be placed together and create the need for one extra printing unit. A different problem arises, since it is not always clear which feature is preferred. Is it better to arrange a sheet such that one more printing unit is required but only 1 500 sheets have to be printed or would it be better to print 2 000 sheets and reduce the amounts of printing units required. In the end it depends if the extra printing unit would mean one more print run through the machine or if it would not change the amount of passes the batch has through a machine. This information is though not known by the employees creating the sheet arrangement. This has to therefore be clarified with the planning department and causes waiting times. Crucial for this decision are not just the amount of layers but also the type of layers which have to be printed. As mentioned earlier some require extra drying units or resting times.

When comparing the rules, interferences, and other required information to arrange a sheet in the optimum setup at Barta, to the information that ganging software works with, it can be concluded that it will not be able to process. Ganging software suppliers where contacted and asked to reproduce the sheet arrangements. The major issue was that there are too many depending variables. Generally, different values and costs are assigned to each decision the software hast to make. The decisions are done such that the overall lowest sum of those values is produced. The results of these decisions are than portrayed as the five selectable sheet designs. Due to the many depending variables, the decisions would have different values depending on other variables and hence it would get to complex for software to follow through. The previous decision if it is cheaper to choose the extra printing unit or produce more sheets can be analysed as following. The value for the extra sheets can be easily calculated, the cost per sheet and the time required for printing one sheet is known. Now the software would though also need to calculate the extra costs of using one printing unit more. It first has to decide if the extra printing unit would create an additional machine run, if so the price would be higher. To conduct this decision the required printing stations need to be clarified. Therefore the information which layer requires how many printing units needs to be available to compute. To therefore conduct one decision three extra variables would need to be considered and an extra question answered. This would though just be one decision of many which would have to be done during the sheet arrangement.

Overall the software required for such arrangements would have to incorporate an expert system, which on itself is difficult to establish. Combining these two systems would exceed the boundaries of all economical possibilities. Ganging software are designed to focus on the artwork which has to be visualised in halftone print and where all prints are done digitally. As explained in the section “3.5 Planning Systems in the Printing Industry” these systems do not have to incorporate all the restrictions due to pre and post working and can solely focus on the sheet setup.

Over all the sheet arrangement can be concluded to be the part in the planning which is essential for all the other surrounding processes, but cannot be automated with ganging software due to the high complexity. In this section expert systems would be of importance to best see how to combine jobs such that they are produced with the lowest costs.

4.4 Changes to the System

The major changes which are made to simplify the planning process and create the possibility that the scheduling can be conducted by any standard skilled worker will be defined in this section. In addition, the optimisations are also targeted to reduce the planning times to make the planning process more efficient. The changes will be listed according to the planning process flow. First the changes required for a better rough plan are described, followed by that of the weekly plan, and eventually for the daily plan.

The information required for the rough planning comes from the sales team. In the expert round the information is presented and discussed with the cards and printed order confirmations. To smooth the process and incorporate all the information such as the filling grades of the batches a cockpit containing the information was created. This cockpit enables each interested party to compare all open orders in regards to the previous defined required parameters. In the cockpit the planning department can already assign items to specific batches and monitor the filling grade live. The expert round then only has to meet once a week to discuss any extraordinary orders and situations.

The information created by this rough schedule will directly be reported to the created cockpits of the other departments. Again these cockpits not just enable a better visualisation, but also have the possibility to enter all created information which can be valuable for analysis and other decisions during planning.

In addition, more information for the sheet arrangement is provided to the lithography department. This includes a thorough analysis of the layers and printing sequences, the establish table which is coherent clearly represents the connections and correlation of the different parameters. With this clear overview the consultation of the planning department during the sheet arrangement and hence waiting times is tried to be reduced.

The weekly and daily planning is incorporated into the ERP system leading to the possibility that all stations and different printing machine can have the actual schedule and hence reduce the print outs and distribution times. Again this cockpit enables entries such that more information is created and can be evaluated with regards if the schedule was good or had deficits.

Especially the planning of the post processes was renewed. This was a simple heuristic approach, leading to many difficulties in the past years. Since the sales information is better visualised in the rough planning, the jobs can be prioritised throughout the production by any empowered employee, particularly by the sales team. With this it is possible to rate a batch according to the priority which incorporates more factors than just the delivery date. The priority is defined by the customer size, the need of the customer for the products, and the amount of required items. In addition, also the post processing departments can enter the waste after inspection and processing times for each item, such that these inputs can be analysed and later used to better prioritise.

Overall the approach chosen to achieve the goals was as the literature recommends, to digitally visualise the information such that it can be distributed easier, resources can be planned beforehand, and a greater flexibility towards the customer is achieved. The better overview should lead to more informed decisions and reduce the know-how required by the lead planner. Further, it should distribute responsibilities to stream line processes, reduce equipment stock, and plan resources beforehand rather than adapting the schedule to the resources.

5 RESULTS

In this chapter the results gained from the changes are discussed. On one side the defined values are analysed and compared and on the other side the intangible advances that the optimisations created are examined. Not all modifications could be done at once, therefore they were implemented one after each other. It was started with the rough plan and continued according to the process flow. Overall, the implementation took 4 months, which leads to a situation in which some values could be monitored longer than others.

During and after the changes got implemented the defined KPI's and times where analysed to see if any value increases or decreases. Table 2 illustrates these values according to the monthly average.

Value	Stand.	Oct.	Nov.	Dec.	Jan.	Feb.
Efficiency (Machine utilisation)	81%	78%	83%	85%	79%	87%
Effectiveness (if the daily schedule could be met)	100%	99%	98%	110%	100%	100%
Rough Plan (per week)	375mins	280min	200 min	210min	180min	150min
Weekly Plan (per Plan)	5h	5.3h	5.1	4.5h	4.7h	3.9h
Daily Plan (Per Plan)	2h	2.5h	2.3h	1.6h	1.2h	1h
Sheet utilisation	90%	88%	86%	91%	90%	95%
Sheets per Hour (average over workers)	103	102	105	95	103	102
Delivery rate	99%	100%	100%	98%	100%	99%

Table 2 KPI and times per month

The rough planning changes were implemented in October. The first two weeks the expert round would still meet daily to see if all data was on hand and the cockpit useable. The first meeting took forty five minutes but after that the daily meeting were reduced to five minutes per day. After the two weeks the meeting was reduced to every second day and eventually in November to once a week. The weekly meeting was longer than the previous daily meetings average duration. This is observable in Table 2 which represents the decreasing time for the rough planning. The more the system was incorporated the lower the amount required for expert rounds and meetings.

The optimisations to the other cockpits where completed in the following month. This at first had no noticeable influence on the times or on the effectiveness. It though created situations in which the planning department was informed about resource difficulties four weeks ahead and the rough plan could already be adjusted, leading to a situation that due to delivery difficulties of a raw material supplier big batches which were produced to stock could be rescheduled such that all produced to call off orders could be delivered. In addition, the implementation of the new cockpits throughout the processes could reduce the time required for the detailed plans. At first as represented in Table 2, the times increased due to the new system implementation, but towards the end the daily planning was reduced by fifty percent. The biggest influencing factor to the time reduction was that the plans had no longer be printed and delivered to the single stations.

The last implementation was the overview for the sheet arrangement, because it took longest to define and edit the necessary data. This change was finalised only in February and therefore the time was not sufficient to analyse any changes.

Overall it can be observed that the efficiency of the planning, represented by the machine utilisation was not negatively impacted by any of the changes. Especially in February the highest value over the last ten years was achieved. Furthermore, the effectiveness of the planning was also maintained. There is one outlier in December were the effectiveness lies by one hundred and ten percent. One hundred percent can be exceeded if the printing staff finished before time with their work and start with the next job. In general, this would mean that the planning did not fully fill the schedule. The reason why December has such a high value can be traced back to the printing cockpit, since the printing staff had a better overview, they could pull different jobs ahead and rearrange the daily schedule such that it would better fit into the moment. Factors which cannot be included by the daily planning but have a huge impact on the schedule are the environmental settings which change during the day and can be best balanced by the printing staff.

Lastly the values defined for the post processing departments show no negative changes but also no positive tendencies. Since the department already had sufficient values before, the goal was not to change these, but to reduce the know-how required to plan and have better parameters to place the decision which batch is queued first. In addition, some intangible effects were noticed. The communication between the sales and planning department was reduced, leading to a further reduction which is not visible in these values.

Concluding, it was observable that the planned and unplanned meetings required to create a valuable plan could be reduced. All in all the time throughout the planning was dramatically reduced. The cockpits where sufficient to transport the information and since each entity could enter appropriate data, this could further be immediately used to make decisions in the other departments, that this new information would apply to. In addition the printing staff had the ability to change the daily program according to the environmental influencing factors and therefore be more self-controlled.

6 SUMMARY AND OUTLOOK

A common issue affecting all companies is the knowledge loss due to retirements and natural personnel fluctuation. Employees that grew with an enterprise and developed a huge knowledge base to conduct their daily work at top standards are especially valuable. Further, these members bare the risk of a huge knowledge loss when they leave. This problem was the main reason why this thesis was done in collaboration with the Franz Barta Gmbh. The threat of the pending retirements especially in the production planning department and the sub sequential knowledge loss is high. This lead to a situation in which the company required an optimisation of their production planning process, such that it can stay competitive after the employee leaves the company. The situation at Barta is such that the two planners deliver efficient and good schedules, but the process cannot be taken over by any standard skilled employee yet. Furthermore, the process is outdated and parts can be easily implemented to the ERP system, such that the time required to plan can be reduced.

The importance of production planning is strong in all kinds of industries. The thorough literature analyses showed a vast majority of influencing factors and how these are managed to best schedule and hence prosecute a cost efficient production in economically high developed countries. The main difficulty with all the planning methods is that they are only simulations and generally only function with simplified and abstracted situations. The more information that needs to be comprehended and considered by the simulation, the more inefficient and misleading it will get. The most accurate simulation is the expert method, which though requires a lot of setup times and money. Specific domain knowledge is required which is further hard to gather since many decisions are based on intuition and cannot be easily rationalised or quantified. Finally, even after such simulations have been programmed the usability is complex, due to unhandy user interfaces and maintenance, adding more data and new parameters is difficult and still requires a lot of knowledge.

In addition, a great influence is the performance of the single departments. The scheduling can only work with the given situations and information. Therefore an important aspect, when optimising the production planning, is also to analyse all processes in manufacturing and administrative, overall in the whole enterprise, to stream line these. Optimised process flows reduce waste times and hence the more time the planning department can schedule for value adding work. The streamlining is not the task of the production planning but a companywide endeavour. Therefore, especially all production processes where analyse with a value stream map and wasted times defined and reduced by applying Lean and JIT philosophy tools. The major point aiding the production planning was the integration of more information and better accessibility to the data carried by the ERP system to the single divisions.

Furthermore, the different divisions create and hold information which is valuable for the entire production. Thus, a station which is fully incorporated into the ERP system and represents all necessary information clearly the simpler it can be analysed and hence lead to the best scheduling decisions. Moreover, each department can see the information which is valuable for itself and responsibilities, decisions, and material planning can be handed to the single divisions and hence the workload of the planning department is reduced. An unforeseen result that occurred was that the printing staff could far easier adapt the daily plan according to environmental influencing factors, which could not be incorporated at the planning stage.

Inputs into the system are not just important from the single divisions, for the planning department, but also from start of a project or order from the sales team. The information regarding the customers is most vital for all of the further scheduling. In the literature review the forecasting for orders and how to reduce the risk of the bullwhip effect over the whole supply chain was analysed. To forecast orders as well simulations where created to conduct the most educated guesses, but only relying on these models can cause issues of overseeing other parameters not incorporated into the simulations. All leading to the outcome, that thoroughly defined projects in terms of amount and call offs, and the more information regarding safety stock and final customer demand throughout the supply chain is available, the simpler and more efficient a schedule can be created. Further, the review showed that customers, in general, change to a more unforeseeable ordering behaviour, which leads to the necessity of a great flexibility in the production planning. More flexibility is created by a higher degree of digital visualisation such that data can be received and comprehended live. The customers of Barta are segmented into four ordering behaviours, of which three can be used to smooth the production plan and the unforeseen orders can be shortly integrated into the schedule and hence supplied due to collection batches. With the creation of the rough planning cockpit, which consists of the thorough customer and order information the time intensive expert meeting could be reduced and orders could be straightforward compared to each other, leading to the ability to better assignment jobs to collection batches with less intuition and rather based on facts. This enables the process to be done by less experienced employees.

The sheet arrangement was defined as an important aspect in the planning, since it would determine how good a batch is filled with items and hence the costs of production. An analysis of software was performed and illustrated the restriction and hence why it cannot be used at Barta. A structured overview of the interfering and general parameters was created, to aid and foster the right decisions. The implementation of this table was time consuming and therefore only handed to the division in February. Therefore, the output of the implementation could not be fully analysed in the thesis. What could be observed was that the communication and know-how exchange with the planning department was reduced by a great amount, leading to less waiting times and should finally result in a lower throughput time.

Concluding all changes originated from this thesis and implemented at Barta could reduce the time required for scheduling, could increase the information flow such that workload and responsibility could be taken of the planners, schedules could therefore be based on more valid and significant values, the processes at the single divisions where analysed and waste times reduced, and finally the system could be changed with not negatively influencing the process capability.

The next step that will be conducted is to hand the new process to a standard skilled employee and compare the outcome with that of the lead planner. This would proof if the overall goal of the thesis, to create a process which can be managed by someone other than the lead planner can be established. At the moment it seems that all implemented adaptions simplified the process enormously and hence made it more efficient. Furthermore, the integration of the overview table for the sheet arrangement have to be analysed and monitored, to see how this affects the processing times and sheet utilisation. If this table can be further clustered and less dependent values can be created on which decisions are formed a new try to implement ganging software can be analysed.

The greatest advancement is that the divisions can implement the data into the ERP system and new connections between different parameters can be found. This can foster the implementation of an expert simulation system, since the process could be found to be best described by only a few input parameters. This could eventually create the possibility of a state of the art automated production planning process.

REFERENCES

Abdel-Malek, L. & Das, S. K., 2003. Modeling the flexibility of order quantities and lead-times in supply chains. *International Production Economics 85*, pp. 171-181.

Abdul-Nour, G., Lambert, S. & Drolet, J., 1998. Adaption of JIT Phylosophy and Kanban Technique to a small sized Manufacturing Firm. *Computers and Industrial Engineering,* Issue 35, pp. 419-422.

Al-Radhi, M. & Kamiske, G. F., 2002. *Total Productive Managment.* 2. ed. München: Carl Hanser Verlag.

Ansari, A. & Modarress, B., 1995. Wireless Kanban. *Production and Inventory Manangement Journal,* 36(1), pp. 60-64.

Bellman, R. E., 1961. *Adaptive Control Processes.* 1. ed. London: Rand Corporation.

Bertrand, J. W. M. & Rutten, W. G. M. M., 1998. Evaluation of three production planning procedures for the use of recipe flexibility. *European Journal of Operational Research*, 21 04.

Biedermann, H., 2016. *Industrial Engineering und Management.* 1. ed. Wiesbaden: Springer Gabler.

Biethahn, J. & Schmidt, B., 1987. *Simulation als betriebliche Entscheidungshilfe.* 1. ed. Berlin: Springer.

Brekalo, S. & Knok, Z., 2010. *Digital technology application in production of labels and stickers in rolls.* Stubicke topice, Hrvastska, Znanstveno stručni skup Tiskarstvo.

Engelmann, A., 1950. *Der Offset Druck in der Praxis.* 2. ed. Leipzig: Fachbuchverlag GMBH.

Goldberg, D. & Harik, G., 1995. *Human behaviour, computation and the design of manufacturing systems,* Urbana: University of Illinois at Urbana-Champaign.

Graves, R., Konopka, J. & Milne, R., 1995. Literature Review of meterial flow control mechanisms. *Production Planning and Control,* 5(6), pp. 395-403.

Grünwald, H., Striekwold, P. & Weeda, P., 1989. A framework for qualitative comparison of production control consepts. *International Journal of Production Research,* 27(2), pp. 281-292.

Has, M., 2008. Ink feed control in a web-fed offset printing press. *The International Journal of Advanced Manufacturing Technologies*, 01 11, p. 414.

Kargar, D. W. & Bayha, F. H., 1987. *Engineering Work Measurment- The principles, techniques, and data of Methods-Time Measurement, background and foundations of work measurement and MTM, plus other related material.* 4. ed. New York: Industrial Press.

Kister, T. C. & Hawkins, B., 2006. *Maintanance Planning and Scheduling.* 1. ed. North Charleston: Butterworth-Heinemann.

Kletti, J. & Schumacher , J., 2011. *Die Perfekte Produktion.* 1. ed. Berlin: Springer.

Lage Junior, M. & Filho, G. M., 2010. Varaitions of Kanban Systems: Literature review and classification. *International Journal of Production Economics,* 125(1), pp. 13-21.

Lambert, S. & Kareta, N., 2021. *Mes Insights.* [Online] Available at: https://www.mes-insights.com/the-automotive-supply-chain-tier-suppliers-explained-a-966964/
[Accessed 01 02 2021].

Nellemann, D. O. & Smith, L. F., 1982. Just-in-Time vs. Just-in-Case Production Systems Borrowed Back from Japan. *Production and Inventory Management Journal,* 23(13), pp. 12-21.

Parson, G. & Rafferty, J., 1998. *Tag Image File Format (TIFF) - F Profile for Facsimile.* [Online]
Available at: https://www.hjp.at/doc/rfc/rfc2306.html
[Accessed 01 02 2021].

Pastore, E., Alfieri, A., Zotteri, G. & Boylan, J. E., 2020. The impact of demand parameter uncertainty on the bullwhip effect. *European Journal of Operational Research,* 283(1.), pp. 94 -107.

Pochet, Y. & Wolsey, L. A., 2006. *Production Planning by Mixed Integer Programming.* 1. ed. s.l.:Springer Science & Buisness Media.

Reichel, J., Müller, G. & Mandelartz, J., 2009. *Betriebliche Instandhaltung.* 1. ed. Berlin: Springer.

Scheer, A. W. & Habermann, F., 2000. Making ERP A Success. *Communications ot the ACM*, 01 04, pp. 57-60.

Scheer, H. G., 2007. *Siebdruck Handbuch.* 1 ed. Lübeck: Der Siebdruck.

Shekhar, R., 2017. *Software Imp* [Interview] (14 07 2017).

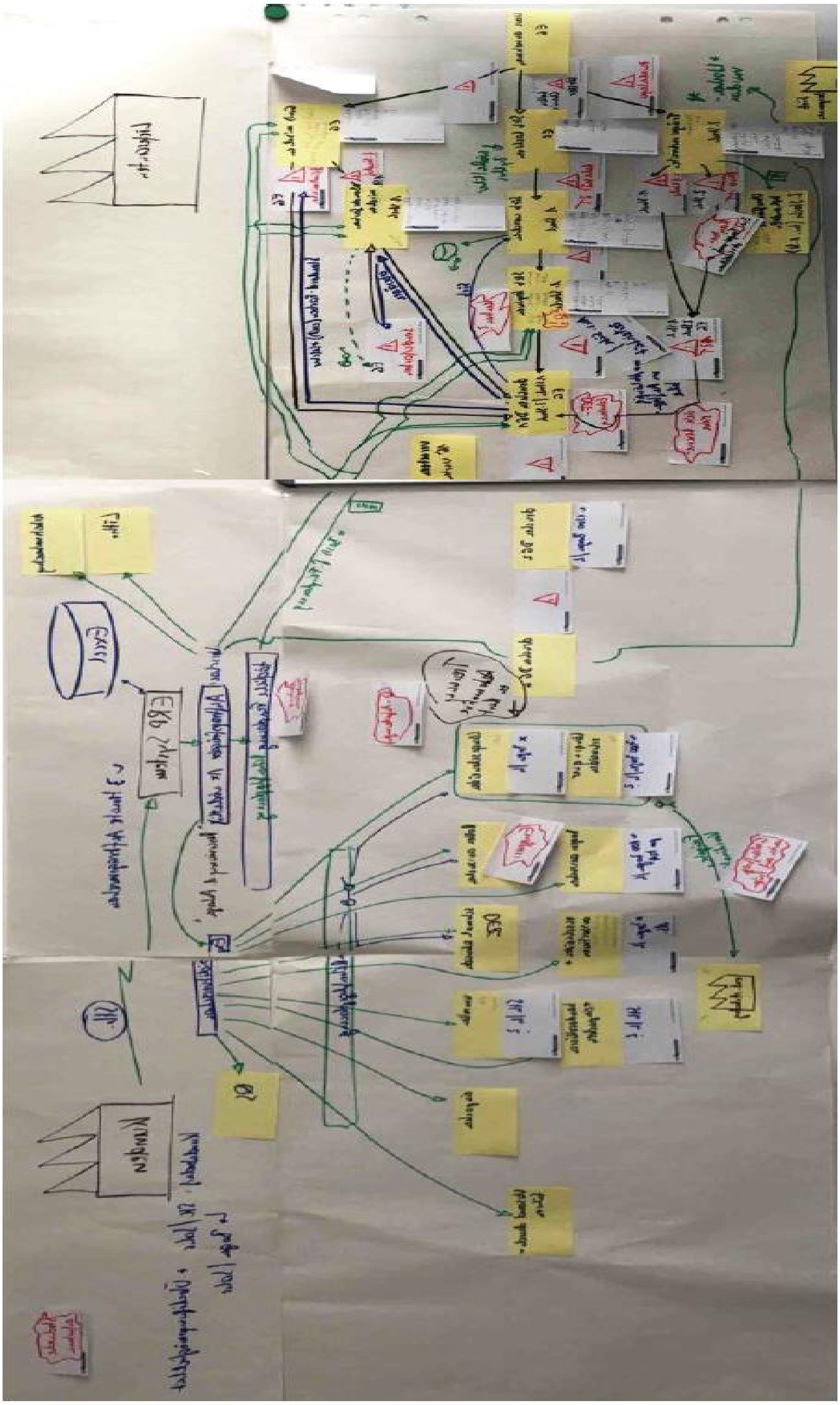
Shiroma, P. J., 2013. *Efficient Production Planning and Scheduling: An Integrated Approach with Genetic Algorithms and Simulation.* 2. ed. s.l.:Springer Verlag.

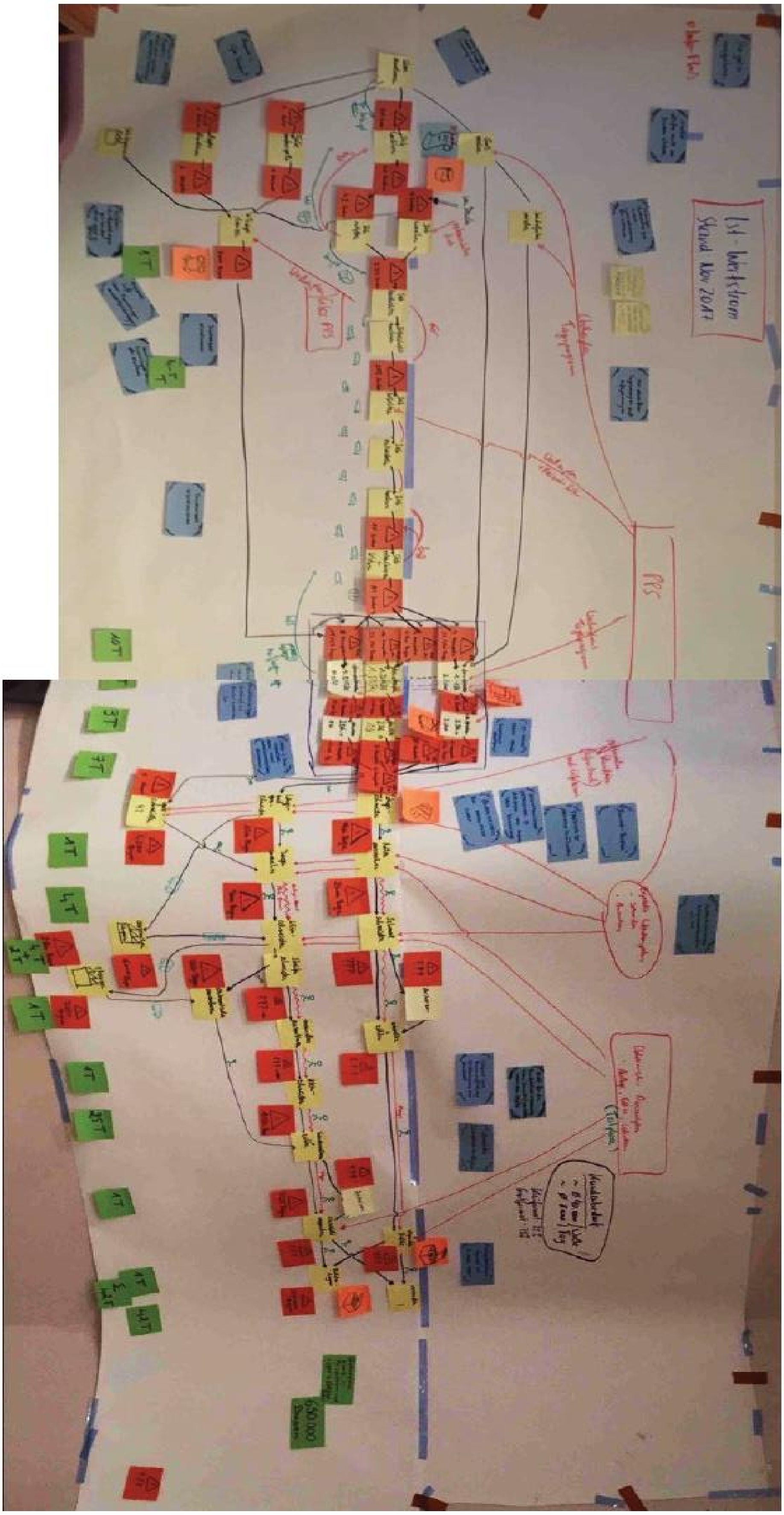
Vollmann, T. E., Jacobs, R. F., Berry, W. L. & Whyback, C. D., 2005. *Manufacturing planning and control for supply chain managment.* 5. ed. Boston: McGrawHill.

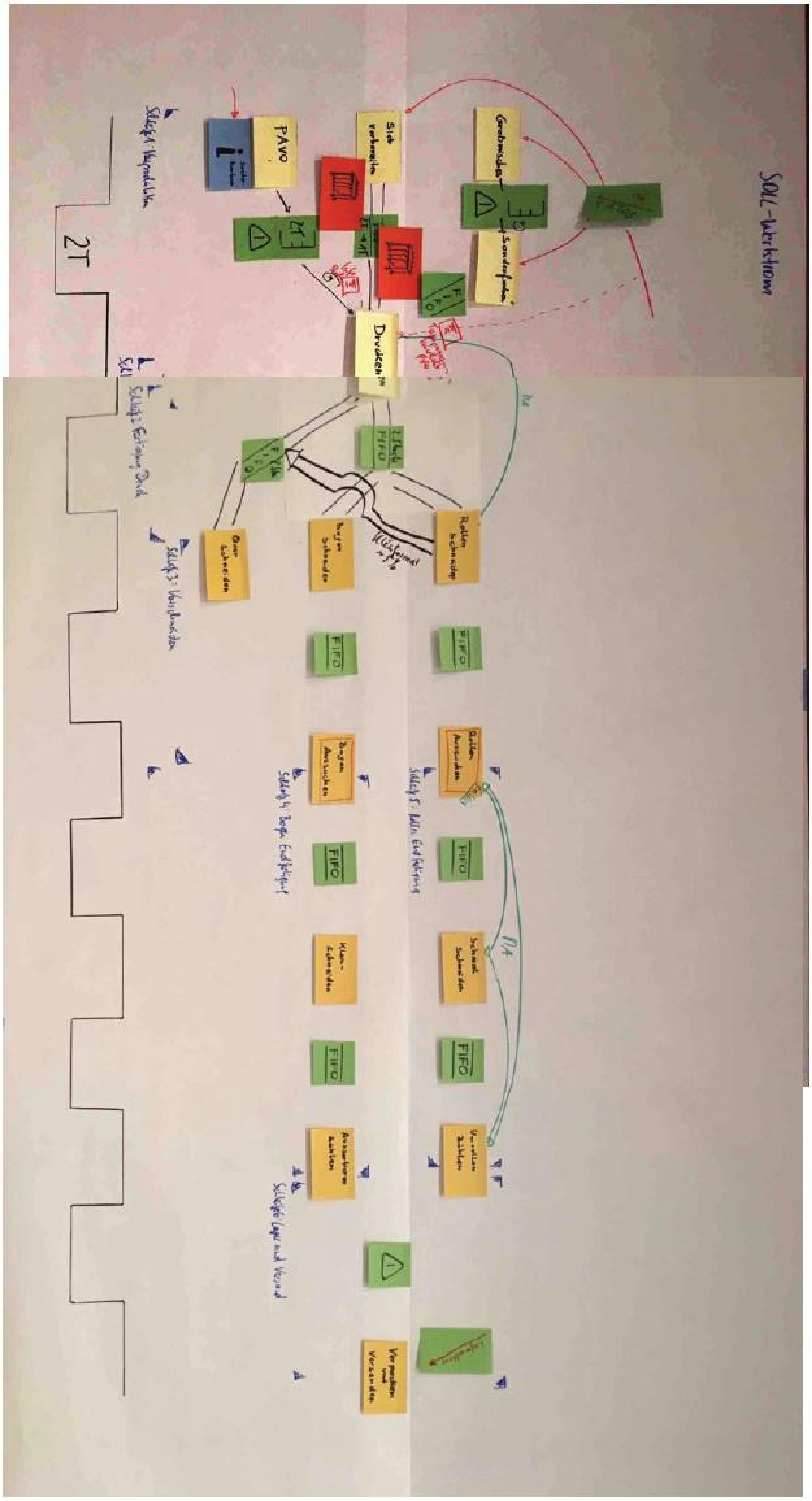
Wiendahl, H.-P., 1992. *Die belastungsorientierte Fertigungssteuerung.* 2. ed. Wiesbaden: Gabler Verlag.

LIST OF PICTURES, FIGURES, TABLES

APPENDIX A






SOLL-Wertstrom
PAVO
Drucken
2T
FIFO
FIFO
FIFO
FIFO
FIFO
FIFO

APPENDIX B

Process step	Number of Employees	Shifts	Limiting Factors	Average throughput time
		Lithography		
Editing Artwork	3	1	Human	1.5 h
Proof	3	1	Human/ Approvals	4 Days
Finalising Artwork	3	1	Human	1 h
Sheet Arrangement	2	1	Human/ Approvals	3.5 h
Total	**5**	**-**	**Human/ Approval**	**5 Days**
		Screen Creation		
Coating	2	2	None	10 min per screen
Laser	2	2	Machine	15 min per screen
Washing	2	2	Machine	8 min per screen
Finalising	2	2	None	5 min per screen
Total	2	-	Laser and Washing machine	38 min per screen
		Carrier Production		
Acclimatisation	1	1	None	1 h per reel
Punching	1	1	None	2.5 h per reel
Total	1	-	None	3.5 h per reel
		Mixing Department (Chemical)		
Mixing	3	2	Raw Materials	2 h per mixture
Delivery	3	2	None	10 min per delivery
Total	3	-	Raw Materials	2.17 h per mixture
		Colour Department (Chemical)		
Tinting	3	3	Human	2 h per tinting
Mixing	3	3	None	0.5 h per mixture
Delivery	3	3	None	0.5 h per mixture (testing)
Total	3	-	Human	1 h per mixture

Printing				
Pre Printing	2	1	Equipment	1 h per batch
Printing	15	3	None	2 Days per Batch
Total	15	3	None	2 Days per Batch
Cutting				
Sheets/ Mix	2	1	None	3.5 h per batch
Reels	2	1	None	2.5 h per batch
Total	2	1	None	3 h per batch
Reel Post Processing				
Inspection	5	1	None	5 h per batch
Cutting	2	1	None	3 h per batch
Finalising	3	1	None	2 h per batch
Total	9	1	None	10 h per batch
Single Cut Post Processing				
Inspection	5	1	None	5 h per batch
Cutting	2	1	None	3 h per batch
Finalising	5	1	None	2 h per batch
Total	12	1	None	10 h per batch