UNIVERSITY OF TWENTE.

IPSKAMP printing
books and more

Reducing the collection time of printing orders at Ipskamp Printing

Bachelor graduation thesis

Victor L. Hettema

FACULTY OF BEHAVIOURAL, MANAGEMENT AND SOCIAL SCIENCES (BMS)

INDUSTRIAL ENGINEERING AND MANAGEMENT (IEM)

Reducing the collection time of printing orders at Ipskamp Printing

Author:

Victor L. Hettema

v.l.hettema@student.utwente.nl

Ipskamp Printing B.V.

Auke Vleerstraat 145

7547 PH Enschede, The Netherlands

+31 53 482 62 62

University of Twente

Drienerlolaan 5

7522 NB Enschede, The Netherlands

+31 53 489 9111

Supervisor Ipskamp Printing

Peter Wientjes

Supervisors University of Twente

Dr. Ir. Leo L.M. van der Wegen

Dr. Lin Xie

Publication date: 9 October 2023

Number of pages: 41 (66 including appendices)

Number of appendices: 3

Preface

Dear reader,

In front of you lies my bachelor thesis titled "Reducing the collection time of printing orders at Ipskamp Printing", which concludes my Bachelor of Industrial Engineering and Management at the University of Twente. I prepared this thesis between February and August of this year and executed it between August and October. As the title states, the goal is to reduce the collection time experienced by the production workers at Ipskamp Printing. I am happy to conclude that this goal has been achieved, and I hope Ipskamp Printing implements my suggestions as soon as possible.

I want to thank Ipskamp Printing for providing me with the opportunity to execute my thesis there and for providing me with a place where I could work. I want to especially thank Peter Wientjes, my supervisor from Ipskamp Printing, for always being there for me and helping me throughout my research. Even though he had to be 3 places at a time on a regular basis, he always found time to help me when I was stuck on something.

I also want to thank my UT supervisors, Dr. Ir. L.L.M. van der Wegen and Dr. L. Xie, for helping me and providing me with valuable feedback throughout my research journey. Their feedback and critiques made sure that I could elevate the quality of my thesis to the next level.

Finally, I want to thank my family and friends for their support throughout my bachelor thesis. I experienced quite some ups and downs throughout these past 10 weeks, but I am very happy they were there for me when I needed them.

I hope this bachelor thesis sheds some light on the journey I've made in becoming an industrial engineer and shows you how I've grown academically.

Victor Hettema

Enschede, October 2023

P.S. I'm also happy to announce I have received a job offering from Ipskamp Printing for the role of Process Engineer, where I will be tasked with overseeing the implementation of the recommendations made in this thesis. I have happily accepted their offering and am very interested in seeing where this role will take me professionally.

Management summary

Research question

This Bachelor thesis is executed at Ipskamp Printing, a printing company located in Enschede, which produces almost anything using a paper medium but focuses on books, brochures and theses. Due to Ipskamp Printing merging with another printing company, they have grown very quickly over the past couple of years. Sadly, production capacity has not grown at the same pace, resulting in relatively many orders being delivered too late. That is why the goal of this thesis is to reduce the collection time experienced in the production process of Ipskamp Printing. More specifically, the following research question is answered by this thesis:

How can Ipskamp Printing improve their storage system to reduce the collection time per production order by at least 30%?

After the research question was determined, the research started with determining what would be the deliverables of the thesis, which are: a product categorization, an overview of all production steps, a collection time distribution and an improved storage policy. These four deliverables will answer the research question together.

Research setup and deliverables

Using the physical characteristics of each order, 17 categories were created and the frequency of each category was extracted from the database of Ipskamp Printing. The characteristics determining a product's category are: the paper type used, whether the product is laminated or not, whether the product has a sewn book block or not and the binding type.These categories were used to show the production steps required for producing them, because their characteristics determine which production steps are required, and later on in the thesis, the categories will be used to determine the collection time distribution of each product sold by Ipskamp Printing. It became apparent that only 8% of the orders at Ipskamp Printing require exotic paper, which is paper that has to be specifically ordered for a specific order. Next to that, gluing is the most popular binding method. The production steps performed by the production department were explained using these categories.

When the product categorization was made, the collection time distribution of each of them had to be determined. Achieving this goal started out with a dataset consisting of 105 datapoints that were collected by a worker on the binding machine. Of these 105 datapoints, 98 were used and made up the foundation for the collection time distribution. Due to only one dataset being collected at one machine, the assumption had to be made that, because each production step collects the same half fabricates from the same storage areas, they experience the same collection times. When the dataset had been processed, Microsoft Excel and a summed squared residuals test were used to determine the collection time distributions for collecting only the book block and collecting both the book block and cover, which follow an ~exp(0.008439) and ~exp(0.006275) distribution, respectively. Due to a lack of a dataset on the collection time of exotic paper, a ~norm(330, 3600) distribution of exotic paper collection time was estimated by the printer operators. These distributions result in a range of expected collection times per product category of between 118.5s and 607.9s.

The final deliverable is an improved storage policy. This deliverable combines the previous three deliverables and requires a systemic literature review (SLR) to provide a well-argued storage policy. The SLR resulted in theory on storage space allocation, the theory of Lean management and the Theory of Constraints. Next to the theoretical policy improvements, both production management and workers have provided some policy improvement suggestions, which were also evaluated. From these theories and suggestions, a selection had to be made for the improved storage policy. The reasoning for selecting these recommendations can be found in Chapter 4. The following section will list the final results and recommendations of this Bachelor thesis.

Thesis results and recommendations

Now follows the list of recommendations and the way I envision to implement them:

1. Use **5S from Lean management** to (schedule time to) periodically organise the paper storage areas. Together with the production workers, management should decide what the standard level of organization for both the paper delivery and standard paper storage areas will be. When this has been decided, the initial organising round must take place, which will take longer than the subsequent daily organising rounds. The workers will check at the start of each day if the these two storage areas are up to standard and if not, they will notify management. Management will figure out why the standard was not upheld and take action accordingly. Following these steps will result in two organised paper storage areas, which in turn will reduce the collection time for exotic paper and reduce the number of (unnecessary) paper orders.

2. Keep the **class-based storage allocation policy** for the large storage area in the middle of the production floor. As has been argued in Section 4.3.1, the class-based storage allocation policy is the best suited for the three storage areas in the middle of the production floor of Ipskamp Printing. However, the size of each of these three storage spaces can be changed, because due to an increase of organization in the paper delivery area, combined with less paper orders coming in, the required size of that storage area will reduce. This means that management should decide on whether the book block or finished product storage area should be assigned this free space and whether or not to switch storage areas around on the floorplan.

3. Introduce a **coloured item that can be attached to the book block carts**, which denotes the day that the book blocks on it were printed. Firstly, a colour should be chosen to denote each working day. Then the workers need to understand how to work with these coloured items and management must ensure that the workers use them. After an initial period in which everyone has to adapt to the new way of working, they will get used to only looking at book bock carts with a certain colour of attached item on it. When they are used to it, the full collection time reduction will become apparent, as the workers will search through only a few carts, instead of all.

4. **Change the shelving used to store the (laminated) covers** into shelving that is modular and has more locations. Implementing this recommendation starts with buying a new shelving frame that has shelves that lie loosely inside of it. Each shelve then becomes a storage location, on which only one order will be stored. A system of keeping track which order is stored in which location has to be thought up. This can either be done physically, by using small whiteboards for example, or digitally, for example by using barcodes on the storage locations. Using a modular shelving system will reduce the collection time for covers by reducing the time spent on searching for the correct order and by reducing the number of actions to perform to retrieve the covers from the shelving unit.

5. **Appoint one person to be responsible for ordering paper**. When only one person is responsible for ordering paper, the mistakes currently happening at this step will disappear. No double paper orders will happen anymore, because that worker knows which paper orders he has placed the days prior and no paper will be out of stock, because he checks the storage levels periodically. This results in paper only being ordered when necessary and will thus reduce the number of paper deliveries. Management should appoint one person for this task and periodically monitor the number and type of paper orders, to check if the worker is doing his job correctly.

6. **Make the order number more legible**, both on the packaging of exotic paper and on the half fabricates. This will reduce the collection time due to the required items being more easily spotted by the workers. Implementing this requires the workers to consistently write order numbers on exotic paper packaging during the daily organization of the paper delivery storage area and consistently writing the order number on a piece of paper that is placed together with the book blocks and covers. Management should explain why they want the workers to perform these actions and also monitor

them closely throughout the implementation of this recommendation. A goal for the future would be to make the printers print a sheet that shows the order number in a large font, instead of the workers having to do that by hand.

7. **Implement Lean management** to reduce the required size of the half fabricate storage areas. Before implementing the theory of Lean management, its implementation at the specific case of Ipskamp Printing should be researched further. It has high potential of reducing collection time and other wastes in their production process, which makes the theory of Lean management so interesting for the future.

When implementing these recommendations it is estimated to reduce the collection time experienced during the production steps of Ipskamp Printing by between 26% and 55%. I therefore conclude that this thesis' research question is answered and that this thesis has succeeded in achieving its goal.

Contents

Preface ... iii
Management summary ... iv
Readers guide ... ix
List of acronyms and definitions ... x
1. Introduction ... 1
1.1 Ipskamp Printing ... 1
1.2 Selecting the core problem ... 2
1.3 Theoretical framework ... 3
1.3.1 Identifying key concepts ... 3
1.3.2 Connecting the key concepts ... 4
1.4 Research design and deliverables ... 5
1.5 Data gathering ... 6
1.6 Conclusion ... 7
2. Current situation ... 8
2.1 Production floor layout ... 8
2.2 Product categorization ... 9
2.2.1 Categorization constraints ... 9
2.2.2 The categorization visualized ... 10
2.3 Workflow per product category ... 11
2.3.1 Production steps per product category ... 11
2.3.2 Paper type workflow ... 13
2.3.3 Lamination workflow ... 14
2.3.4 Stapling workflow ... 14
2.3.5 Sewing workflow ... 14
2.3.6 Binding workflow ... 14
2.4 Current storage policy ... 15
2.4.1 Paper delivery policy ... 15
2.4.2 Paper storage policy ... 15
2.4.3 Cover storage policy ... 16
2.4.4 Book block storage policy ... 16
2.4.5 Finished product storage policy ... 17
2.5 Conclusion ... 17
3. Collection time distribution ... 18
3.1 Reality of data gathering ... 18
3.1.1 Alterations to data collection ... 18
3.1.2 Consequences to dataset reliability and validity. ... 19

3.2 Processing of dataset 19
3.2.1 List of assumptions 19
3.2.2 Visualization and processing of the dataset 19
3.2.3 Adjusting the dataset to include cover collection time 22
3.3 Collection time distribution per production category 23
3.4 Conclusion 25
4. Storage policy improvement 26
4.1 SLR results 26
4.1.1 Physical policy improvement theory 26
4.1.2 Operational policy improvement theory 28
4.2 Policy improvements from Ipskamp Printing 29
4.2.1 Management storage policy suggestions 30
4.2.2 Worker storage policy suggestions 30
4.3 Selecting policy improvements 31
4.3.1 Making a selection from the SLR results 31
4.3.2 Most promising policy suggestions 33
4.3.3 Additional policy improvements 34
4.4 Implementing policy improvements 34
4.4.1 Periodical organization of paper storage areas 35
4.4.2 Differentiation of items in storage 36
4.4.3 Reducing required storage 37
4.5 Conclusion 37
5. Conclusion and recommendations 38
5.1 Conclusion 38
5.2 Recommendations 39
5.3 Limitations 40
5.4 Further research 41
References 42
Appendix A 44
A.1 Tables of standard paper 44
A.2 Calculations of collection time distribution with different book block fraction 44
Appendix B: Systemic literature review 46
Appendix C Enlarged graphs and figures 55
.... 56

Readers guide

1. Introduction

The first chapter of this Bachelor thesis introduces Ipskamp Printing to the reader, shows how the research question is determined and the plan for answering the research question is given.

2. Current situation

Chapter 2 explains the current situation at Ipskamp Printing. It starts with a categorization of its products. Then it explains how each production step is performed at Ipskamp Printing's production department. It ends with a blueprint of the production floor, which illustrated how little space there is left on the production floor.

3. Collection time distribution

In the third chapter the collection time distribution for each product category is determined. First it is explained how the dataset is collected and what assumptions have been made to use the dataset for this research. Afterwards, using excel and a summed squared residuals test, the collection time distribution per production step is determined and finally the collection time distribution per product category is listed.

4. Storage policy improvements

Chapter 4 starts out with a systemic literature review (SLR) wherein relevant theories for this thesis were found. The chapter continues with listing storage policy improvements suggested by both production management and workers. These theories and suggestions are evaluated and the chapter ends with a list of storage policy improvements.

5. Conclusion, recommendations and further research

The main part of the thesis ends with Chapter 5. In this chapter the research is concluded and the recommendations for Ipskamp Printing are given. Then the limitation to the research performed for this thesis are listed and finally areas of future research are identified.

A.

The first part of Appendix A shows the tables of the paper brands and weights that fall in the standard paper category. The second part shows the calculations made to check if collecting the book blocks makes up 70% of the collection time for the book blocks and covers of an order.

B. Systemic literature review

Appendix B contains the systemic literature review performed for Chapter 4. Each step is listed and its conclusion can be read at the end.

C. Enlarged graphs and figures

The last appendix contains enlarged graphs and figures. This appendix is added because some of the graphs and figures in this thesis are hard to read.

List of acronyms and definitions

Definitions used during this thesis:

Dispatch department	The department of Ipskamp Printing that is responsible for the incoming and outgoing orders.
Post-processing department	The department of Ipskamp Printing that is responsible for the production steps after a product is finished at the production department.
Section	When used in the context of book binding, a section is a grouping of printed paper sheets, that are folded and sewn along the fold. Multiple of these sections make up the complete book block of a sewn product.
Self-cover	A product that is considered as a self-cover is one that does not have a separate cover sheet. The first and last page of the book block are the front and back covers of the product. An example of self-cover products are instruction manuals.
Book block	The stack of pages on which the text of a book, brochure or thesis is printed, before they are combined with the cover to form a finished product.
Wire-O	A binding method where, on the left side close to the spine of the product, a metal spiral is threaded through punched holes. This binding method can be found on, for example, notebooks.
Paper weight	The weight of paper is expressed as gr/m^2, thus one square metre of paper weighs a certain amount of grams. A higher weight often means a thicker and sturdier paper.

Acronyms used during this thesis:

SLR: Systemic Literature review

TOC: the Theory of Constraints

1. Introduction

This chapter starts with an introduction to Ipskamp Printing, the company this thesis is written for, to the reader. Afterwards, the decision-making process for the core problem is explained and the core problem is chosen. The theoretical framework relevant for the completion of this thesis is then described. Fourthly, the research design, including the sub-research questions and deliverables, is presented. Finally, the theory on the data collection for this thesis is given.

1.1 Ipskamp Printing

Ipskamp Printing is, as their name suggests, a printing company. Their main focus is on producing brochures, theses and both soft- and hardcover books. Next to these products, they also produce flyers, business cards and any other product on a paper medium with a maximum size of A3. These additional unbound products are mainly legacy items produced for certain large clients and they are not advertised. Ipskamp Printing sells to both business and individual customers and their printing runs start at only a few books/brochures and can be as many as 10,000 for both customer types. Their soft cover products are all produced in-house; as for the hardcovers only the finishing steps are performed at their daughter company, Bonzet.

Ipskamp Printing's business clients can take advantage of a larger variety of services than their individual clients. In addition to a single printing run, they can also use printing on demand, multi-run and in-house storage services. Printing on demand means that any number of products ordered (which could be only 1) before 09:00 are sent out that same day at 15:00. Multi-run means that for one product, multiple runs throughout the year are possible with the only effort required for a new run being one email. Finally, in-house storage is used for customers that ask for printing on demand, but their products are too complex to produce profitably in very small printing runs. Ipskamp Printing instead does a slightly larger printing run and stores these products in their warehouse, from where they are picked, packaged and shipped when the customer orders their product again.

The order category most produced by Ipskamp Printing is a softcover product with a laminated cover, which is bound with glue. This product goes through the following production steps: The product's pages are printed on large empty sheets of paper, which are cut to size and form the book block. The cover is printed on a different machine and after printing, a thin plastic film is applied to the cover, which is called laminating the cover. This layer gives the cover a shiny or matte finish, depending on the laminate type, and protects against scratches. When lamination is finished, the cover and book block are glued together along the spine of the product and then the product is sent off to the dispatch department for packaging or to the post-processing department. At the post-processing department, binder holes can be added to the product, additional sheets of promotion material can be placed in between the product's pages and it can be sealed in plastic film.
The production of hardcover products follows the same steps as that of softcover products up until the binding phase, because hardcover products require a sewn book block, while softcovers do not have this requirement. When the covers have been printed and laminated and the book blocks are sewn, the half fabricates are sent off to Bonzet, the daughter company of Ipskamp Printing that is responsible for hardcover production. There the cover is combined with a piece of cardboard to form the hardcover and the product is bound using thread and glue. For hardcover products, the only post-processing option is sealing in plastic film.

A more elaborate explanation of the different production processes at Ipskamp Printing can be found in Section 2.3 workflow per product category.

1.2 Selecting the core problem

Ipskamp Printing has tasked me with improving the efficiency of their production process, more specifically increasing their daily production capacity by reducing the time spent on searching for and gathering the required materials per production step. Their vision is to eventually be able to print 1 of 1 products profitably, which is almost impossible with their current way of working. Because of the different services they provide to clients, a suboptimal storage system and quite some human error in the production process, their production times are way longer than they want them to be. This section will show which problem is chosen to be the core problem for this thesis and how this decision was made. After talking to production management, the following problem cluster was made:

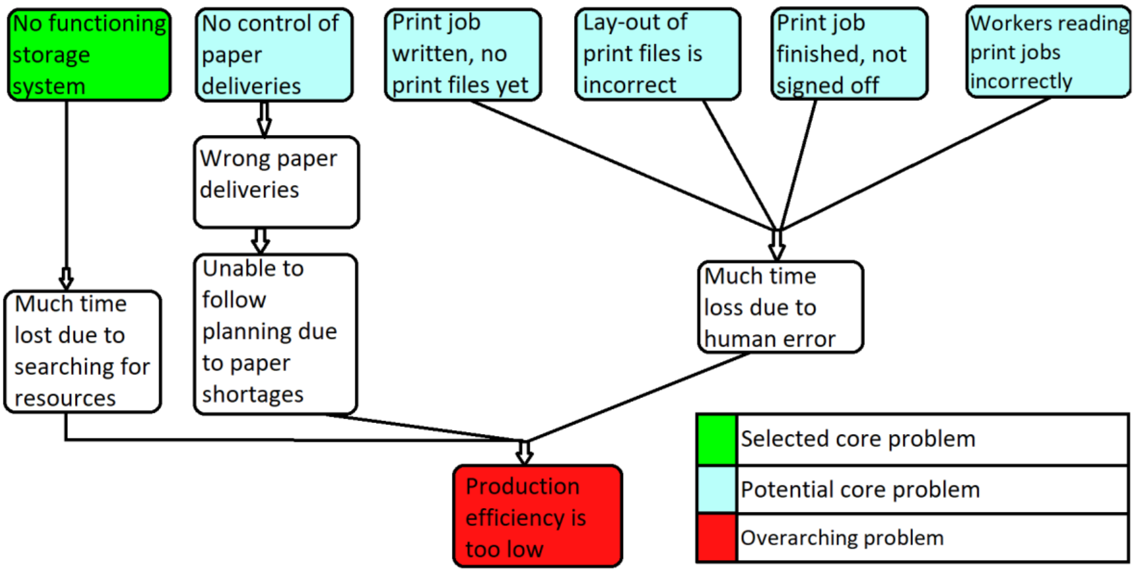


Figure 1 Problem cluster made for Ipskamp Printing

Some of the problems in this cluster were elaborated upon by production workers later on in the research process. They explained that the human error problem also includes mistakes made during and after printing the half fabricates, gathering the wrong materials for an order because of misreading the badly legible order numbers on the tickets or planning mistakes resulting in (almost) missed deadlines. Next to the human error problem, the non-functioning storage system problem was broadened with the following problems: special ordered paper is really hard to find in the paper storage area, the relatively large number of small orders (1–30 products) leads to storage problems and the storage of laminated covers is also a large point of concern.

It can be concluded that there are quite a lot of possible core problems. However, both production managers and most of the production workers agreed upon the lack of a functioning storage system being the core problem for this thesis. They expressed their concerns regarding the large number of human errors in the production process, but said that the chosen core problem is a more pressing matter. This is the case, because it happens too often that an order is delivered after its due date, the number of which management does not monitor, but they have expressed their dissatisfaction about it in multiple instances. Part of the reason for late deliveries is that a large amount of the time a product stays in the production process is the time required for collecting all required materials, which can be reduced by improving the storage system. Next to that, when applying the 'relevance rule' of Heerkens (2021), which says that the selected core problem should be the most relevant to the objective and should have (one of) the best cost-benefit ratios, the selected problem is a suitable core problem. In this case, the benefit of improving the storage system is large according to production management and the cost is relatively low because the only costs for the research are the small amount of time the workers need to invest in gathering data for the required dataset and the small compensation for my time at the office of Ipskamp Printing. The expected costs for implementing possible improvements to the storage system will also be lower than the expected costs for reducing the human error in the production system, because of the cost of training staff compared to investing in some new storage attributes.

For each order there are two storage phases: that of the empty paper sheets and that of the half fabricates (book block and cover). Due to the lack of an optimal storage policy, there are very few rules on how to store parts of the order in both of these two phases. There are designated storage areas for the empty paper sheets and each half fabricate, but no other storage rules exist. Different orders can be stacked on top of each other, divided over multiple carts or stored in an illogical/unchronological order. This leads to long collection times in both of these storage phases, because the production workers need to search for the required materials for each of the production steps in these unorganized storage areas. The fact that both storage phases are impacted by the lack of a functioning storage system, that long collection times result in a decrease in production capacity, which in turn leads to late deliveries and that this problem has a good cost-benefit ratio are important arguments for the decision to consider the lack of a functioning storage system as the core problem for this thesis.

‘The lack of a functioning storage system’ needs to be rewritten into a research question that shows a discrepancy between norm and reality and shows how this can be measured (Heerkens, H. & Winden van, A., 2021). Therefore this core problem is formulated as the following research question:

How can Ipskamp Printing improve their storage system to reduce the collection time per production order by at least 30%?

The 30 percent reduction stems from management, who estimates that 30% is a reasonable reduction to expect, given the time constraint of 10 weeks for this thesis and the space constraints of the production floor. Furthermore, following from this formulation, the storage system’s efficiency, or rather lack thereof, is measured by the average collection time, the time required to collect all required resources and half fabricates, per production order.

1.3 Theoretical framework

The first section of the theoretical framework will identify and explain the key concepts of this Bachelor thesis. The section afterwards will combine these concepts and formulate the theoretical framework.

1.3.1 Identifying key concepts

The first and most important key concept is how to define the production process. The production process of Ipskamp Printing is a business process concerned with producing one or multiple (different) products; therefore, to arrive at the definition of the production process, the definition of a business process is required. Weske (2007) defines a business process as follows: A business process consists of a set of activities that are performed in coordination in an organizational and technical environment. These activities jointly realize a business goal. […]. In the case of this thesis, the organizational and technical environment is the production department of Ipskamp Printing and the business goal of this department is the production of printed products, like books and theses. Because the environment of the production department excludes the environments of both the dispatch and post-processing departments, the production process’ activities do not include the activities performed at these two departments. This distinction results in the following definition of the production process at Ipskamp Printing:

The production process encompasses the activities performed at the production department of Ipskamp Printing, which consist of printing, laminating, cutting to size, sewing, and binding of products.

The second key concept is throughput time. Johnson (2003) defines throughput time as the length of time between the release of an order to the factory floor and its receipt into finished goods inventory or its shipment to the customer. Tönissen, et al. (2012) define throughput time as what describes how long a product remains within the production system. The definition best suited for this thesis is the one from Tönissen, et al. The reason for this is that at Ipskamp Printing it often happens that half fabricates are stored for 1 or 2 days before the product is finished. If the definition from Johnson were used, then the collection time would be dwarfed by the storage time. Thus, the definition of Tönissen et al. is chosen, but they use production system while the production process, which is defined above, is used during this thesis. Using this definition, storage time is explicitly removed from the throughput time. This results in the following definition of throughput time:

Throughput time is the time that a product takes to move through the production process, explicitly removing the time an product stay in storage from the calculation of throughput time.

The production department's layout is the third key concept. The layout is considered as the orientation of all machines, storage areas and other items on the production department's floor. The layout is what determines the positioning of the storage shelves and areas; therefore, the layout is the foundation of the storage policy.

Then the storage policy has to be defined. A policy is "a set of ideas or a plan of what to do in particular situations that has been agreed to officially by a group of people, a business organization, a government, or a political party" (Cambridge dictionary, 2023). A storage policy for this bachelor assignment will therefore be defined as a set of rules that determine how and when the available storage space at Ipskamp Printing should be used.

The fifth key concept is collection time. Collection time is defined as the sum of time spent searching for, gathering and transporting resources and half fabricates to the required machine per order. For almost all production steps collection time occurs; therefore, the collection time per order is the sum of the collection time experienced per production step of that order. In short, it is the time a worker needs to get all the required things to his workstation to start with a production step on an order, summed over all the production steps of that order.

Finally, the storage system is the overarching term used to denote the layout of the storage areas on the production department's floor, together with the storage policy. Improving this is the main focus of this bachelor assignment.

1.3.2 Connecting the key concepts

This section of the theoretical framework shows how the key concepts are put into use and which theories are used to connect them during this Bachelor thesis. First the connection between collection time and the storage system must be made, because from this connection all remaining parts of the theoretical framework stem. Afterwards the other important connections between key concepts are explained.

Collection time is influenced by multiple factors. The main ones are: the effectiveness of the storage system (if the storage areas are efficiently laid out and if the storage policy is achieving its desired result) and adherence to the storage policy by the production workers. This thesis concerned with both of these factors.
As mentioned before, the effectiveness of the storage system is measured by the collection time per order; therefore, collection time should decrease with an increase in storage system effectiveness. This can be achieved in two ways: increasing the efficiency of storage area positioning and improving the

storage policy such that paper and half fabricates are easier to find in those storage areas. If the positioning of the storage areas is improved, the workers have to walk shorter distances to the storage area(s) to retrieve what they need to start work on their production step of an order, therefore decreasing collection time. When the storage policy is improved, there are more clear rules on what materials are stored where and in what order; therefore, it takes less time to search for the required materials and thus decreases collection time.
However, if production workers do not adhere to the storage policy, then improving it will not have the desired effect. The research for this thesis is performed because of the long collection times per order, which is mainly due to the lack of an effective storage policy. If a new policy is set in place, but not adhered to, then there will be no decrease in the collection time per order. It is therefore very important to ensure adherence to the new policy.

Secondly, it is important to show the relation between decreasing collection time and in turn throughput time. Because Ipskamp Printing is a commercial company, they want to decrease throughput time, which increases their maximum production capacity per day, which reduces the cost price of an order, thus increasing their profit margins. As mentioned before, the definition of throughput time is the time that a product takes to move through the production process, explicitly removing the storage time from the equation. Thus, throughput time can be decreased by decreasing the time it takes to perform the production steps or by decreasing the collection times. Decreasing the required time per production step requires considerably more effort and investment than reducing the collection time, which is the reason that this thesis focuses on reducing the collection time per order.

Finally, the link between collection time and the storage policy has to be explained. As previously mentioned, the storage policy is defined as a set of rules that determine how and when the available storage space at Ipskamp Printing should be used. Currently, the storage policy only tells the production workers in what storage areas which paper should be stored, which storage area is dedicated for the book blocks and in which carts the covers should be placed. There are no additional rules for the storage policy. As will be explained in Chapter 3, the collection times using the current storage policy are too long. Expanding, and thereby improving, the storage policy is expected to reduce the collection time to a more acceptable level. Due to the lack of rules on how to store materials and half fabricates, searching for the required materials of a production step can take a long time, so if the searching can be reduced by improving the storage policy, the collection time per order is in turn also reduced.

1.4 Research design and deliverables

To answer the main research question, sub-research questions are required whose answers will aid in answering it. Next to that, they help formulate the deliverables of this thesis. The following section shows all of the sub-research questions, together with a short explanation of their importance.

1. **What is the current situation on the production floor at Ipskamp Printing?**

The first sub-research question is the first descriptive research question and needs to be broken down into 4 smaller question to show each part of this sub-research question.

A. **What product categories does Ipskamp Printing have?**

The product categorization will be made from order data from the last 9 months and some input from production management. Answering this question requires mainly secondary data and has a qualitative result, which is a product categorization that incorporates all orders of Ipskamp Printing.

B. **What is the standard production procedure for each product category?**

This research question will be answered by conducting interviews with production management and workers, which will result in a detailed flow chart of the operations for each product category. Thus primary data is used to create a qualitative result.

C. What is the current storage policy?

This is another question that will be answered by conducting interviews. It results in a list of rules and activities related to storing resources and half fabricates. It thus requires primary data and has a qualitative result.

D. What is the current layout of the production floor at Ipskamp Printing?

Sub-research question 1's last question will results in a detailed blueprint of Ipskamp Printing's current production floor layout. It will be created by measuring the size of the production floor and all things occupying space on it. This research question requires primary data, which has a qualitative result.

2. What is the current collection time distribution of each product category?

Sub-research question 2 is the second descriptive research question and will mainly be answered through measurements made by production workers, because they are the ones who need to collect the materials per printing order. These measurements will be gathered per order per machine. When these measurements have been performed, they will be combined with the categorization from research question 1a, which will result in the baseline collection time distribution per product category. This baseline is vital for solving the action problems of sub-research question 4. Because of the importance of this baseline, extra care in avoiding biases will be taken and as much input from production workers and management as possible will be used, to ensure that the baseline distribution is as accurate and scientifically valid as possible. Thus, this research question requires primary data and has a quantitative result.

3. Which storage policy problems have been research and implemented before?

The third sub-research question is the systemic literature review (SLR) sub-research question of this bachelor thesis. It will result in a list of possible solutions to the core problem at Ipskamp Printing, which will be evaluated during the answering of sub-research question 4. Next to possible solutions, the SLR will also provide criteria, which will be used to evaluate possible storage policies. To conclude, a search in secondary data will be performed and this research question will have qualitative results.

4. What changes to the storage policy can decrease collection times?

Sub-research question 4 is the action problem of this thesis. The inputs for answering this question are the baseline collection times per product category from question 2, the list of possible storage policy improvements of sub-research question 3 and the evaluation criteria identified in the SLR of sub-research question 3. From the list of possible improvements a selection will be made based on the evaluation criteria. Afterwards, this selection will be researched further and will be ranked on feasibility. This ranking will be based on the specific environment of Ipskamp Printing's production department. The most feasible policy improvements will be made into a proposition to production management and after this is done the research question will be answered.

1.5 Data gathering

For the purpose of constructing a collection time distribution per product category a dataset is required. This dataset can best consist of measurements made by the production workers, because they have the expertise on the production process and the act of measuring datapoints can easily be incorporated into their work routine.

The measurements will be performed as follows: The worker starts his production step for an order by selecting that order on the computer, then he writes the order number into a stopwatch application on the computer and starts the stopwatch. Then he searches for and gathers all required resources/half fabricates for his production step. When all required resources/half fabricates have been gathered and are at his workstation he stops the stopwatch. Then the application on his computer records the measured collection time for him. When he starts a new order, these steps will repeat. How this dataset will be made valid and reliable will now be explained.

Validity

Cooper and Schindler (2014) define a research instrument as valid, more specifically as 'internally valid' when the answer to the following question is yes: Does the instrument really measure what its designer claims it does? Because this way of measuring collection times also incorporates the time workers spend on talking to other people, bathroom breaks and other non-resource-gathering activities the measurement system isn't perfectly valid. However, this will be somewhat remedied by constructing a collection time distribution from the dataset.
Next to the non-resource-gathering activities in the collection times, there are no aspects of this way of measuring that could result in an invalid dataset.

Reliability

According to Cooper and Schindler (2014), a measure is reliable to the degree that it supplies consistent results. If a measure is used multiple times, at different time intervals for example, the results it provides should be consistent. The difference between validity and reliability is well visualized by the following picture:

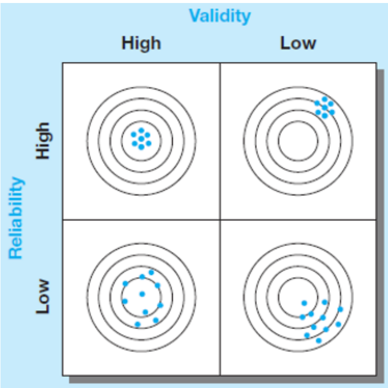


Figure 2 Validity & Reliability chart from Cooper, D. R., & Schindler, P. S. (2014) P259

One problem for the reliability of the dataset is the seasonality of Ipskamp Printing's activities. The months leading up to the summer holiday often have increased incoming orders, which results in increased collection times due to a more crowded storage system. Sadly, there is no way to remedy this problem, because this thesis is based on a dataset which is collected during these months. Due to the time constraint of 10 weeks for a Bachelor thesis, it is not possible to perform measurements over a long enough time to visualise the seasonality experienced by Ipskamp Printing.

Next to the seasonality of Ipskamp Printing's activities, there are no reliability problems for this way of measuring. All workers follow the same steps for their measurements, which results in a reliable dataset.

1.6 Conclusion

This chapter introduced Ipskamp Printing to the reader. It is a printing company that produces almost anything that can be called a book, brochure or flyer. The inefficiency of their production process is the reason for conducting this thesis and after researching all problems encountered in the production process, the lack of a functioning storage system was chosen as the core problem in Section 1.2. Section 1.3 shows the theoretical framework where the key concepts of production process, throughput time, layout, storage policy, collection time and storage system are explained and linked to the core problem and each other. Remedies to the core problem will be researched with the help of four sub-research questions, which are listed in Section 1.4. The chapter ends with Section 1.5 with the theory on the gathering of the dataset.

2. Current situation

This chapter answers sub-research question 1; 'What is the current situation on the production floor of Ipskamp Printing?' Section 2.1 shows a technical drawing of the current layout of the production floor of Ipskamp Printing and explains where the paper and half fabricates are stored. Section 2.2 shows what the product categories are and uses the categorization to categorize archived order data. Then Section 2.3 goes into detail on each step of the production process. Afterwards, Section 2.4 explains the current storage policy and Section 2.5 ends the chapter with an conclusion.

2.1 Production floor layout

The following figure depicts a technical drawing of the production floor at Ipskamp Printing. The dimensions have been measured by hand using a tape measure, so some imperfections may be present. The scale is 1:100 and the following drawing only depicts the items that are really difficult to move, like shelves, machines and tables, and the dedicated storage areas. In reality the production floor is more cluttered, but this is hard to draw due to the orientation of the clutter constantly changing.

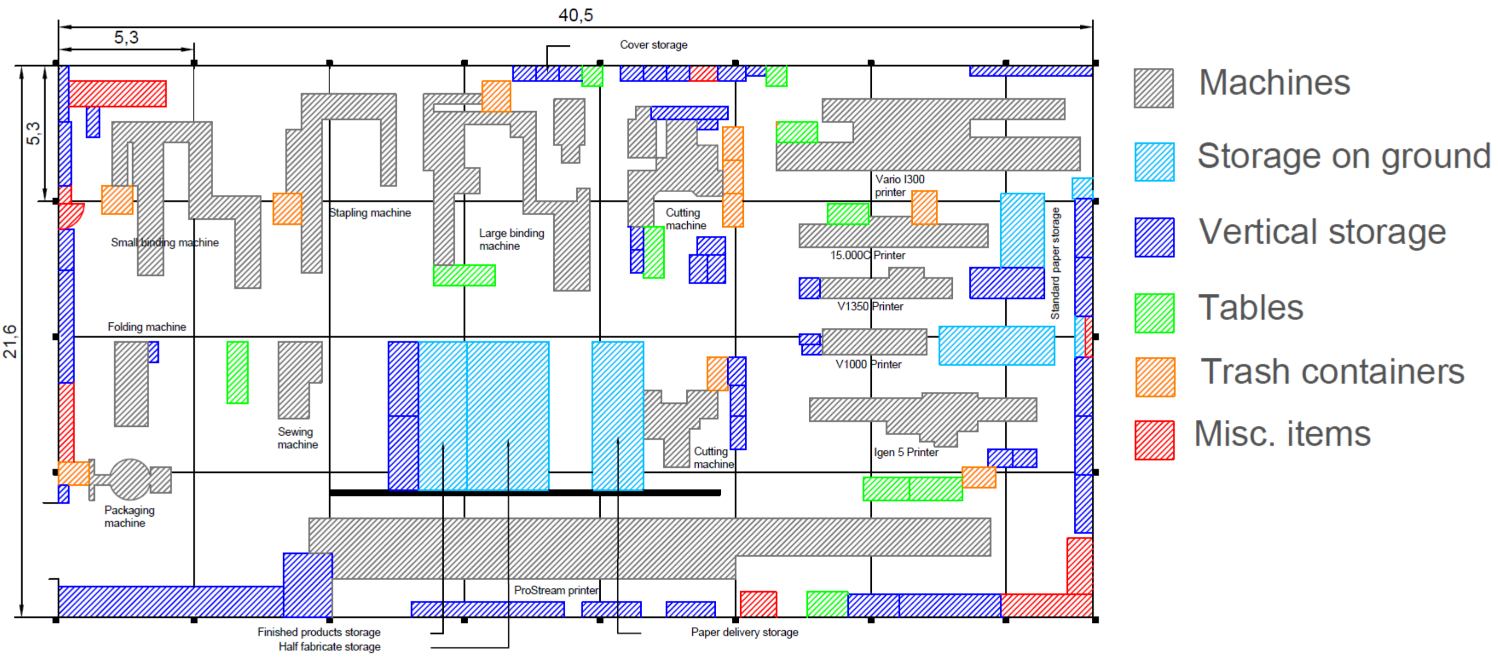


Figure 3 Technical drawing of Ipskamp Printing's production department (Larger size in Appendix C)

The bottom left part of the production floor is where the dispatch department is positioned and from where the paper orders are taken onto the production floor. The light blue ground storage areas in the middle of the drawing are where, from left to right, the finished products, book blocks (sometimes together with the covers) and deliveries of paper are stored. The paper that is categorized as standard paper (for the explanation on standard and exotic paper, see Section 2.2.1) is moved from the paper delivery area to the standard paper storage area, located at the top left of the drawing. The standard paper storage area uses both ground and vertical storage. The vertical storage areas in the drawing consist of some type of vertical storage, like shelves and cover storage carts. The tables are either used for packaging, stacking products, or half fabricates or a pc is placed on top of it from where the planning is read and the production system is updated. All trash containers are for paper, except the one on the bottom left. This one is used for plastic packaging waste. Finally, the miscellaneous items are things like a door, air compression unit, fire security devices or a server housing.

2.2 Product categorization

The products produced by Ipskamp Printing have to be categorized, such that they can be analysed for this thesis. Thus the scope of the thesis has to be taken into consideration for the creation of this categorization. Section 2.2.1 is concerned with the constraints of the categorization and the formulation of it, while Section 2.2.2 shows the visualization of the order data from Ipskamp Printing's archive using this categorization.

2.2.1 Categorization constraints

The first point of consideration is that this thesis is concerned with the production department's problem of its workers experiencing long collection times. It would therefore be a logical choice to exclude the steps of a product's production process that are not performed at the production department. This choice leads to the exclusion of all operations done by the post-processing department, all operations performed at Bonzet and the steps of packaging and shipping the orders. Excluding the production steps performed at Bonzet has another consequence for the categorization, because the hardcover products are bound there. Therefore, hardcover products have at least one production step less than their softcover counterparts. If the hardcover and softcover products were placed in the same category, this would lead to large discrepancies in the collection time of orders in the same category. Therefore, it is decided to group all hardcover products together into one category, such that they can be analyzed as a separate group. This group always has sewn book blocks, covers printed on only one type and weight of paper, with or without lamination and both standard and exotic paper types are grouped into this categorization.

Another logical step is to categorize Ipskamp Printing's orders based on their attributes. The attributes of an order can easily be found in the archive, so categorizing past and future orders will be an easy feat. Next to that, categorizing products based on their attributes will aid in creating a collection time distribution per product category, because most attributes are a result of a specific production step. This means that when a product is in a certain category, the production steps for that category are inherent to it. A product's attributes relevant for this thesis are: binding method, laminated or unlaminated and paper type used.

Binding method

Ipskamp Printing provides all binding methods which are commonly used, which are: Glued, sewn, stapled, and Wire-O. In addition to these binding methods, unbound products are also an option. The categories that result from the distinction in binding method are: Glued, sewn, stapled and unbound. Notice that Wire-O is missing from these categories; this is explained by the fact that Wire-O binding is done at the post-processing department; thus, this binding method is not considered for this thesis. Wire-O binding is therefore categorized as an unbound product, as it leaves the production department unbound.

Lamination

Lamination is a yes-or-no category, either the product is laminated, requiring an additional production step or it is unlaminated. All types of lamination are grouped together, because a different laminate type does not result in additional steps. Lamination is part of the categorization because unlaminated covers are stored separately from the laminated covers, which has an impact on the production steps after the lamination step.

Paper type

The third attribute of an order is the paper used to print the book block on. Ipskamp printing has 19 brands/types of paper used for book block printing in storage (almost) all the time, of which 2 are on a roll for the Prostream machine and the remaining 17 are delivered as individual sheets. For cover production, there are in total 3 types of paper used, but the type of cover paper is irrelevant for this

categorization, because printing the covers is assumed to not cause additional collection time. For a detailed overview of the paper types in storage at Ipskamp Printing, see Appendix A.1. Categorizing the order per brand/type would result in way too many categories, of which three will be very large categories and 16 quite small categories. Therefore, the brands are split up into two types, standard and exotic paper. Standard paper includes all paper types in stock at (almost) all times and exotic paper includes all paper specifically ordered each time a customer asks for it. This distinction is helpful, because the printer operators experience irrelevant amounts of collection time for standard paper, while for exotic paper the collection time is relatively long. This again aids in the creation of the collection time distribution later on.
For simplicity all paper weights of each brand are grouped together. If these would be isolated, the categories would explode in size. See appendix A.1 for a detailed overview of the standard paper brands and their weights.

The previously mentioned considerations result in the following categories:

Standard unlaminated stapled (SUStapl)	Exotic unlaminated stapled (EUStapl)
Standard unlaminated glued (SUGlue)	Exotic unlaminated glued (EUGlue)
Standard unlaminated sewn (SUSew)	Exotic unlaminated sewn (EUSew)
Standard unlaminated unbound (SUUnb)	Exotic unlaminated unbound (EUUnb)
Standard laminated stapled (SLStapl)	Exotic laminated stapled (ULStapl)
Standard laminated glued (SLGlue)	Exotic laminated glued (ELGlue)
Standard laminated sewn (SLSew)	Exotic laminated sewn (ELSew)
Standard laminated unbound (SLUnb)	Exotic laminated unbound (ELUnb)
Hardcover	

Table 1 Product categories and their abbreviations

2.2.2 The categorization visualized

Using the aforementioned categories, the order data of the months November 2022 up to and including July 2023 has been examined and categorized. Aggregating the results in a graph yields the following figure:

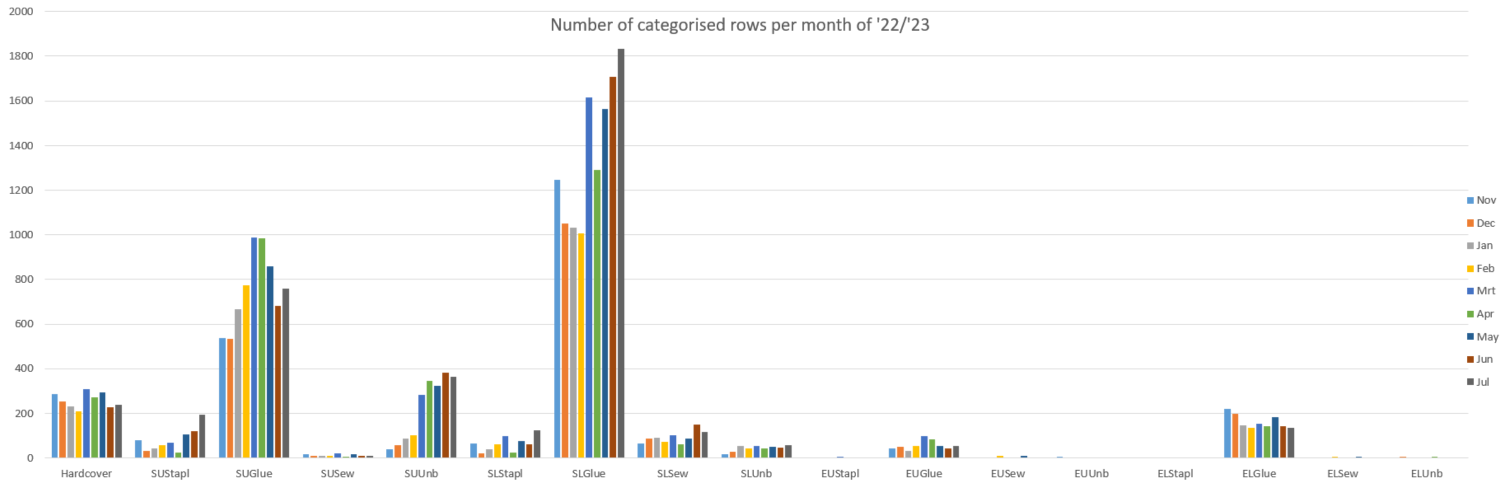


Figure 4 Graph showing the categorised order data of Nov-July '22/'23

As the title of the graph shows, categorized Excel rows are used as input, not specific orders. The reason for this is that an order can have sub-orders, like a bookmark or flyer, that have the same order number, but require different production steps. The reason for the distinction between rows and unique order numbers is to incorporate those sub-orders, which can be printed on different paper. The next graph shows the order data from the same period, but only showing unique orders. Note that the unique order number graph shows about half of the order per category. The reason for this is that each order mostly has two rows describing the order, one for the book block and one for the cover. There are some additional rows for flyers, business cards and other similar legacy items, but this accounts for only 3% of the total rows.

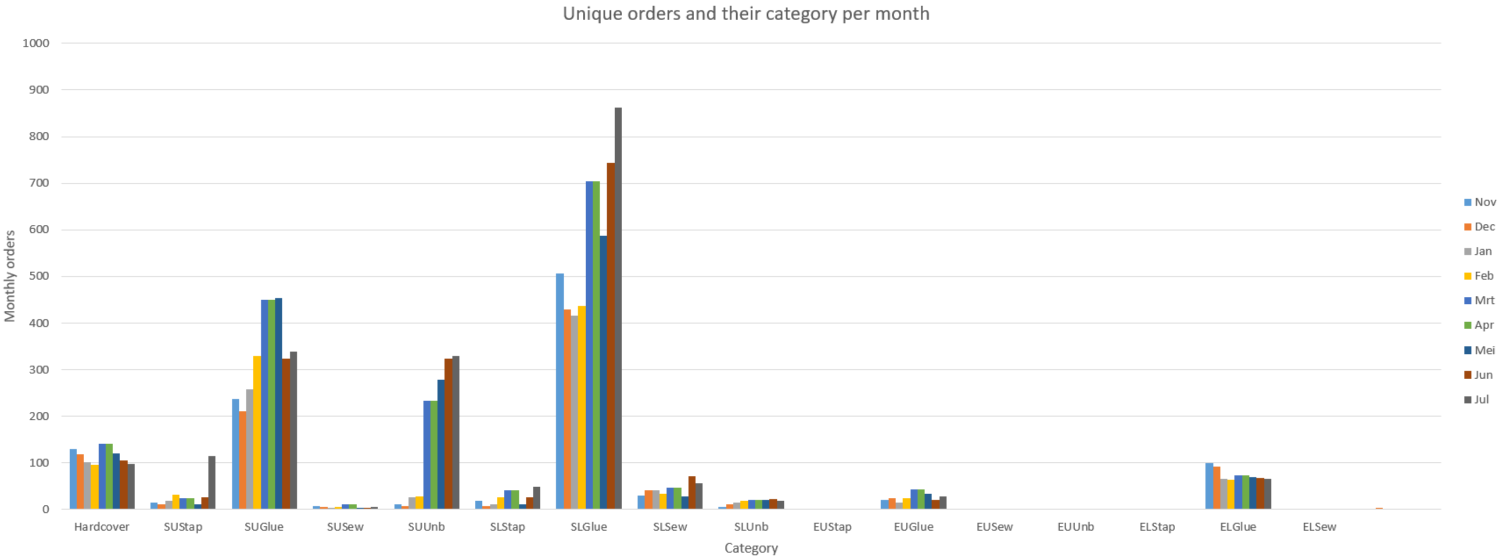


Figure 5 Graph of unique order numbers and their categories from the archive of Nov-Jul '22/'23

Both graphs show that standard paper use heavily outweighs exotic paper use; about 8% of all orders require exotic paper. Even though this is a relatively small percentage, it is still relevant, due to the significantly longer collection times experienced at the printing step of these orders. Next to the difference in paper use, the most popular binding type can easily be read from the two graphs, which is glueing. Glued products make up 71% of all orders in these nine months, compared to 13% unbound, 8% hardcovers, 4% stapling and 4% sewing. The categories of SUGlue, SUUnb and SLGlue show that Ipskamp Printing does not experience constant demand for all their products and that the demand does not follow the same pattern for each category. The increase in orders in June and July for the SLGlue and SUUnb categories can be explained, for the most part, by the fact that the academic year starts 1–1.5 months later, which results in more orders for theory and workbooks, which often fall into one of these two categories.

The following section will explain the steps taken for the production of each of the abovementioned product categories.

2.3 Workflow per product category

This section explains the workflow of the production steps per product category in detail. The first section shows a schematic overview of each production step performed for each product category, after which Sections 2.3.2 to 2.3.6 show the workflow of paper type, lamination, stapling, sewing and binding, respectively.

2.3.1 Production steps per product category

Figure 6 shows the production steps per product category. Note that it is divided into standard paper, exotic paper and hardcover. This selection is made because the steps after the paper choice are the same for standard and exotic paper and hardcover products are not finished at Ipskamp Printing. Each production step will be elaborated upon in the following sections.

To illustrate the difference in the time that each step requires, the following example order is considered: an order of 100 books of 200 pages that use standard paper from sheets, not from a roll; the cover requires glossy laminate; the book block is sewn together and the product is bound. Due to the book block being sewn, each sheet of paper contains 4 pages of the book, because the sheet will be folded in two therefore there are 2 pages on each side of the sheet. The following table shows how much time each step takes.

Activity	Capacity of machine	Number of sheets/products to be processed	Required time for example order
Printing cover	250 sheets/min	100	24 sec
Printing book block	250 sheets/min	5000	20 min
Laminating cover	800 sheets/hour	100	7.5 min
Sewing book block	600 books/hour	100	10 min
Binding book	600 books/hour	100	10 min
Total			47 min 54 sec

Table 2 Production time of an example order

One thing to note is that the capacity of the cutting and stapling machines equals that of the binding machine. When looking at the table, printing the cover takes almost no time compared to the other production steps and it can be concluded that the capacity of the printer is the constraint of the system, as all other steps require significantly less time than printing the book block. The following figure shows the steps takes to produce a product at Ipskamp Printing. The steps with a red dot are the steps that experience collection time. The sections after the figure will describe the production workflow of each of these production steps.

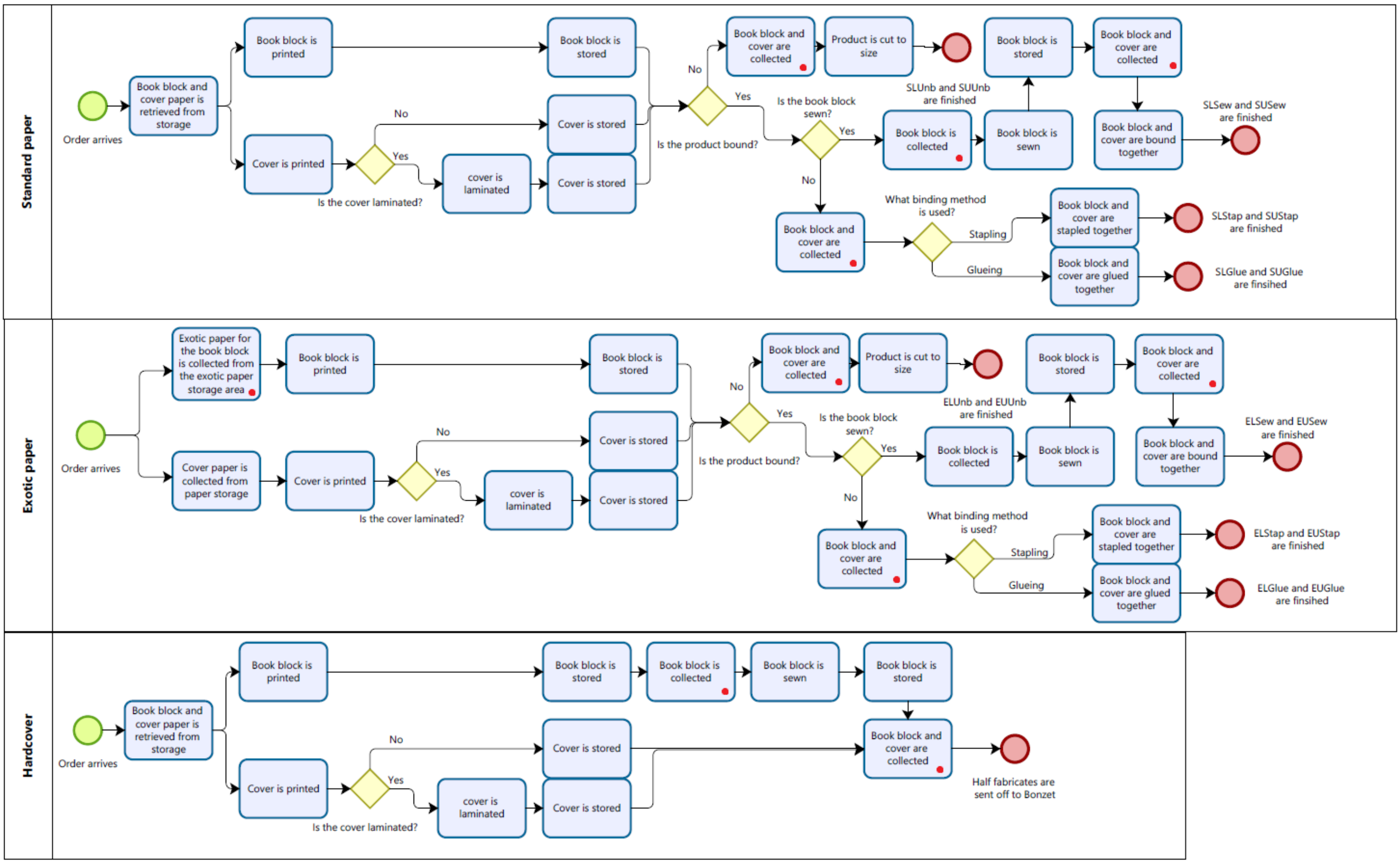


Figure 6 Business process model showing the production steps of Ipskamp Printing

2.3.2 Paper type workflow

Book block production

Book blocks take the most time on the printers, because for each product only 1 cover has to be printed, but anywhere from 20 to 1,000 pages need to be printed. If the book block is produced on the Prostream machine, a roll of paper is placed at the front of the machine and is fed into it. Then the machine starts producing the pages for the book block. The digital files are uploaded to the machine's memory and it can continue with the next order without having to stop. When the book blocks are finished, they are placed on a cart and placed in the book block storage area.

If the book block is produced on a different machine than the Prostream, then the paper doesn't come from a roll, but rather from a package with individual sheets. These sheets are either taken from the standard paper storage area or they are taken from the paper delivery area, which is positioned in the middle of the production floor, when the order requires exotic paper (called exotic paper storage in the figure below). Collecting the exotic paper takes considerably longer than collecting the standard paper, mostly because of the lack of a storage policy for the paper delivery area.
When the paper has been collected, it is put into one or more input drawers of the printer and the correct files are selected on the printer, after which the printer starts running. When the printer is finished, the book blocks are put on a cart and moved to the book block storage area or directly to the machine of the next production step.

Cover production

The covers are all printed on the V1000, V1350 and Varioprint printing machines. These printers are chosen for this job, because they produce the highest colour quality, which is more important for the cover of a product than for its pages. Collecting the paper for the covers and printing them follows the same steps as for the book blocks, but no distinction is made between standard and exotic paper for the covers. Only after the covers are printed does the workflow differ for the book blocks.

Each order can ask for lamination of the cover or no lamination at all. The printed covers are, stacked together for each order, separated in four groups: unlaminated, matte laminated, glossy laminated and linen laminated. The covers that need to be laminated with matte or glossy laminate are placed on grey carts with special compartments for both types of laminate and moved to the lamination station. The covers that do not require lamination are stored on a dedicated cart and the covers that will be linen laminated are moved to the lamination machine by hand. The following figures show the paper and lamination workflow of standard paper and exotic paper products.

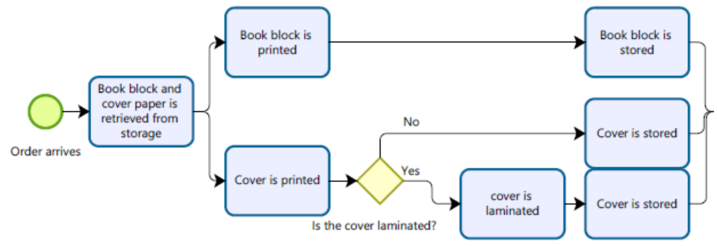


Figure 7 Schematic of the paper workflow for products made of standard paper, which includes hardcovers

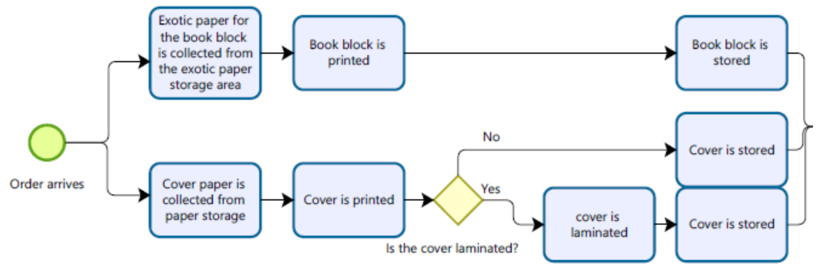


Figure 8 Schematic of the paper workflow for products made using exotic paper

2.3.3 Lamination workflow

When the covers arrive at the lamination station, a worker selects a lamination type and feeds the covers of one order with that lamination type into the machine. He selects the right dimensions of the covers and then runs the machine. After the machine is finished, the worker stores all the covers of the same order on a shelf with the order ticket on top. These steps are the same for all laminate types. Even though each cover is laminated one after another, this step does not require much time, due to the small number of covers to be laminated.

2.3.4 Stapling workflow

To finish a product by stapling, first a worker collects the book blocks and covers for an order and brings them to the machine. Then the book blocks and covers are fed into the stapling machine and the right settings for that order are selected. After being started, the machine collects one cover and book block at a time and folds, staples and cuts the product to its final shape. When the machine is done, the product is finished if no additional steps are required. The stapler can also work with products that do not contain a separate cover sheet; these orders are called self-cover orders. These orders do not require any other or extra steps. Stapling is the least time-consuming way of binding, because the stapling machine is fed with a stack of covers and a stack of book blocks, thus the worker does not have to feed the machine book blocks one by one, as is the case with the binding machines.

2.3.5 Sewing workflow

Only the book blocks are sewn together, so the worker on the sewing workstation only has to search through the book block storage area. After the worker has collected the book blocks, which at the moment still only consist of individual pages of a single order, they are loaded into the machine. The right settings are selected and the machine first sews all the sections of the book block individually and then sews the sections together. When the machine is finished, the sewn book blocks are moved to the book block storage area. Sewing requires more time than laminating, because of the large number of pages that are sewn into 4 page sections, who are then sewn together into a sewn book block.

2.3.6 Binding workflow

The binding machine binds both sewn and unsewn book blocks. This stage is also the last production stage this thesis is concerned with, any additional production steps are of no importance.

Before the machine can be used, a worker needs to collect the book blocks and covers for an order. When he has found them, the covers are fed into the machine as a stack, but the book blocks are put in one after another by the worker. The machine grinds the spine of the book block, then applies glue and finally combines the book block and cover into the finished product. After the binding machine is done, another machine called 'driesnijder', or ‘three-cutter’ in English, cuts the products to their final size. The worker then either sends them to the dispatch department or they get loaded on a cart or pallet and sent off to have additional production steps done. The following figures show the difference in binding between softcover (both standard and exotic paper) and hardcover products.

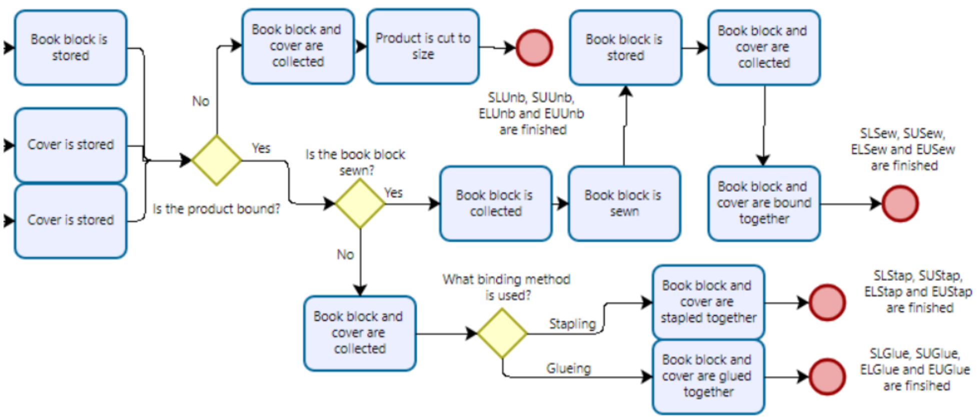


Figure 9 Schematic view of the binding process of softcover products

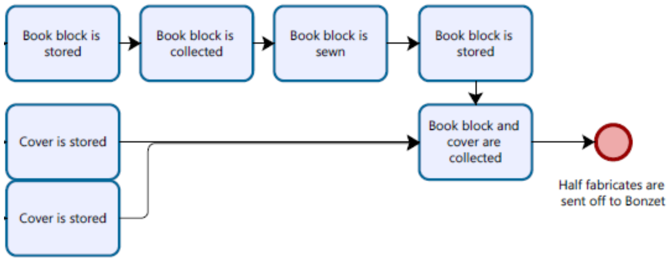


Figure 10 Schematic view of the binding process of hardcover products

2.4 Current storage policy

The following sections go into detail on how resources and half fabricates are stored before, during and after the production process. Section 2.4.1 explains how the paper deliveries are handled, Section 2.4.2 is concerned with the storage of blank paper (sheets), Section 2.4.3 explains how covers end up at the lamination workstation and how the (un)laminated covers are stored, Section 2.4.4 shows how the book blocks are stored and finally Section 2.4.5 tells the reader how and where the finished products are stored.

2.4.1 Paper delivery policy

Any ordered paper, be it complete pallets or smaller orders of either individual sheets or a big roll, enters the warehouse at the dispatch department. From there the paper is moved by forklift into the designated paper delivery area of the production floor. Sometimes, due to the storage area being completely occupied, the paper orders are stacked on top of each other. There are no further rules in place that determine how to store the paper in this area. The stacking of paper orders and the lack of storage rules leads to problems, as the printer operators experience long collection times if they require a specific ordered paper.

2.4.2 Paper storage policy

As can be seen from the categorization in paragraph 2.2, Ipskamp Printing uses two categories of paper; standard and exotic. These two categories have their own storage policy, because the standard paper has its own dedicated storage location, while exotic paper does not.

Standard paper storage policy

Inside the standard paper category, there are 22 different paper types, of which 17 are the standard paper types for the book blocks delivered as individual sheets, 2 are the standard paper types delivered on a big roll and 3 are the standard paper types used for covers. The weight range of paper used for the book block is usually 80–170 gr/m2. For a softcover book's cover, the weight range is 240–300 gr/m^2 and the covers of hardcover books are always printed on paper with a weight of 170 gr/m^2. This distinction in the usage of paper has consequences for its storage place and policy. Firstly, because there are many more sheets used for each book block than for each cover and secondly, because covers and book blocks are often printed on different machines. The standard paper that is used the most for book blocks is stored on pallets placed on the ground next to the printers. All other standard paper is stored in their packaging in shelves next to the printers. The shelves have a set orientation, while the pallets do not. This means that the pallets can be changed around inside the storage area, but this does not lead to many problems, due to the experience in paper type recognition by the workers and the signs that are sometimes placed on top of the paper. Two points to note are that the printer operators experience very short collection times when they require standard paper, because of its proximity to the printers and the standard paper is placed in their respective storage positions by the workers responsible for the printers.

Exotic paper storage policy

The storage policy of exotic paper is less elaborate, because this paper type does not have individual storage positions. The paper sheets remain in their packages in the paper delivery area of the warehouse until they are required by the printer operators. Then the packages are picked up by hand or by a hand trolley and transported to the printers, where the paper will be used.

2.4.3 Cover storage policy

After the covers are printed they either go to the lamination station or directly into storage. If the covers do not require lamination, they are stored in a separate cart close to the printers. If they do require lamination, they are placed on a grey cart with two compartments, one for the covers that need to be laminated with glossy laminate and the other compartment for covers that need to be laminated with matte laminate (see Figure 11). When this cart is full, it gets moved to the lamination station. The covers that need to be laminated with linen laminate have their own place in a cart close to the lamination workstation.

Figure 11 A grey cart used for transporting covers that require lamination

After being laminated, the covers are separated into two groups, theses and other products. The theses' covers are stored on a separate cart close to the lamination machine. The other covers are stored in a series of carts against the wall, about 10m away from the lamination workstation (see Figure 12). The stack of laminated covers is placed on a shelf, with the order's ticket sticking out so the order number is visible. If all shelves are filled, stacks are placed on top of each other. This results in long collection times when a specific order is required by the binding machine, due to the worker having to search through many stacks of covers.

Figure 13 Two storage carts for laminated covers

There are two main problems with storing the laminated covers this way: the covers for an order that is laminated first end up on the bottom of a stack with multiple orders and due to the stacking of covers it is very hard to find the right covers when they are required by the binding or stapling machine.

2.4.4 Book block storage policy

If the number of products in the order is sufficiently small (<10 products), then the book blocks are transported by hand from the printer to a 'book block cart' (see Figure 13) already in the book block storage area, which is next to the paper delivery storage area, or directly to the next station. If the number of products is larger, the book blocks are first placed on a new book block cart. This cart is then rolled to the storage area. From here, the cart is rolled to the station where the next step of the production process is done, which is either to sew, staple or bind them. If the book blocks are sewn and are not used in the binding machine directly afterwards, they are stored on the same cart they came from

Figure 12 A book block cart used for transporting printed book blocks to subsequent workstations

and the cart is placed back into the half fabricate storage area.

2.4.5 Finished product storage policy

When the products are bound, they either require additional steps or they can be packaged. The dispatch department is responsible for the packaging and storage of finished products and also for the transport of bound products to the next station. The finished products storage area is next to the half fabricate storage area, here the boxes with finished products are temporarily stored until the postal service comes and picks them up. There is no storage policy in place, as the pallets with boxes are randomly placed in this storage area. However, improving the policy of this area is outside the scope of this thesis, because the steps of storing and collecting finished products are not on the list of activities performed by the production department.

2.5 Conclusion

This chapter showed the current situation at Ipskamp Printing. Section 2.1 showed a technical drawing of the current layout of Ipskamp Printing's production floor and explained where all different storage areas are located. Section 2.2 showed how the product categorization is set up, it being based on paper type used, whether the cover is laminated or not, whether the book block is sewn or not and the binding type of the product. The archived order data from November 2022 until July 2023 is visualised in this section, using the aforementioned product categorization. It was found that gluing is the most used binding method and that exotic paper only makes up 8% of the total number of orders in this period, all other orders used standard paper. Then Section 2.3 explained how an order flows through the production department and how the production steps of printing, laminating, sewing, stapling and binding are performed. It showed that, for an example order, printing the book block takes the most time and printing the cover the least time. Section 2.4 lists the current storage policy in the production department with some pictures of the storage methods in use. The storage policy at Ipskamp Printing is different for each storage area; paper delivery, standard paper storage, cover storage, book block storage and finished products storage, which is explained in detail in this section. This explanation of each storage area separately will help in understanding how each of the storage policy improvements of Chapter 4 will play out.

3. Collection time distribution

This chapter is aimed at answering the second sub-research question of this thesis: "What is the current collection time distribution of each product category?" To arrive at the answer a plan for collecting measurements has been set up in Chapter 1, however, this plan could not be followed the way it was intended. Section 3.1 explains what has changed between the planning and execution step. A dataset has been collected, which will be processed in Section 3.2. The processed dataset will be used to construct the collection time distribution for each product category in Section 3.3, after which Section 3.4 concludes this chapter.

3.1 Reality of data gathering

Gathering data for a collection time dataset per production step did not go according to plan. Section 3.1.1 explains why the plan could not be followed and how the problems that arose were remedied. Section 3.1.2 lists what the consequences of not adhering to the original planning are for both the reliability and validity of the dataset.

3.1.1 Alterations to data collection

The plan, as written in Chapter 1, was to ask the workers of each production step (printing, sewing, stapling, cutting to size and binding) to measure their collection time during an hour of each shift. These measurements were planned to start at the end of the preparation phase of this thesis, which was three months before the execution phase of this thesis started. This meant that when the execution phase started, a large number of measurements would have been performed, from which a dataset for each production step could be constructed. However, this plan was never adhered to. Even though the effort required by the workers is minimal, they said it was too much additional work to fit in their shift. In total, three meetings with the production manager and the workers were had, where the importance of data collection was explained to the workers. After each talk, they collected data for one day, after which they stopped again. All workers behaved this way, except for one who works on the binding machine. This worker did not only measure correctly, she measured throughout her whole shift, instead of only an hour. Due to her efforts there is a dataset for at least one production step; the binding step.

Having a dataset for only one production step is not enough to base conclusions on; therefore, a solution to the absence of a dataset for the remaining production steps had to be found. There were two possible solutions to this problem: applying the dataset from the binding step to the other production steps except printing or finding a way of extracting collection times from the order database. The second option proved to be impossible, because from the order's status updates in the database there was no way of differentiating between collection time and time the order's half fabricates remained in storage. This meant that the dataset collected at the binding step, had to be applied to the stapling, cutting to size and sewing steps as well. How this is done is explained in Section 3.2. Because the collection time experienced at the printers is not due to a worker collection half fabricates, but due to him collecting exotic paper, a different solution had to be found for the absence of a dataset at the printers. It was decided that a distribution and its parameters would be estimated based on the experience of the printer operators. All three printer operators were asked to give an estimate for the time it takes to retrieve exotic paper from the paper delivery area and all three gave about the same answer. It takes roughly 30 seconds to walk to the paper delivery area, around 3–5 minutes to retrieve the required exotic paper and 1 minute to bring back the paper to the printer. Using these estimations, it is assumed that the collection times for exotic paper follow a normal distribution with mean equal to 330 seconds and standard deviation equal to 60 seconds. The normal distribution was chosen due to the probability of the collecting taking more or less time being about equal.

3.1.2 Consequences to dataset reliability and validity.

The decision to use the dataset collected for the binding step for the sewing, cutting to size and stapling steps as well, has consequences for the reliability and validity of the dataset of each production step. The dataset of the binding step is valid, as it measures the collection time experienced while a worker is performing that step. For the sewing, cutting to size and stapling steps, the dataset is the same as the one from the binding step and is therefore not valid. The datasets of these production steps are not collected while performing those steps, thus the dataset does not accurately display the collection times of those steps. Using the binding dataset at three other production steps assumes that the distance to the storage area from the workstations performing those steps does not result in a change in collection time. This assumption reduces the validity further. However, in reality the differences in proximity to the storage area will not result in large differences in collection time, due to them being relatively small.

The dataset for the binding step is reliable, because only 3% of the datapoints can be considered an outlier, more explanation on the outliers can be found in Section 3.2. This low number of outliers shows a very consistent dataset, thus the dataset is reliable. Using this dataset for three other production steps makes it invalid for those steps, but does not make it unreliable, although it does impact their reliability. The workers at these steps have to collect the same half fabricates from the same storage areas, which is the reason why reliability is not impacted as much as validity, but because the datapoints are not collected at these steps, it could be the case that in reality the collection times at these steps are a lot less consistent than those experienced at the binding step. Therefore, it cannot be concluded that the dataset is completely reliable for the steps of binding, cutting to size, stapling and sewing, but it is also not unreliable.

3.2 Processing of dataset

This section will show how the dataset of collection times measured by the one production worker is processed and what distribution can best be fitted to the dataset. Before the processing of the dataset starts in Section 3.2.2, Section 3.2.1 lists the assumptions made for the dataset and gives the reason for them. Section 3.2.3 combines the assumptions mentioned in Section 3.2.1 and the calculations made in Section 3.2.2 into the collection time distribution for collecting both covers and book blocks

3.2.1 List of assumptions

The following assumptions are made for the dataset:

1. When collecting the book blocks and covers, the book blocks add 70% of the total time, the covers add 30%.
2. The datapoints in the dataset are divided by 0.7 to arrive at the distribution of collection time for collecting both the book block and cover.

The worker which measured the datapoints explained that she does not have to collect the covers and book blocks separately, because they are placed together by another worker. This other worker places the covers and book blocks on the same book block cart, which means that the worker who is measuring her collection times only has to search through the book block storage area. Assumption 1 and 2 are therefore necessary to first estimate the percentage of time spent on collecting the covers compared to the book blocks and then to adjust the dataset such that it shows the total collection time of both half fabricates.

3.2.2 Visualization and processing of the dataset

The worker at the binding machine has measured 100 useful datapoints over 5 weeks. About 5 datapoints had to be removed due to no clear description of the order number for that measurement or no useful product information being present in the archive for that order number. Of these 100 datapoints 97 are in the range of [8, 575] seconds; the remaining three datapoints are 795, 1630 and 2343 seconds. These outliers are very large, especially the last two, which shows that, because the storage system at Ipskamp Printing is unoptimized, it can happen that a worker requires ~25 minutes or more to collect the required materials. This large collection time cannot be attributed to an unusually large order, because these were medium-sized orders.

These outliers could skew the dataset in the wrong direction; thus it is researched if these outliers should be included or if they can be excluded. Therefore, calculations for six scenarios were performed, using either the square root rule or Sturges' rule for determining the bin size, which is the size of the interval for one column of the histogram, using all 100 datapoints or excluding either the 2 or 3 largest outliers. The square root rule calculates the bin size, as the name suggests, by taking the square root of the number of datapoints in the dataset. Sturges' rule calculates the bin size by the following formula: $log_2(n) + 1$ with n being the total number of datapoints in the dataset. These two rules for determining the bin size are used, because when using relatively small datasets, as is the case here, their results can differ significantly. Therefore both rules are used and at the end of the calculations their results are compared and the best option is chosen.

The following steps were taken to start the processing of the dataset:

1. Choose if 2, 3 or no outliers are removed from the dataset.
2. Use Microsoft Excel's descriptive statistics function
3. Determine the bin size for a histogram using either the square root rule or Sturges' rule and the maximum of the dataset.
4. Use the previously determined bin size and Microsoft Excel's histogram function to graph the dataset.

These steps resulted in the following histograms:

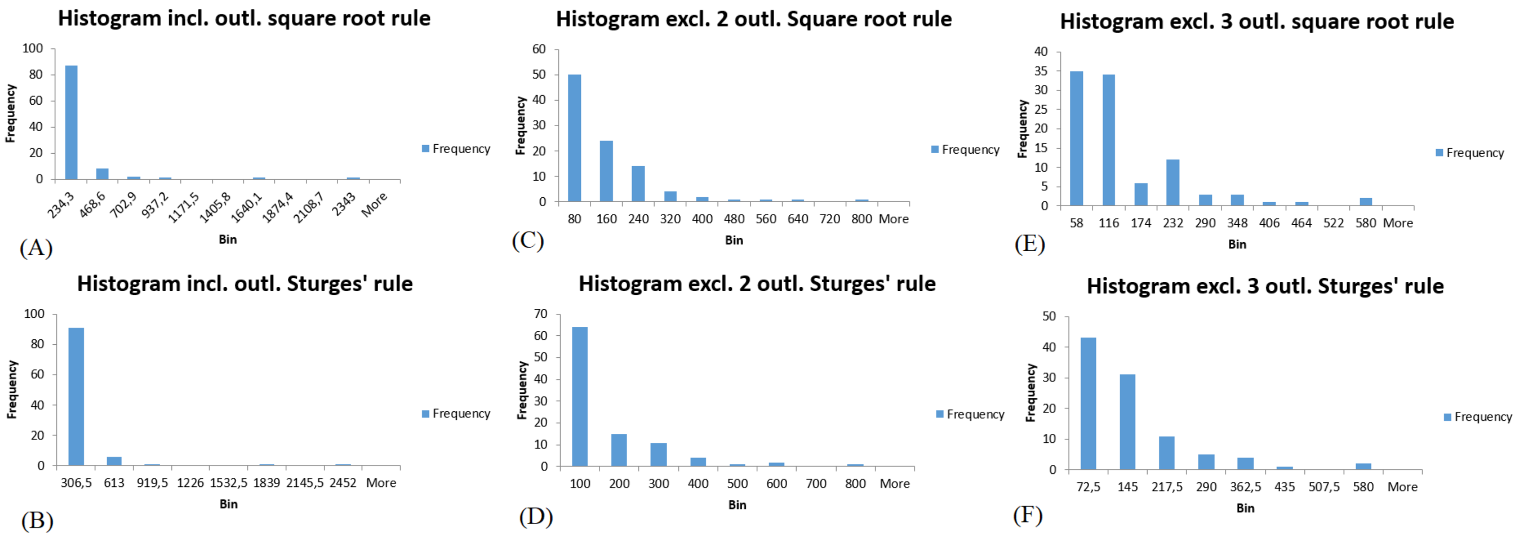


Figure 14 Histograms of the dataset using either the square root rule or Sturges' rule (enlarged graphs in Appendix C)

From the histograms two things can be concluded; including the outliers results in a histogram that does not provide much useful information and the dataset seems to follow an exponential distribution. This second conclusion can be very useful, as this chapter aims at finding the collection time distribution per product category. To check if the dataset does follow an exponential distribution, the following steps were taken:

5. Use Microsoft Excel's descriptive statistics feature to determine the mean of the dataset.
6. Calculate λ, the rate parameter of the distribution, by solving the following equation: $\lambda = \frac{1}{mean}$ (From the properties of the exponential distribution: $E[X] = \frac{1}{\lambda} \Rightarrow \lambda = \frac{1}{E[X]}$)

7. Create the cumulative density function (CDF) using the bins of the histograms as the x parameter, the previously calculated λ and the EXPON.DISTR function of Microsoft Excel.
8. Calculate the expected number of datapoints in each bin, given the CDF is assumed as being the correct approximation of the dataset.
9. Graph the measured amount of datapoints per bin together with the expected amount of datapoints.

The following graphs are the result of the previous steps:

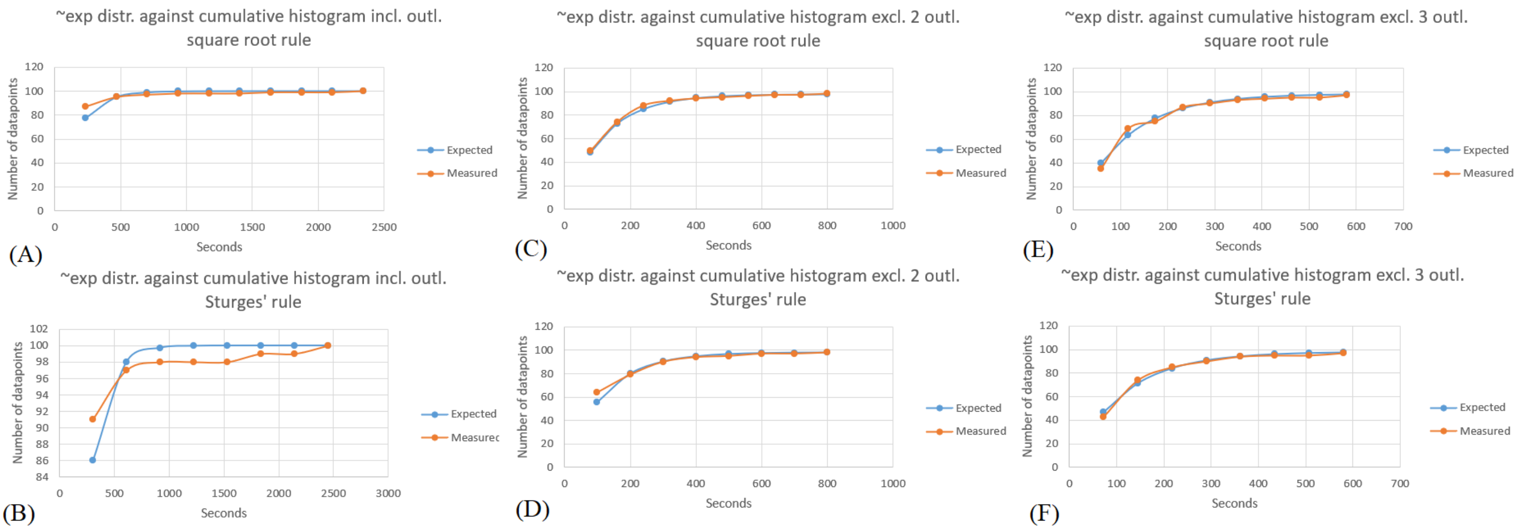


Figure 15 CDF of the assumed exponential distribution graphed against cumulative histogram (enlarged graphs in Appendix C)

Graphs 15.C and 15.F seem to be an almost perfect fit of the dataset to an exponential distribution, but before this can be concluded, a test has to be performed to check if this conclusion is valid. The test used to determine if the dataset follows an exponential distribution will be the sum of squared residuals (SSR), which calculates the difference between the expected value of a variable and the actual value of that variable and squares that difference (Glen, n.d.). A SSR of zero shows a perfect fit of the dataset to the tested distribution; thus, the lower the SSR, the better the dataset fits. The following table shows how the SSR was calculated for the dataset including the outliers and using the square root rule to determine the bin size, which is the distribution shown in Graph 15.A. The λ = 0.006414 used as the rate parameter of the CDF is the result of step 5&6.

Bin (x value)	**Measured frequency**	**Cumulative frequency**	**CDF ~exp(0.006414)**	**CDF * 100 datapoints**	**Residual**	**Squared residual**
234.3	87	87	0.777513	77.7513	9.248703	85.53851
468.6	8	95	0.9505	95.04995	-0.04995	0.002495
702.9	2	97	0.988987	98.89868	-1.89868	3.60498
937.2	1	98	0.99755	99.75497	-1.75497	3.079921
1171.5	0	98	0.999455	99.94548	-1.94548	3.784908
1405.8	0	98	0.999879	99.98787	-1.98787	3.951631
1640.1	1	99	0.999973	99.9973	-0.9973	0.99461
1874.4	0	99	0.999994	99.9994	-0.9994	0.9988
2108.7	0	99	0.999999	99.99987	-0.99987	0.999733
2343	1	100	1	99.99997	$2.97*10^{-5}$	$8.83*10^{-10}$
SSR						102.9556

Table 3 SSR calculation for the dataset including outliers using the square root rule

This calculation was also performed for the other 5 scenarios, graphing the six scenarios against an exponential distribution with λ = 0.006414, λ = 0.008439 and λ = 0.008969 for the scenarios including the outliers, excluding 2 outliers and excluding 3 outliers, respectively. These calculations resulted in the following table:

SSR	Incl. outl.	Excl. 2 outl.	Excl. 3 outl.
Square root rule	103	18.8	71.4
Sturges' rule	38.9	70.7	28.7

Table 4 SSR for all six scenarios of the original dataset

Table 4 shows that the SSR is lowest for the dataset excluding 2 outliers and determining the bin size using the square root rule. It can therefore be concluded that the collection time experienced at the binding production step follows an exponential distribution with λ = 0.008439. From the exponential distribution's properties the following characteristics can be calculated:

$$E[X] = \frac{1}{\lambda} = \frac{1}{0.008439} = 118.5\ seconds$$
$$Var[X] = \frac{1}{\lambda^2} = \frac{1}{0.008439^2} = 14{,}041.6\ seconds$$
$$\text{Standard deviation } = \sqrt{Var[X]} = 118.5\ seconds$$

3.2.3 Adjusting the dataset to include cover collection time

As mentioned in Section 3.2.1, the dataset only contains datapoints for collecting the book blocks, not for the covers. To remedy this problem, each datapoint in the dataset is divided by 0.7, to arrive at the (estimated) collection time for both the covers and book blocks. Steps 1 through 9 have also been performed using the dataset divided by 0.7. This resulted in the scenario excluding 3 outliers and using Sturges' rule to determine the bin size having the lowest SSR of all. This means that the collection time distribution for collecting both the book blocks and covers follows an exponential distribution with λ =0.006275. Note that the average collection time is not that of the book block's distribution divided by 0.7, the reason for this is excluding one more outlier from the dataset. The histogram and graphs of this scenario are shown below and the properties of this distribution are given as well.

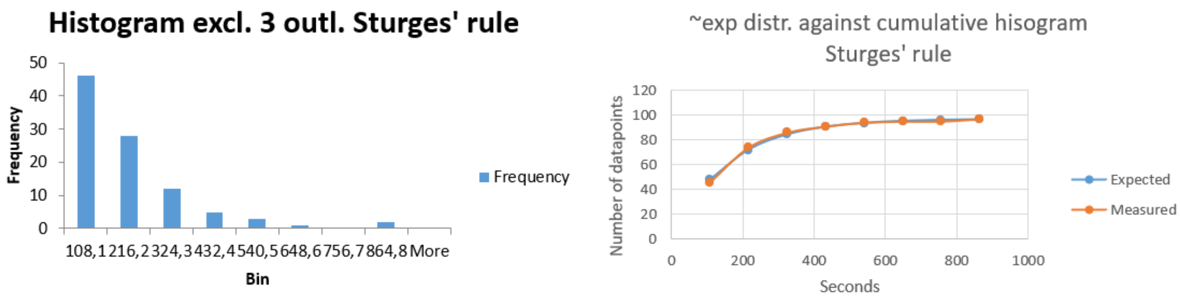


Figure 16 Histogram and exponential distribution graph of dataset divided by 0.7 excluding 3 outliers and using Sturges' rule

Properties of the ~exp(0.006275) distribution:

$$E[X] = \frac{1}{\lambda} = \frac{1}{0.006275} = 159.4\ seconds$$
$$Var[X] = \frac{1}{\lambda^2} = \frac{1}{0.006275^2} = 25{,}369.4\ seconds$$
$$\text{Standard deviation } = \sqrt{Var[X]} = 159.4\ seconds$$

To test whether the assumption of the book block adding 70% of the collection time to the total collection time for both half fabricates is reasonable, the collection time distribution is also calculated assuming a 60% and 80% scenario. These calculations can be found in Appendix A.2. The 60%

scenario resulted in an ~exp(0.005379) distribution with E[X] = 185.9s and the 80% scenario resulted in an ~exp(0.007172) distribution with E[X] = 139.4s. The results of this test show that the assumption of 70% is reasonable, because the average collection time for both half fabricates does not drastically change with either an increase or decrease of the percentage that collecting the book block adds to the total.

3.3 Collection time distribution per production category

Before arriving at the collection time distribution per product category, the collection time distribution for each production step has to be determined. As mentioned before, the dataset of the collection time measurements only comes from the binding machine, but these measurements will be used for the stapling, sewing and cutting steps as well. This section first shows how the collection time distributions per production step are determined and then combines them to a distribution per product category.

Collection time for the printing step

As mentioned before, at the printing step only exotic paper orders experience collection times, the standard paper orders do not. The collection time for exotic paper is estimated to follow a normal distribution with the mean equal to 330 seconds and the variance equal to 3600 seconds (~Norm(330 , 3600)).

Collection time for lamination

The covers that require lamination are either moved to the lamination workstation on a cart or are stored very close to the workstation on a different cart. Therefore it is assumed that no collection time is experienced during the lamination production step.

Collection time for sewing

When a product is sewn, only the book block is sewn, not the cover. Therefore the collection time experienced at the sewing production step follows an ~exp(0.008439) distribution, with the mean equal to 118.5 seconds and the variance equal to 14,041.6 seconds.

Collection time for binding, stapling and cutting to size

It is assumed that all orders have a cover and a book block, however, about 1,5% of the orders are ‘self-cover’ orders, orders which do not have a cover but instead have their first and last page of the book block as their ‘cover’. This percentage is deemed too low to make specific calculations for these orders.

Because it is assumed that all orders have a cover and the half fabricates for all three steps are taken from the same storage system, the collection time for the binding, stapling and cutting to size production steps follow the same distribution. This is the ~exp(0.006275) distribution with the mean equal to 159.4 seconds and the variance equal to 25,369.4 seconds.

Collection time per product category

The following table shows which distribution the collection time of a product category follows. The means of the distributions are summed, because the collection time for each production step is assumed to be independent of the other steps. For hardcovers it is assumed that they are made from standard paper, therefore this category does not experience collection times for the printing step.

Category	Printing collection time distribution	Sewing collection time distribution	Stapling/Cutting to size/Binding collection time distribution	Total average collection time
Standard unlaminated stapled (SUStapl)	-	-	~exp(0.006275)	159.4 seconds
Standard unlaminated glued (SUGlue)	-	-	~exp(0.006275)	159.4 seconds
Standard unlaminated sewn (SUSew)	-	~exp(0.008439)	~exp(0.006275)	227.9 seconds
Standard unlaminated unbound (SUUnb)	-	-	~exp(0.006275)	159.4 seconds
Standard laminated stapled (SLStapl)	-	-	~exp(0.006275)	159.4 seconds
Standard laminated glued (SLGlue)	-	-	~exp(0.006275)	159.4 seconds
Standard laminated sewn (SLSew)	-	~exp(0.008439)	~exp(0.006275)	277.9 seconds
Standard laminated unbound (SLUnb)	-	-	~exp(0.006275)	159.4 seconds
Exotic unlaminated stapled (EUStapl)	~Norm(330 , 3600)	-	~exp(0.006275)	489.4 seconds
Exotic unlaminated glued (EUGlue)	~Norm(330 , 3600)	-	~exp(0.006275)	489.4 seconds
Exotic unlaminated sewn (EUSew)	~Norm(330 , 3600)	~exp(0.008439)	~exp(0.006275)	607.9 seconds
Exotic unlaminated unbound (EUUnb)	~Norm(330 , 3600)	-	~exp(0.006275)	489.4 seconds
Exotic laminated stapled (ULStapl)	~Norm(330 , 3600)	-	~exp(0.006275)	489.4 seconds
Exotic laminated glued (ELGlue)	~Norm(330 , 3600)	-	~exp(0.006275)	489.4 seconds
Exotic laminated sewn (ELSew)	~Norm(330 , 3600)	~exp(0.008439)	~exp(0.006275)	607.9 seconds
Hardcover (HC)	-	~exp(0.008439)	-	118.5 seconds

Table 5 Collection time per product category

Most standard paper categories only need to be stapled, cut to size or bound, which results in an average collection time of 159.4 seconds per order of those categories. 2 standard paper categories need to be sewn, which results in an average collection time of 277.9 seconds per order of those two categories.
Hardcovers only need to be sewn at Ipskamp Printing, therefore the average collection time per order is 118.5 seconds for hardcovers.
The exotic paper categories have the highest average collection times per order, mainly due to the time it takes to collect exotic paper. Categories using exotic paper and not being sewn have an average

collection time of 489.4 seconds per order. Categories using exotic paper and being sewn have an average collection time of 607.9 seconds per order.

Although exotic paper orders experience much more collection time, and therefore might look like the place where the focus should lie, the improvements to the storage policy should still focus on all categories. If reducing the collection time of exotic paper would be the focus, the goal of reducing the collection time per production order by at least 30% would not be achieved, as the non-exotic paper orders would not be impacted enough by the storage policy improvements. Next to that, the exotic paper categories only consist of 8% of the total orders over a nine-month interval, showing that the standard paper categories are just as, or perhaps more, important than the exotic paper categories. Therefore, even though collecting exotic paper takes the most time of all production steps, the storage policy improvements should be aimed at reducing each production step's collection time.

3.4 Conclusion

This chapter showed how the dataset was collected and processed. Section 3.1 explained that a dataset for each production step could not be collected and that this problem was remedied by using the dataset which was collected at only one production step, the binding step, for the sewing, cutting to size and stapling production steps as well. In Section 3.2 the dataset is processed. This section starts out with explaining the assumption that collecting the book block makes up 70% and collecting covers makes up 30% of the time required to collect the book blocks and covers of an individual order. With this assumption stated, six scenarios were created, which were then evaluated. These scenarios used either the square root rule or Sturges' rule to determine the number of bins and bin size for a histogram of the dataset which either included or excluded outliers. This histogram was then used to test the dataset for an exponential distribution. A summed squared residual test was performed to select the best fitting rate parameter λ for the exponential distribution of each scenario, after which the scenario with the lowest summed squared residual was chosen as the scenario that denoted reality the best. The chosen scenario's exponential distribution from Section 3.2 is used to determine the collection time distribution per product category in Section 3.3, which are determined by the steps a product of each category has to undergo before being finished. The section concluded with the findings that most standard paper categories have an average collection time of 159.4 seconds per order and that most exotic paper categories have an average collection time of 489.4 seconds.

4. Storage policy improvement

This chapter starts with a systemic literature review (SLR). During the SLR, theory on storage policy improvement was collected, which will be listed in Section 4.1. In Section 4.2 suggested policy improvements from production management and the production workers are listed. Section 4.3 will explain why certain theory from Section 4.1 and certain suggestions from Section 4.2 are selected to be implemented at Ipskamp Printing and Section 4.4 will explain how these theories and suggestions can best be implemented. Finally, Section 4.5 concludes this chapter.

4.1 SLR results

The SLR did not result in sources that could directly be used for improving the storage policy at Ipskamp Printing. However, sources describing management methodologies in general were found, from which specific parts can be used for improving the storage policy at Ipskamp Printing. Most applicable theory stems from the theory of Lean management. The applicable theory will be split into two categories: policy changes regarding the physical storage system and policy changes regarding the operational usage of the storage system, listed in Sections 4.1.1 and 4.1.2 respectively.

4.1.1 Physical policy improvement theory

Each time an item has to be stored, a decision has to be made where in the storage area it should go, in other words, which location will be allocated to the item. This allocation can be random or according to a storage allocation policy. The three most prevalent policy types (Çevikcan, et. al., 2014 and McInerney & Yadavalli, 2022) will be listed in this section. Next to that, the theory of 5S, taken from the theory of Lean management, describes a method of cleaning up and setting standards for the physical state of work environments, which could be useful at Ipskamp Printing. The description of 5S follows after the storage allocation policies.

Storage allocation policies

The three most common storage allocation policy types are randomized allocation, dedicated allocation and popularity based allocation (Çevikcan, et. al., 2014 and McInerney & Yadavalli, 2022). Popularity based allocation can be subdivided in the class-based, full-turnover-based, within aisle, across-aisle, reserve stock separation-based storage policies, ABC class-based storage policy, the ABC class-based storage policy with family grouping and ABC class-based storage policy with actual sales. Although the paper by Çevikcan, et. al., (2014) and the paper by McInerney & Yadavalli (2022) are written for warehouse storage policies, these policies can be applied to any storage area or buffer, however, the size of the storage area and the number of different items inside of it mostly determine which storage allocation policy is the best option.

Randomized storage is the simplest policy of all, because it ignores the (expected) time an item stays in storage and its characteristics (Çevikcan, et. al., 2014). The space the item is stored in is chosen by the worker that is storing the item. The main advantage to this policy is that it requires the smallest possible warehouse size of all storage policies, because no partitioning of the storage locations is present (Goetschalekx, 2012). The main disadvantages are increased average travel distance and an unorganised storage area.

The **closest-open storage policy** is a form of random storage, which is created when pickers are responsible for deciding where to store the items to be picked. The items are placed in an open storage location that is closest to the entry/exit point of the storage area or warehouse. Therefore the items get clustered around the entry/exit point of the warehouse/storage area and are dispersed towards the back of the area/warehouse (McInerney & Yadavalli, 2022).

When using **dedicated storage**, each item has its own storage location where the item is replenished at and retrieved from. This means that when an item is out of stock or still in production, part of the storage area is unused, because it is allocated to that item and thus cannot be used for a different item. Resulting in the lowest space utilization of all storage policies (Çevikcan, et. al., 2014). An advantage is that workers get familiar with the storage locations (Koster, et. al., 2007). Dedicated storage can also be based on physical and/or functional similarity, like size and weight. An example of this is storing all heavy things on lower levels of storage.

Popularity based storage policies take into consideration how often an item is retrieved. The main goal of these policies is reducing the average travel distance per retrieval round, which is achieved by placing the most popular items closest to the input- /output point(s) of the storage area (Sule, 1994). Çevikcan, et. al. (2014) defined the following popularity based storage policies: class-based, full-turnover-based, within aisle, across-aisle and reserve stock separation-based. McInerney and Yadavalli (2022) added the ABC class-based storage policy, the ABC class-based storage policy with family grouping and ABC class-based storage policy with actual sales to this list.

When using the **class-based storage** policy, the available storage space is divided into areas, which are dedicated to one class of items in the organization. Inside these areas, random storage is applied (Roodbergen and Vis, 2009). The main advantage of this storage policy is that popular items can be placed close to the input/output point(s) and that the storage space utilization can be high due to the use of random storage (chan and Chan, 2011). The **ABC class-based storage policy** is a variant of the class-based storage policy that dictates the number of classes to be three. Which items are stored into each class is determined by a common characteristic (McInerney and Yadavalli, 2022). This storage policy can be expanded into the **ABC class based storage policy with family grouping**, which groups the items of the same class together based on a 'family' characteristic that they possess.

The **full-turnover-based** storage policy places the items with the highest frequency of retrieval in the most easily accessible locations closest to the input/output point(s) (Roodbergen and Vis, 2009). It follows from the definition that the retrieval frequency of each item has to be known before a storage allocation can be made, which could be a disadvantage of the method. The **ABC class based storage policy with actual sales** is a storage policy that combines the class-based and full-turnover-based policies. This is a storage policy that groups products together that are often sold together. One disadvantage to this storage policy are the frequent storage layout changes, which are a result of changing demand (McInerney and Yadavalli, 2022).

Within aisle and **across-aisle** storage policies both work with a storage area with more than 1 aisle. Within aisle storage places the most popular item in the first location of the first aisle, the second most popular item in the second location of the first aisle, etc. When the first aisle is filled, items are allocated to the second aisle's first, second, third, … storage locations. This continues until all items have a dedicated storage location. Across aisle storage places the most popular item in the first location of the first aisle, the second most popular item in the first location of the second aisle, etc. When the first location of each aisle is filled, the cycle repeats for the second location, third location, etc. This continues until all items have been allocated a storage location. (Pan and Wu, 2012)

With the **reserve stock separation-based** storage policy, working stocks are separated from reserve stocks. Working stocks are packed together and are relatively small. These stocks are positioned close to where the operators and order pickers require the items. Reserve stocks are relatively large stocks where the reserve for the working stocks is kept, often positioned relatively far away from the working stocks (Sule, 1994). Two types of reserve stock policies can be identified: floating-slot and fixed-slot. The floating-slot policy assigns storage slots to the reserve stock based on availability of empty storage locations, quite like the random storage allocation policy. The fixed-slot policy determines a number of slots per item that are allocated to its reserve stock quite like the dedicated storage allocation policy (Mulcahy, 1994).

The theory of 5S

The theory of 5S is a part of the Japanese theory of Lean management. It is a set of rules that when followed help to keep work areas organised. It focusses on visual order, cleanliness, organization and standardization. The 5Ss are (Slack and Brandon-Jones, 2019):

1. **Sort**: Sort all things present in the work area into two groups, what is absolutely needed and what is not. Then only keep wat is needed at the work area.
2. **Straighten**: Position the needed items in such a way that they are easily reachable whenever they are needed.
3. **Shine**: Clean up the work area, no dirt or clutter can be present
4. **Standardize**: Keep the work area continually clean and organized, then make this the standard for the work area.
5. **Sustain**: Commit to upholding the standards and develop pride in upholding the standards.

Implementing 5S helps in first organising the work area and then setting standards in place and upholding them. Organising a work area using a methodology like 5S is more efficient than just doing it ad-hoc.

4.1.2 Operational policy improvement theory

Reducing collection times can be done in two ways: by reducing travel distance between a workstation and storage area or by reducing the time it takes to get an item out of its storage location, which includes searching for the item. Reducing travel distance is not achieved by improving the storage policy. Therefore, this section focuses on reducing the time it takes to get an item from its storage location. Two ways of achieving this have been identified: reducing the number of stored items in the storage area and reducing the time spent searching for an item.

Reducing the number of stored items

When there are less items stored in a storage area with many similar looking items, it is easier to find and retrieve a required item. This in turn decreases the collection time as a whole. The most prevalent production management theory that aims at reducing buffers (which is what the storage areas at Ipskamp Printing are) is Lean management. Next to Lean management, the Theory of Constraints (TOC) could also be an option for reducing the buffer size. Even though the TOC does not aim specifically at buffer reduction, it can be a result of its implementation. Both these theories will be briefly listed here.

The theory of Lean management aims at reducing inventory levels gradually to eventually end up at a production system that does not require buffers. Lean sees inventory levels as a ‘blanket of obscurity’ over the production system which prevents problems from being noticed (Slack and Brandon-Jones, 2019). When Lean management is implemented perfectly, all production stages are controlled in such a way that no buffers are required and that all demand, both internal and external, is met right at its due date. This is done by engineering the production flow in such a way that one production step only delivers its output to the next step when that step has empty capacity for it. This flow ensures that no overproduction is present, no unnecessary movement between production steps is required and the production flow of the complete process can be optimized.

To arrive at this perfect scenario from a production process that uses buffers, the buffers need to be reduced in size gradually and the production process should be adapted to solve the problems that appear each time the buffer size is decreased (Slack and Brandon-Jones, 2019). The buffer size is incrementally reduced after the production flow has been incrementally changed into a more lean one. This goes on until either the perfect Lean implementation is achieved or that management deems further buffer reduction as having a negative effect on the process.

The Theory of Constraints (TOC) works by identifying the constraint to the production process and planning all other stages of the process according to the constraint (Simsit et. al., 2014). Next to the planning part, the theory states that this constraint should be reduced or removed, such that a different part/stage of the production process becomes the new constraint. The practical methodology of TOC is called Drum-Buffer-Rope (DBR), where the drum is the production pace of the process, determined by the constraint and the rope is a way of communicating the pace to the other production stages (Duclos and Spencer, 1995). The only buffer in the system (of a one constraint system) is before the constraint, to ensure that its utilization stays at its maximum.

Due to the fact that all other production stages are planned according to the pace of the constraint, they require no or very small buffers, only the constraint requires a relatively large buffer, which means that implementing TOC can have a reducing effect on the total buffer size required. If the production process currently uses multiple buffers, implementing TOC can reduce that number or, at least, shrink the size of them, because of the planning part of TOC.

From both these production management theories it can be concluded that if a planning is made that takes the capacity of the system as a whole as well as the capacity of the individual stages into consideration, the total buffer size can be reduce, which in turn reduces collection times.

Reducing the time spent on searching for an item

When the time spent on searching for an item is reduced, the overall collection time is reduced as well. Therefore it necessary to find ways that enable workers to immediately find the items they require. As mentioned in Section 4.1.1 certain storage allocation policies help greatly in reducing the time spent on searching for items, like the dedicated storage, withing-aisle and across-aisle policies. Random or class-based storage allocation, when compared to these policies, can result in significantly more time spent on searching for an item if the items are visually similar. Because the storage allocation policies have been discussed previously, this section will discuss how to reduce the time spent on searching for items that are visually similar, as is the case at Ipskamp Printing.

The theory of Lean management uses kanbans, which is the Japanese word for card or signal (Slack and Brandon-Jones, 2019). It is used to communicate a message about the status of an order, machine, half fabricate, raw resource, etc. Depending on what message is conveyed and what production process it is used in, a kanban can have many different forms; a punch card, a coloured ball, a shape drawn on the production floor, a light on a machine or anything else that can be used to communicate a message.

Because kanbans are used to convey a message, they can be used to differentiate between visually similar items in storage. A kanban can be used to denote the item's category, day of purchase, day of production, planned retrieval day or any other characteristic of the item. When kanbans are used in storage, searching times can be reduced, because a worker only has to search through the items with one specific kanban attached to them, instead of searching through all items. When a kanban is mainly used to differentiate between visually similar items, it would be best to use a coloured item that is easily attached to the item or the container that the item is in. Examples of this can be stickers, carabiners, magnets or markings made with markers. The colour then denotes a characteristic of the stored item, which can be any of the previously mentioned characteristics. Multiple different kanbans can be used parallel to each other if it is useful to have multiple characteristics visually displayed.

4.2 Policy improvements from Ipskamp Printing

After brainstorming with production management and the production workers some suggestions for policy improvements have been gathered. This section lists them and gives a short explanation of their expected results. Section 4.2.1 lists the suggestions made by production management and Section 4.2.2 lists those made by the production workers.

4.2.1 Management storage policy suggestions

Management gave the following suggestions to improve the storage policy:

- Organise the storage areas periodically, specifically the paper delivery area.
- Attach a label or sign to the pallets with standard paper.
- Store the cover and book block together right after the book blocks finish printing.
- Place exotic paper order not 5 days, but 3 or 4 days before the order starts production.

The first suggestion for a storage policy improvement made by production management is a periodical clean up or organising of the storage areas, specifically the paper delivery area. When this is done every day or every two days, there would be a lot less clutter in the storage areas, the items required for the next day would be really easy to find and the items would be positioned in such a way that retrieving them takes little effort.

Due to the visual similarity of the paper stored in the standard paper storage area, management suggested that attaching a label or sign to the pallets with the standard paper can be an improvement to the storage policy. The reason for this is that the printer operators know what paper type is on each pallet, but anyone else will not be able to differentiate between them. Thus if management or operators of a different workstation want to help out at the printers, they need to search for the correct paper, which means that they experience collection time for standard paper. Implementing a label or sign will remedy this problem by making it very easy to differentiate between the paper types.

The third policy improvement suggestion made by production management is that they want the cover and book block to be gathered and placed together into storage right after the book blocks finish printing. The covers are most often printed before the book blocks, because they require less time, which means that right after the book blocks finish printing, both half fabricates can be stored together. Implementing this suggestion would result in less covers being stored in the cover storage, because they are removed from there earlier in the production flow. This would cause an, albeit small, reduction in total collection time, because searching for covers would take a little less time, due to there being a few less covers on the cover storage carts than there are currently.

Management’s last suggestion is to place exotic paper orders one or two days later than is currently done, because currently exotic paper is ordered 5 days before an order is planned to start printing. Part of the reason for this is that paper needs to acclimatize, for example really cold paper first has to heat up to room temperature before it can be used in the printers. However, this 5 day lead time is mostly in place because that is what the printer operators are used to. Management explained that 5 days is not necessary, because the paper suppliers promise a 1-day lead time and paper does not require 4 days to acclimatize. Therefore, if paper is ordered 3 or 4 days before the order is planned to print, it has enough time to acclimatize and there is less paper stored in the paper delivery area. Ordering exotic paper later also reduces the risk that the paper has to be thrashed because an order was cancelled.

4.2.2 Worker storage policy suggestions

The production workers suggested the following storage policy improvements:

- Make only one person responsible for ordering the paper.
- Plan time in the workers’ schedule to organize the storage areas.
- Create a system to track the stock levels of standard paper.
- Reduce the total number of paper types offered to customers.
- Immediately use exotic paper when it is delivered.
- Make the order numbers more legible, such that they are more easily recognised.

The first suggestion made by the production workers is not specifically a suggestion for the storage policy, but it does influence it. They suggested that there should be one person responsible for ordering paper and by extension for managing the standard paper stock levels. Now all three printer operators order paper without communicating with each other. This results in paper being ordered twice and paper being ordered while there is more than enough paper in storage to fulfil the planned orders. When one person is responsible for ordering paper, these mistakes happen significantly less often, resulting in less paper being stored in the paper delivery area.

One suggestion was given by both workers and management: to periodically organise the paper delivery area. However, the workers want to have time specifically scheduled for it, instead of management just telling them that they are required to organize is, as has been the case in the past. Production workers explained that, mostly due to an increase in smaller orders, they have less time in a day to perform other tasks than operating the machines. Therefore, they want to have time specifically scheduled to perform the task of organising the paper delivery area.

Production workers also suggested to create a system that tracks the standard paper stock levels. This can be digital or physical. They expect that when such a system is implemented, the mistakes with ordering paper described earlier would cease to happen and it would take less time to check the stock levels.

The fourth suggestion made by production workers is to reduce the total number of paper types offered to customers. This would reduce the number of different paper orders and one worker explained that many paper types look and feel very similar, which in his opinion means that it is better to only offer one of the types that are very similar. If this suggestion would be implemented, the space required for the paper delivery area can be reduced, which open up floorspace for more half fabricate storage.

The printer operators also suggested to immediately use exotic paper when it arrives at the paper delivery area. This would result in no space in the paper delivery area being taken up by exotic paper and collection times for the exotic paper almost completely disappearing.

Finally, most production workers are annoyed by the small print of the order numbers on the order tickets. It makes it hard to read the order numbers and in turn hard to find the right half fabricates. If these numbers could be enlarged it would reduce the time spent on searching for half fabricates.

4.3 Selecting policy improvements

This section shows how certain theories mentioned in Section 4.1 are selected for implementation at Ipskamp Printing, then certain suggestions from Section 4.2 are selected according to these theories. Section 4.3.1 shows the selection process of the theories, Section 4.3.2 uses the theories selected in the section previous to choose which suggestions can be implemented at Ipskamp Printing and finally, Section 4.3.3 lists a few additional policy improvements based on the selected theories.

4.3.1 Making a selection from the SLR results

The theories presented in Section 4.1 have to be evaluated for implementation at Ipskamp Printing, this evaluation will then be used to select the theories whose implementation will result in achieving the goal of this thesis, which is: “reducing the collection time per order by 30%”. Selecting these theories will be according to two criteria, which were thought up during the SLR: How much work implementing the theory will take and how much collection time reduction the implementation of that theory can cause. The theories selected for implementation should have the highest collection time reduction for the least amount of work.

Physical part of the storage policy

First up is the theory with regards to the physical part of the storage policy, the storage space allocation and the 5Ss of Lean management. Both these theories are applicable to Ipskamp Printing, albeit with some alterations.

Currently, there are three distinct parts of the storage area in the middle of Ipskamp Printing's production floor: the paper delivery area, book block storage area and finished product storage area. Inside these areas, items are stored randomly, sometimes on top of each other, as is the case in the paper delivery area. Apart from these three storage areas, Ipskamp Printing has a storage area for covers and for standard paper, which are not in the middle of the production floor (See Figure 3). When looking at the three storage areas in the middle of the production floor, the storage allocation policy in place looks a lot like the class-based storage allocation policy. The question that remains is if this is the optimal storage allocation policy for this storage area. To answer this question, the 10 policies discussed in Section 4.1.1 have to be compared to each other. Before the comparison starts, one policy can be left out: reserve stock separation-based. This policy states that there should be a small working stock and a larger reserve stock, but the items stored in these three storage areas cannot be split into working and reserve stock. The book blocks of one order are retrieved all at the same time, an exotic paper order is retrieved and used completely for one order and finished products of an order are retrieved and shipped as one package.

The remaining storage allocation policies can be divided into two categories: mainly random allocation, which are the random and class based policies, and mainly dedicated allocation, which are the dedicated, within-aisle, across-aisle, ABC class-based and turnover-based policies. As Goetschalekx (2012) noted, random storage allocation requires the least amount of physical space, due to no partitioning of the storage area being required for its application and empty locations being available to all items that have to be stored. When looking at Ipskamp Printing's situation, the main constraint to the storage system is its size, therefore a random storage allocation policy would be best suited for them. Dedicated storage would require too much space and is hard to implement on an individual order basis, within- and across-aisle storage does not result in a large reduction of the time required for an item's retrieval, due to the small size of the storage area and turnover-based storage is not applicable to Ipskamp Printing, due to them working with individual orders, not standardised products.

Now a choice between the random and class-based storage policies has to be made. When only considering the floorspace constraint, the random storage allocation policy should be selected, because with the class-based policy it can happen that the storage area of one class is filled completely, while in another class's area there is some space left, which cannot be utilized due to the storage allocation policy. Next to that, implementing a random storage policy also takes the least amount of time. However, if the second criterium, that of the most collection time reduction, is also taken into consideration, the random storage policy might not be that interesting anymore. In this case the class-based policy looks more interesting, because instead of a worker having to search through the whole storage space, as would be the case with the random storage allocation policy, only one section of the storage area is dedicated to the item that he is looking for. Another problem that arises with implementing the random storage policy at Ipskamp Printing is that their stored items are visually very similar, which increases the collection time when not separated by class. Therefore, because reducing collection times is the main goal of this thesis, the class-based storage allocation policy is selected as being the most beneficial storage allocation policy for Ipskamp Printing. This means that the storage allocation policy does not change, but the size of each class's storage area can change. More on this in Section 4.4.

The second theory listed in Section 4.1.1 is 5S. Due to both production management and production workers suggesting that the storage area should be periodically organized, there is strong evidence that a theory like 5S can be beneficial to Ipskamp Printing. Implementing 5S also complies with the two selection criteria stated: having a large collection time reduction as a result of its implantation for little effort, because implementing 5S would only require about 15 minutes a day, while greatly reducing exotic paper collection time. 5S states that first the work area should be organized and cleaned first, then the standard of cleanliness should be documented and finally the people working in that area should keep it up to standard (Slack and Brandon-Jones, 2019). The storage area at Ipskamp Printing can greatly benefit from this methodology, due to the current lack of a ruleset and cleanliness standard of the storage area.

Operational part of the storage policy

Reducing the number of stored items is a great way of reducing collection times, however, actually reducing the number of stored items without disrupting the production flow is not easy. It requires a planning that keeps the throughput of the whole system at an acceptable level, while reducing the number of items stored in the buffer between stages. In the SLR two production management theories that can have this result were identified, Lean management and the Theory of Constraints (TOC). Lean management specifically focusses on reducing and eventually removing buffers, while TOC focusses on improving the utilization of the system's constraint, which can result in shrinkage of buffers. Next to that Lean management aims at improving the complete process by reducing waste throughout the whole process (Slack and Brandon-Jones, 2019), while TOC aims at improving the complete process by reducing the effect of the system's constraint on the production flow (Simsit et.al, 2014). When considering the scope of these two management theories (process wide compared to zoomed in on the constraint), Lean management would be a better pick for Ipskamp Printing. The main reason for this is that there are many wastes present throughout the process, thus when Lean management is implemented, not only would the buffers reduce in size, the wastes occurring throughout the production process would also decrease. Choosing Lean management over TOC would take more work to implement, as it is a company-wide intervention, compared to TOC only being a production-wide intervention. However, because there is a lot of waste created in the production process of Ipskamp Printing, implementing the theory of Lean management would result in more collection time reduction than TOC, because Lean management has a more broader view.

As mentioned before, when time spent on searching for items in storage is reduced, so is the total collection time. Part of the time spent on searching will be reduced by the use of a class-based storage allocation policy and the implementation of 5S. Next to these suggestions, Ipskamp Printing can benefit from the use of visualization of their half fabricates and raw resources. To illustrate this problem: it is very hard to differentiate between the raw resources, due to most paper types being the same shade of white and the half fabricates are only identifiable by a small order number on the order ticket. Therefore any way of visualizing an item's category, status or order number could be useful. Kanbans, taken from the theory of Lean management, can be a good way to achieve the goal of visualizing the distinctions between items in storage, thus reducing the collection time experienced for little effort.

4.3.2 Most promising policy suggestions

Most of the suggestions made by both production management and production workers are promising. There are only three suggestions that either cannot be implemented or do not have significant collection time reduction as a result. These suggestions are: using exotic paper right when it arrives, offering a smaller number of paper types and combining the book blocks and covers of an order right after the book blocks finish production. Management explained that trials were run where exotic paper was used immediately after it was delivered, but it created more problems than it solved. Offering a smaller number of paper types is also not possible due to the highly competitive market of printing companies. If Ipskamp Printing does not offer a paper type the customer requests, he will go to a competitor that does offer it, which is not something management wants. Finally, if the cover and book block would be placed together into storage right after the book blocks finish printing, it would not result in a significant collection time reduction, the only thing that would change is the moment of collecting both half fabricates.

Most of the remaining suggestions fall into the Lean management category: pallet labels and making order numbers legible are forms of a kanban, the periodical cleanup is part of the 5S methodology and ordering paper 3 or 4 days in advance instead of 5 days is reducing the paper delivery area's (or exotic paper buffer) size, which is a goal of Lean management. Finally, making one person responsible for ordering the paper and having a system that keeps track of standard paper stock levels, will reduce waste in the form of ordering mistakes. As previously mentioned, implementing the theory of Lean management has high potential for Ipskamp Printing therefore, these possible implementation will be discussed in Section 4.4.

4.3.3 Additional policy improvements

Throughout the research at Ipskamp Printing, I have formulated three additional policy improvement suggestions:

- Change the cover storage shelving to increase the number of individual storage locations and make these locations' size modular.
- Check inventory levels periodically, instead of sporadically.
- Write the order numbers from paper deliveries on the packaging with a large marker.

Currently, the cover storage has 15 individual shelves with two storage locations on each shelve, see Figure 17 for two of the three shelving units dedicated to cover storage. As can be seen from the picture, covers of multiple different orders are stacked on top of each other and the lower and upper shelves are not used. If these shelving units would be changed to units that have more individual locations and those locations being modular, searching for and collecting covers would be faster than it currently is. The reasons for this are that the different orders would not be stacked on top of each other and when each order is stored on an individual location, a system can be created that keeps track of which order is stored in which location.

Figure 17 Part of the laminated cover storage

The standard paper stock levels are only sporadically checked, which sometimes results in paper being ordered while there is still a large quantity in storage. This is wasteful behaviour, because it clogs up the paper delivery area, because there is no other space these paper order can be placed. If instead of sporadically the stock levels are checked periodically, before every ordering round for example, then paper will only be ordered when it is necessary. This reduces the size requirements and clutter in the paper delivery area.

A way to decrease the collection time of exotic paper is by writing the order number of the order which uses that exotic paper clearly legible on top of the paper packaging. The exotic paper is delivered with a sticker on the packaging that lists the paper type and the order number of the order that uses the paper. It is a small amount of effort to write the order number clearly legible on the packaging and it will reduce the time spent on searching for the correct exotic paper significantly.

4.4 Implementing policy improvements

This section shows how the theory mentioned in Section 4.1 and the suggestions from Ipskamp Printing mentioned in Section 4.2 can be implemented. First Section 4.4.1 discusses the implementation of periodically organizing the standard paper storage area and the paper delivery area.

Then the use of kanbans to differentiate between items in storage is discussed in Section 4.4.2 and finally in Section 4.4.3 the possible improvements to the production process created by implementing Lean management at the production department are discussed.

4.4.1 Periodical organization of paper storage areas

Periodical organization of the paper storage areas can have large positive results in a short amount of time and without requiring drastic changes in workflow. The standard paper storage area should keep using the dedicated storage allocation policy and the other storage areas should stick to using the class-based policy. Because of the storage area's size being the main constraint and reducing collection time being the second, these storage allocation policies are selected. See Section 4.3.1 for a more elaborate explanation. It is advised to plan time for organising the paper storage areas on a daily basis, because each day new paper deliveries arrive and paper is taken from the standard paper storage area, which means that the level of organization in these two storage areas changes daily. Now follows a list of steps to be taken to organize each of the two paper storage areas.

For the paper delivery area:

- Place standard paper into the standard paper storage area.
- Cut the paper that requires it to size and place it into its storage area.
- Write the order number on top of the exotic paper packages with a marker.
- Trash all paper that is not needed anymore.
- Position the exotic paper based on the day that it will be used for printing.

For the standard paper storage area:

- Check the stock levels of all standard paper and communicate which paper types have to be ordered.
- Ensure that each standard paper type is stored in the correct storage location.

As mentioned before, organising the paper storage areas daily will have the best results, because if each day these areas are organized, the collection time for exotic paper can be reduced by about 55%, due to the time spent on searching for and retrieving the exotic paper being reduced from an estimated 3-5 minutes to about 1 minute. Simply put, the average time it takes to collect exotic paper goes from an estimated 330s to 150s. This large reduction is achieved by removing time consuming activities that are currently required to retrieve exotic paper from the paper delivery area. Currently, the printer operator has to search through the whole paper delivery area, because the deliveries are not positioned on the date that paper is required for printing, but they are placed at random in the storage area, sometimes even on top of each other. When the operator has finally found the correct paper, he has to move multiple pallets around and sometimes even needs to get a forklift truck to remove pallets from a stack. After all these activities are finished, he can finally move the paper to the printer and start his work. When the paper delivery storage area is organised and the order number is written in large font on the packaging of the paper, finding the correct paper order is much more easy. After the operator has found the correct paper order, he can use his hand trolley to pick up the pallet and bring it to his printer, because the paper he needs on that day is stored in the most accessible place of the paper delivery storage area. Due to the removal of unnecessary searching for the correct paper order and moving around multiple pallets, the collection time of exotic paper can be reduced by 55%.

The main advantage of a daily clean-up of the standard paper storage area is, due to the daily stock level check, that the number of unnecessary paper deliveries of standard paper will be reduced, which results in less clutter in the paper delivery area. It therefore helps reducing the collection times of exotic paper. The daily standard paper storage area organization can also be combined with making one person responsible for ordering all the paper. This person will check if the people of the last day have organized the storage area according to the standards set in place and if new paper actually has to be ordered. This system would remove about all ordering mistakes.

The daily organising of the paper storage areas will follow the 5S methodology, by first removing everything that is not necessary in those storage areas, then setting a standard in place of the level of organization and cleanliness of the storage areas and finally adhering to the steps mentioned previously, such that the standard will be upheld. Each morning the workers check if the storage areas have been organised according to the standards set in place and if the level of organization is insufficient, management is notified. In this way management can tackle any problems that arise with the daily organising of the paper storage areas and ensure that the standards are upheld. A periodical cleanup of the half fabricate and the finished products storage areas is not required, because the number and position of the items stored in them is constantly changing.

4.4.2 Differentiation of items in storage

The highest collection time reduction for orders that do not require exotic paper can be achieved by reducing the time spent on collecting half fabricates, which can most easily be done by reducing the time spent on searching for the correct half fabricates. A great way to achieve this goal is to increase the ease of differentiating between both book blocks and covers. The theory of kanbans is applicable here, because it uses visual ways of communicating the status or category of an item in storage, which is exactly what is needed at the production department of Ipskamp Printing. Two types of kanbans can be implemented, attaching a coloured item to a book block cart and making order numbers more legible.

The coloured item attached to a book block cart will show which day the book blocks have been printed. This results in a worker having to search through less book block carts, thus reducing collection time. If the coloured items are used together with making order numbers more legible, it is expected that the collection times of book blocks can be reduced from an average of 118.5s to an average of 75s, a reduction of 37% This reduction is achieved because of the fact that instead of searching through all book block carts in storage, the worker only has to search through the ones that have an item attached to them of a specific colour and the different book blocks on each cart are more easily differentiated, due to the order numbers being more legible. For example, instead of a worker needing to search through all 6 book block carts in storage, he only has to search through the 3 carts with a red item attached to them, because red denotes Monday as the day of printing and the worker knows from the IT system that the book block was printed on Monday. The different book blocks that lay on these three carts are easily identified, due to the more legible order numbers, which reduces the time it takes to find the correct book block.

The best way of making the order number more legible is to place an additional piece of paper on top of the last printed book block and cover with the order number clearly legible written on it. It would be ideal if the printing machines would do this automatically, but until that has been implemented, writing it by hand will suffice. This additional step does take a little time and creates a bit of waste, but it reduces the collection time more than the additional time the step takes and the decrease in collection time is worth more than the waste.

Next to using kanbans to differentiate between book blocks in the book block area, changing the shelving where the covers are stored into one with more locations, which can change in size, will result in covers being found more easily, thus reducing the cover part of the collection time. It is important that the locations can change in size, because then they can accommodate the different number and size of covers that Ipskamp Printing can produce. Creating a shelving unit with locations that can change in size is easily done, the only requirements are that the actual shelves are not attached to the shelving frame, but can freely be taken in and out, which together with a shelving frame that has multiple attachment points for each shelve forms a modular shelving system. Then, If the covers of only one order are stored in each storage location, the locations can be marked by the order number that is stored at that location, making finding the right order number more easy. Next to finding the right covers more easily, when the covers are found, they can easily be picked up from the storage location, instead of a worker first having to move all the covers of different orders that have been stacked on top of it. These changes to the storage policy and shelving of the covers is expected to reduce the average collection time of covers from 40.9s to an estimated 30s, a 26% reduction, which is the result of the worker having to perform less actions before having collected the cover.

4.4.3 Reducing required storage

Reducing the required storage space for paper deliveries and half fabricates is not as straight forward as organizing storage areas or implementing kanbans, but it will have a positive impact on the collection times. If Lean management would be adopted throughout the whole production department, next to the required storage areas being reduced in size, the throughput could be greatly improved, due to many wastes being removed from the production process. Researching how Lean management can be implemented at the whole production process of Ipskamp Printing is outside the scope of this thesis, but it should be researched, because of the large throughput improvement the implementation of Lean management can have.

4.5 Conclusion

This chapter showed how selected theories can be used to create practical storage policy improvements. Section 4.1 is dedicated to the systemic literature review (SLR) of this thesis. Here multiple theories are described including storage allocation policies, Lean management and the theory of Constraints (TOC). Section 4.2 listed improvements to the storage policy which were suggested by production management and the production workers. On one thing they immediately agreed: periodically cleaning up the paper storage areas. Next to this, there were 8 other suggestions. These 9 suggestions and the theory of Section 4.1 were evaluated in Section 4.3 and a selection that could be implemented at Ipskamp Printing was made. The implementation of this selection is discussed in Section 4.4 which showed how the collection times are expected to be reduced by implementing different storage policy improvements. Organising the paper storage areas periodically is expected to reduce the exotic paper collection time by 55%, next to also reducing unnecessary paper orders. Implementing kanbans in the book block storage area is estimated to reduce the collection time for book blocks by 37%. Changing the shelving used for storing the covers is expected to reduce the required cover collection time by 26% and implementing Lean management throughout the production process can reduce the collection times even further.

5. Conclusion and recommendations

This chapter marks the end of this thesis. First the research will be concluded in Section 5.1. Then Section 5.2 lists the recommendations that follow from the concluded research and explains how these recommendations can be implemented. Section 5.3 lists the limitations experienced during the research for this bachelor thesis and the chapter ends with Section 5.4 which identifies areas of further research.

5.1 Conclusion

Chapter 2 shows the current state of the production department of Ipskamp Printing. It starts out with categorizing all the products sold by Ipskamp Printing. In total 17 categories are created, which are based on the product's characteristics. The characteristics considered are paper type used for the book block, whether or not the cover is laminated, whether or not the book block is sewn, and the binding method used. Afterwards, the chapter shows a blueprint of the production floor, which shows how little space there is left on the production floor, thus why more efficient use of the storage space is required. Then the chapter continues with an explanation on how each production step is performed and in what way each product category flows through the production department. The chapter ends with explaining what the current storage policy is for each storage area.

The first chapter containing research results is Chapter 3, which shows how the collection time distribution per product category is determined. The dataset on which these distributions are based is collected by 1 worker in production, who works on the binding machine. This dataset is used to determine the collection time distributions for collecting only the book block and collecting both the book block and cover, which follow an ~exp(0.008439) and ~exp(0.006275) distribution respectively. The collection time distribution for exotic paper is estimated by the printer operators and follows a ~norm(330, 3600) distribution. Based on the production steps a product category requires, the collection time distribution for that category is determined using these three distributions. The chapter ends with a table showing the expected collection times per product category, which ranges from 118.5s to 607.9s.

Chapter 4 is the second chapter containing research results, this time the theoretical results, as the chapter starts with the results of a systemic literature review (SLR). It lists different storage allocation policies, parts of the theory of Lean management and the Theory of Constraints (TOC). After the SLR, the storage policy improvement suggestions of both production management and workers is listed. The theories and suggestions are evaluated and at the end of the chapter it is explained how these theories and suggestions can be implemented. The policy improvements are grouped together into three subjects: periodical organization of the paper storage areas, easier differentiation between stored items and reducing the total number of items stored.

In Chapter 4 it is concluded that the periodical cleanup of the paper storage areas results in a 55% reduction of the expected time required to collect exotic paper, that using a visual identifier on the book block carts result in a 37% reduction in collection time of book blocks and a change in shelving for covers result in a 26% reduction of collection time. When these storage policy improvements are implemented the goal of this thesis, a 30% reduction in overall collection time, will have been achieved. Therefore it is concluded that the research question listed at the start of this thesis, has been successfully answered.

5.2 Recommendations

Only stating the results of the research is not enough, these results need to be translated into recommendations for Ipskamp Printing, such that they have a concise overview of what they should do to reduce the collection times. This section lists those recommendations and the way they can be implemented:

1. Use **5S from Lean management** to (schedule time to) periodically organise the paper storage areas. Together with the production workers, management should decide what the standard level of organization for both the paper delivery and standard paper storage areas will be. When this has been decided, the initial organising round must take place, which will take longer than the subsequent daily organising rounds. The workers will check at the start of each day if the these two storage areas are up to standard and if not, they will notify management. Management will figure out why the standard was not upheld and take action accordingly. Following these steps will result in two organised paper storage areas, which in turn will reduce the collection time for exotic paper and reduce the number of (unnecessary) paper orders.

2. Keep the **class-based storage allocation policy** for the large storage area in the middle of the production floor. As has been argued in Section 4.3.1, the class-based storage allocation policy is the best suited for the three storage areas in the middle of the production floor of Ipskamp Printing. However, the size of each of these three storage spaces can be changed, because due to an increase of organization in the paper delivery area, combined with less paper orders coming in, the required size of that storage area will reduce. This means that management should decide on whether the book block or finished product storage area should be assigned this free space and whether or not to switch storage areas around on the floorplan.

3. Introduce a **coloured item that can be attached to the book block carts**, which denotes the day that the book blocks on it were printed. Firstly, a colour should be chosen to denote each working day. Then the workers need to understand how to work with these coloured items and management must ensure that the workers use them. After an initial period in which everyone has to adapt to the new way of working, they will get used to only looking at book bock carts with a certain colour of attached item on it. When they are used to it, the full collection time reduction will become apparent, as the workers will search through only a few carts, instead of all.

4. **Change the shelving used to store the (laminated) covers** into shelving that is modular and has more locations. Implementing this recommendation starts with buying a new shelving frame that has shelves that lie loosely inside of it. Each shelve then becomes a storage location, on which only one order will be stored. A system of keeping track which order is stored in which location has to be thought up. This can either be done physically, by using small whiteboards for example, or digitally, for example by using barcodes on the storage locations. Using a modular shelving system will reduce the collection time for covers by reducing the time spent on searching for the correct order and by reducing the number of actions to perform to retrieve the covers from the shelving unit.

5. **Appoint one person to be responsible for ordering paper**. When only one person is responsible for ordering paper, the mistakes currently happening at this step will disappear. No double paper orders will happen anymore, because that worker knows which paper orders he has placed the days prior and no paper will be out of stock, because he checks the storage levels periodically. This results in paper only being ordered when necessary and will thus reduce the number of paper deliveries. Management should appoint one person for this task and periodically monitor the number and type of paper orders, to check if the worker is doing his job correctly.

6. **Make the order number more legible**, both on the packaging of exotic paper and on the half fabricates. This will reduce the collection time due to the required items being more easily spotted by the workers. Implementing this requires the workers to consistently write order numbers on exotic

paper packaging during the daily organization of the paper delivery storage area and consistently writing the order number on a piece of paper that is placed together with the book blocks and covers. Management should explain why they want the workers to perform these actions and also monitor them closely throughout the implementation of this recommendation. A goal for the future would be to make the printers print a sheet that shows the order number in a large font, instead of the workers having to do that by hand.

7. **Implement Lean management** to reduce the required size of the half fabricate storage areas. Before implementing the theory of Lean management, its implementation at the specific case of Ipskamp Printing should be researched further. It has high potential of reducing collection time and other wastes in their production process, which makes the theory of Lean management so interesting for the future.

5.3 Limitations

As is the case with most research projects, this thesis was subject to a number of limitations. This section lists them.

- The **dataset was not complete**. Instead of the collection time being measured for the printing machine, cutting machine, lamination machine, stapling machine, sewing machine and binding machine, only data at the binding machine has been collected. This resulted in using the dataset collected there and apply it to all other machines except the printers. This limitation had a large impact on the validity of the dataset, and by extent this thesis, and therefore should be the first limitation to be removed in future research.
- The **dataset is small**. Only 105 measurements have been made, of which 100 are used. When the number of measurements goes up, more statistically relevant results can be produced. This limitation had a relatively small impact on the validity and reliability of the dataset and results, but could still be greatly improved.
- The **dataset is only measured over 5 weeks**. As mentioned before, Ipskamp Printing does not experience constant demand, which means that the collected dataset might not be representative to another time of year. It has been collected in a busy period, which means that the impact of this limitation is minimal, but the question remains what the collection times in other parts of the year are.
- The **dataset's quality is dependent on a human who is making the measurements**. This means that there might be mistakes present in the measurements. Again, a limitation with a relatively small impact overall, because the dataset is used to calculate a distribution, which averages all measurements.
- Due to the time constraint of a bachelor thesis, **self covers are not taken into consideration**. This means that a part of the products experience different collection times and might require their own category, however, this is not researched during this thesis. The self covers only consist of 1.5% of all orders, thus they have a small impact on the validity of this thesis.
- Due to the one worker who collected data only collecting half fabricates that have been placed together, the **collection time for covers is a complete estimation**. This limitation is a result of the first limitation and has a large impact on the validity of this thesis, therefore it should be the second limitation to be removed in further research.

5.4 Further research

This section lists the points for further research at Ipskamp Printing. These points are the result of limitations previously mentioned or ways to elaborate on the results presented in this thesis.

- Next to the storage policy, the positioning of the storage areas has an impact on collection time. Researching what collection time reduction can be achieved by **changing storage area positioning** could result in more improvements.
- **Changing the layout of the whole production floor** might also result in collection time reductions, this can be researched further.
- Researching ways of **implementing the theory of Lean management** at Ipskamp Printing is a research area with high potential.
- **Measure the actual data**. A lot of this thesis' results are based on assumptions, due to a lack of data. For future research, Ipskamp Printing could start measuring the actual data, thus improving the validity of the dataset.
- Find a way to **automate data collection**. This will enable future researchers to have a dataset which they can use for more improvements to the production process of Ipskamp Printing.

References

Ajol, T. A., Ismail, I., Gran S. S., & Ibrahim, A. F. A., (2015) *An enhanced storage location assignment policy by minimizing handling cost for warehouse XYZ*, *2015 International Conference on Computer, Communications, and Control Technology (I4CT),* Kuching, Malaysia, 2015, pp. 408-412, doi: 10.1109/I4CT.2015.7219608.

Ariafar, S., Ismail, N., Tang, S. H., Ariffin, M. K. A. M., & Firoozi, Z., (2011) *Inter-cell and intra-cell layout design in a cellular manufacturing system*, *IEEE Symposium on Business, Engineering and Industrial Applications (ISBEIA)*, Langkawi, Malaysia, 2011, pp. 28-33, doi: 10.1109/ISBEIA.2011.6088823

Çevikcan, E., Sari, I.U., & Kahraman, C. (2014) Multi-objective assessment of warehouse storage policies in logistics and a fuzzy information axiom approach. Springer. https://doi.org/10.1007/978-1-4471-5295-8_3

Chan, F.T.S., Chan, H.K. (2011) Improving the productivity of order picking of a manual-pick and multi-level rack distribution warehouse through the implementation of class-based storage. *Expert Syst Appl* 38(3):2686–2700

Cheng, T.C.E., & Podolsky, S. (1996). *Just in time manufacturing: An introduction* (2nd ed.). Springer Science & Business Media

Cooper, D. R., & Schindler, P. S. (2014). *Business Research Methods* (12th ed.). New York: McGraw-Hill/Irwin

D'Antonio, G., Chiabert, P., (2018). *An Integrated Tool for the Optimization and Simulation of Hybrid Product-Process Layouts*. In: Chiabert, P., Bouras, A., Noël, F., Ríos, J. (eds) Product Lifecycle Management to Support Industry 4.0. PLM 2018. IFIP Advances in Information and Communication Technology, vol 540. Springer, Cham. https://doi.org/10.1007/978-3-030-01614-2_70

Duclos, L.K. & Spencer, M.S. (1995). The impact of a constraint buffer in a flow shop. *International journal of production economics.* 42, 175-185, https://doi.org/10.1016/0925-5273(95)00197-2

Glen, S. (n.d.). *Sum of Squares: Residual Sum, Total Sum, Explained Sum, Within*. Statistics How To. Retrieved October 4, 2023, from https://www.statisticshowto.com/residual-sum-squares/

Goetschalekx, M. (2012) Storage systems and policies. In: Riccardo M (ed) Warehousing in the global supply chain: advanced models, tools and applications for storage systems. Springer, London

Goldratt, E.M., Cox, J. (1984). The Goal. Croton-on-Hudson,The North River Press, NY

Goldratt, E.M., Cox, J. (1992). The Goal - A Process of Ongoing Improvement. Second Rev. Ed., North River Press Publishing Corporation, Great Barrington, MA

Guo, W., Jiang P., & Yang M., (2023) *Unequal area facility layout problem-solving: a real case study on an air-conditioner production shop floor*, International Journal of Production Research, 61:5, 1479-1496, DOI: 10.1080/00207543.2022.2037778

Heerkens, H. & Winden van, A., (2021). *Solving Managerial Problems systematically* (1st ed.). Routledge

Johnson, D. J., (2003), *A framework for reducing manufacturing throughput time, Journal of Manufacturing Systems*, Volume 22, Issue 4, Pages 283-298, ISSN 0278-6125, https://doi.org/10.1016/S0278-6125(03)80009-2.

Jun-Huei, J., Jia-Ging, C., Chih-Hung, T. & Rong-Kwei, L. (2010). Research on enhancement of TOC simplified drum-buffer-rope system using novel generic procedures. *Expert systems with applications*, 37, 3747-3754. doi:10.1016/j.eswa.2009.11.049

Kootanaee, A.J., Nagendra Babu, K. & Talari, H.F. (2013). Just-in-time manufacturing system: From introduction to implementation. *International Journal of Economics, Business and Finance,* 1(2), 07-25. https://ssrn.com/abstract=2253243

Koster de, R, Le-Duc T, Roodbergen K.J. (2007) Design and control of warehouse order picking: a literature review. *European journal of operations research* 182:481–501

McInerney, S.E., & Yadavalli, S. (2022). Increasing warehouse throughput through the development of a dynamic class-based storage assignment algorithm. *The South African Journal of Industrial Engineering*, *33*(2), 157–167. https://doi.org/10.7166/33-2-2651

Mulcahy, D.E. (1994) Warehouse distribution and operations handbook. McGraw-Hill Education, New York

Pan, J.C.H., Wu, M.H. (2012) Throughput analysis for order picking system with multiple pickers and aisle congestion considerations. *Comput Oper Res.* 39:1661–1672

Ramya, G., Chandrasekaran, M., & Shankar, E. (2019). Case study analysis of job shop scheduling and its integration with material requirement planning. *Materials Today*. 16, 1034-1042. https://doi.org/10.1016/j.matpr.2019.05.192

Roodbergen, K.J., Vis, I.F.A. (2009) A survey of literature on automated storage and retrieval systems. *European journal of operations research.* 194(2):343–362

Simsit, Z.T., Sebla, N., & Vayvay, Ö. (2014). Theory of Constraint: A Literature Review. *Procedia - Social and Behavioral Sciences,* 150, 930-936. doi: 10.1016/j.sbspro.2014.09.104

Slack, N., & Brandon-Jones, A. (2019). *Operations Management* (8th ed.). Pearson.

Sule, D.R. (1994) Manufacturing facilities: location, planning and design. PWS Publishing, Boston

Sunardi et al (2020) *Redesign of The Production Facility Layout by Using Systematic Layout Planning Method at Cahaya Bintang Mas Company Surabaya* J. Phys.: Conf. Ser. 1569 032007

Tarigan, U., Cabyo, F.D., Tarigan U.P.P., & Ginting, E., (2019). *Facility Layout Design Through Integration of Lean Manufacturing Method and CORELAP Algorithm in Concrete Factory. IOP Conf. Ser.: Mater. Sci. Eng.* 505 012015
DOI 10.1088/1757-899X/505/1/012015

Tönissen, S., Klocke, F., Feldhaus B., & Buchholz, S., (2012), *A study on throughput time of multi-technology platforms*, Procedia CIRP, Volume 2, Pages 60-63, ISSN 2212-8271, https://doi.org/10.1016/j.procir.2012.05.040.

Weske, M., (2007), *Business Process Management,* (2nd ed.). Springer. DOI 10.1007/978-3-642-28616-2

Yang, T., Peters, B. A., (1996) *Flexible machine layout design for dynamic and uncertain production environments*, European Journal of Operational Research, Volume 108, Issue 1, 1998, Pages 49-64, ISSN 0377-2217, https://doi.org/10.1016/S0377-2217(97)00220-8

Zaerpour, N., de Koster, R.B.M., & Yu, Y., (2013) Storage policies and optimal shape of a storage system, *International Journal of Production Research*, 51(23-24), 6891-6899, DOI: 10.1080/00207543.2013.774502

Appendix A

A.1 Tables of standard paper

Brand name	Paper weight (gr/m^2)
Maxi Gloss/Satin	90-350
Magno Gloss/Satin/Matt	90-400
Heaven 42	115-400
UPM Digi Finesse Silk/Gloss	115-300
Maxi Offset	60-300
Soporset Offset	60-350
Soporset Preprint	80-300
Bio Top 3 Next	80-300
GreenTop	80-300
Lessebo Design 1.3	80-440
Lessebo Design Smooth	90-240
Rebello 110	80-300
EOS 2.0	80-120
GenYous	90-400
Z-Offset Indigo	80-300
Invercote G	200-380
Invercote Creato	200-400

Table 6 Overview of the paper brands in the standard paper category delivered as sheets

The table above shows the paper brands that are delivered as sheets and are part of the standard paper categorisation. The paper weights are delivered in steps of 10gr/m^2 up to the 170 or 180 gr/m^2 level and afterwards they are often delivered in 200, 240, 260, 280 and 300 gr/m^2 weights.

Brand name	Paper weight (gr/m^2)
Red Label Inkjet	80, 90, 100, 120, 160
Magno Plus Silk	100, 115, 130, 150, 170

Table 7 Overview of the paper brands in the standard paper category delivered on a roll of multiple km long

Brand name	Paper weight (gr/m^2)
Cover carton (Single-side brushed)	240
Cover carton (Single-side and Double-side brushed)	260, 300
Recycled	300
Biotop	300

Table 8 Overview of the paper brands in the standard paper used for cover production

A.2 Calculations of collection time distribution with different book block fraction

This appendix shows the same calculations performed in Section 3.2.3, but instead of assuming that collecting the book block takes 70% of the collection time of both the book block and cover, it is assumed to be 60% and 80%. The results of assuming 60% of the total are as follows:

SSR	Incl. outl.	Excl. 2 outl.	Excl. 3 outl.
Square root rule	102.9	14.2	66.4
Sturges' rule	38.8	66.4	11.8

Table 9 SSR for each scenario of the dataset divided by 0.6

As is done in Section 3.2.3, the scenario with the lowest SSR is chosen, which is 11.8, achieved by using Sturges' rule and excluding 3 outliers. The histogram and distribution against cumulative histogram graphs are as follows:

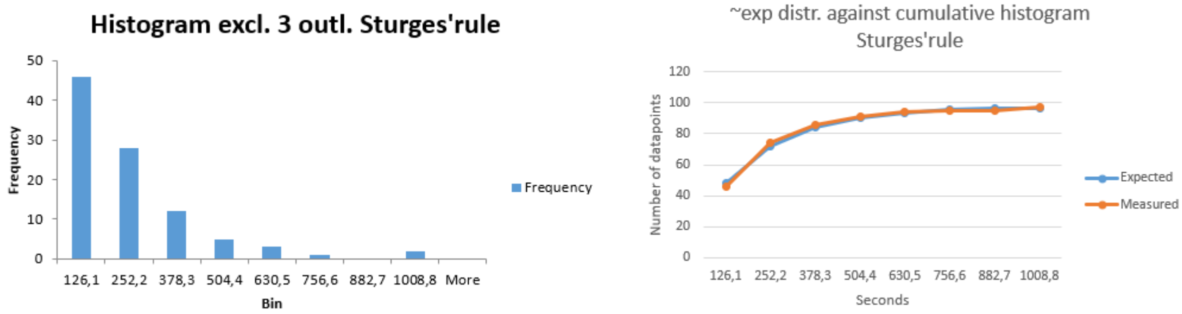


Figure 18 Histogram and exponential distribution graph of dataset divided by 0.6 excluding 3 outliers using Sturges' rule

This scenario depicts a ~exp(0.005379) distribution, which has the following properties:

$$E[X] = \frac{1}{\lambda} = \frac{1}{0.005379} = 185.9\ seconds$$
$$Var[X] = \frac{1}{\lambda^2} = \frac{1}{0.005379^2} = 34{,}558.8\ seconds$$
$$\text{Standard deviation } = \sqrt{Var[X]} = 185.9\ seconds$$

Now, the results of assuming collecting the book block makes up 80% of the total collection time:

SSR	Incl. outl.	Excl. 2 outl.	Excl. 3 outl.
Square root rule	102.8	17.5	66.4
Sturges' rule	38.8	66.4	11.8

Table 10 SSR for each scenario of the dataset divided by 0.8

Again, as is done in Section 3.2.3 the scenario with the lowest SSR is chosen, which is 11.8, achieved in the same way as with assuming that collecting the book block makes up 60% of the total collection time. The graphs for this scenario are as follows:

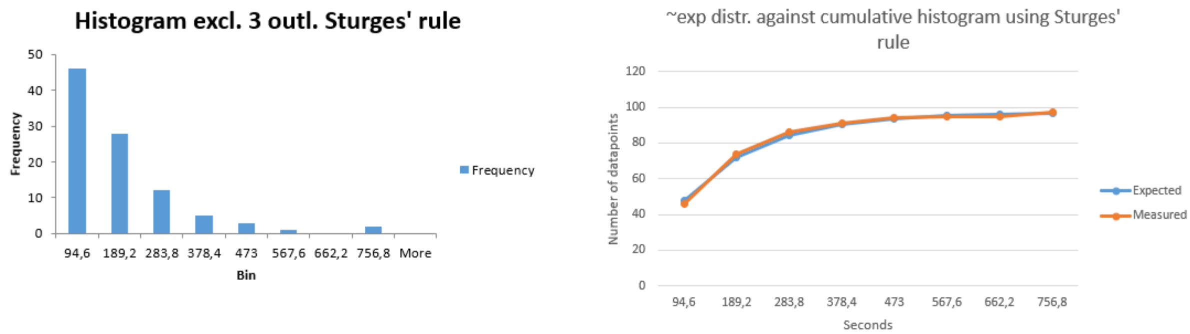


Figure 19 Histogram and exponential distribution graph of dataset divided by 0.8 excluding 3 outliers and using Sturges' rule

This scenario depicts a ~exp(0.007172) distribution, which has the following properties:

$$E[X] = \frac{1}{\lambda} = \frac{1}{0.007172} = 139.4\ seconds$$
$$Var[X] = \frac{1}{\lambda^2} = \frac{1}{0.007172^2} = 19{,}432.36\ seconds$$
$$\text{Standard deviation } = \sqrt{Var[X]} = 139.4\ seconds$$

Appendix B: Systemic literature review

B.1 Problem statement

The collection times at Ipskamp Printing are too long, which is partially because of the lack of an concise storage policy. This SLR aims at finding improvements and/or additions to the current policy to improve the effectiveness of the storage system as a whole and therefore decrease throughput times.

B.2 Research question

The sub-research question of this thesis with which this SLR is concerned is formulated as follows:

What storage policy problems have been research and implemented before?

This sub-research question is formulated too broadly for a SLR, therefore it has to be rewritten, such that its key concepts can be extracted and used for the SLR. The following research question will be used for the SLR:

What are the requirements for an effective and efficient storage policy of a production floor where raw resources and half fabricates are stored separately?

B.3 Key concepts

Now the research question is formulated, the key concepts need to be decided upon. The following table shows the selected key concepts.

#	Key concept
1	Storage
2	Policy
3	Production
4	Floor
5	Resources?
6	Half fabricates?

Table 11 Key concepts for this SLR

The fifth and sixth key concepts are not yet decided upon, as it is unsure if these two concepts are implied by the first and second concepts already.

B.4 Additional search terms

The key concepts mentioned before are not elaborate enough to ensure that enough useful sources can be found during the literature search, therefore additional search terms are selected and noted in the following table. The additional search terms will be used to tweak the search query used at the academic databases later on in this SLR.

Key concept	Related terms / synonyms	Broader terms	Narrower terms
Storage	Repository, stockpile, storehouse,	Depot, cache	Shelve(s), pallet(s), rack(s), buffer(s)
Policy	Approach, code, guideline(s), protocol	Plan, strategy, organization, program	Rule(s), method
Production	Manufacturing, fabrication	Making, constructing	Assembling
Floor	Hall, department, domain, facility,	Setting, environment,	Workstation
Resources	Supplies, materials, requirements	Input	Goods

Half fabricates	Half completed, half constructed, half finished, half produced		

Table 12 Additional search terms based on the key concepts

B.5 Inclusion and exclusion criteria

To aid in selecting sources from the list of results of the search queries, inclusion and exclusion criteria are useful. These criteria determine when a source can be considered useful for this SLR or when the source should not be taken into consideration. The following table shows the criteria used for evaluating the search results.

Inclusion criteria	Exclusion criteria
Source explains how the policy improvement can be measured	Theory or paper not applicable to a manufacturing/production environment similar to that of Ipskamp Printing
The source shows the real-world results of the storage policy implementation	

Table 13 Inclusion and exclusion criteria for this SLR

Both the inclusion criteria are concerned with the practicality of this thesis. The goal is to reduce collection times, which is a very practical goal, therefore having real-world results would make a source a lot more credible. Explaining how policy improvement can be measured entails that there are certain variables that can be measured, which in turn means that these variables can be made into evaluation criteria for the possible policy improvements later on in the thesis.

The exclusion criteria is noted down, because there are a plethora of different production environments, from steel production to micro-chip production, for which different storage policies exist. If a production environment differs too much from Ipskamp Printing, the source that describes it will be excluded.

B.6 Databases to be used

This SLR will be using two databases: Scopus and Business source elite. Scopus will be used for tweaking the search query and finding some sources, afterwards Business source elite will be used to find more expert sources on policy improvement.

B.7 Searching

First an initial search will be performed on Scopus to tweak the search query. Then with the tweaked search query a second search is performed on Scopus. Finally a third search is performed on Business source elite to search for more expert or complex sources.

B.7.1 Search query tweaking

Date	Source	Search string	# of hits	Remark(s)
07-09-2023	Scopus	Storage AND Policy AND Production AND Floor	28	Capacitated Lot Sizing Problem (CLSP) could be something to take a look at. Many of the most relevant hits are about warehouses where workers or robots drive around or are concerned with production environments too different from Ipskamp Printing.

07-09-2023	Scopus	(Storage OR Repository OR Stockpile OR storehouse Or Depot OR Cache OR Shelve* Or Pallet* Or Rack*) AND Policy AND Production AND Floor	32	Only a few more hits and the most relevant hits stayed about the same. 1 source is saved for later research.
07-09-2023	Scopus	(Storage OR Repository OR Stockpile OR storehouse Or Depot OR Cache OR Shelve* Or Pallet* Or Rack*) AND (Policy OR Approach OR Code OR Guideline* OR Protocol OR Plan* OR Strategy OR Organization OR Program Or Rule* Or Method*) AND Production AND Floor	280	Buffer is a good synonym for storage. There are a few new articles in the most relevant top 20, but most of them are not useful, as they are concerned with flooring companies or very complex production processes
07-09-2023	Scopus	Repository OR Stockpile OR storehouse Or Depot OR Cache OR Shelve* Or Pallet* Or Rack* Or Buffer*) AND (Policy OR Approach OR Code OR Guideline* OR Protocol OR Plan* OR Strategy OR Organization OR Program Or Rule* Or Method*) AND (Production OR Manufacturing OR Fabrication OR Making OR Constructing Or Assembling) AND Floor	408	Theory of constraints (TOC) and drum-buffer-rope methodology can be interesting theories to investigate. Most of the top 20 most relevant hits are not concerned with a storage policy the way it is defined in this thesis. There are also a lot of hits focussing on technology improvement/implications.
07-09-2023	Scopus	(Storage OR Repository OR Stockpile OR storehouse Or Depot OR Cache OR Shelve* Or Pallet* Or Rack* Or Buffer*) AND (Policy OR Approach OR Code OR Guideline* OR Protocol OR Plan* OR Strategy OR Organization OR Program Or Rule* Or Method*) AND (Production OR Manufacturing OR Fabrication OR Making OR Constructing Or Assembling) AND (Floor OR Hall OR Department OR Domain OR Facility OR Setting OR Environment OR Workstation)	9.297	There are way more hits this time around and many more useful ones in the top 20 most relevant. There are also still a lot of hits that are concerned with vehicles or automated storage packing and unpacking, which are irrelevant for this thesis. Also sources on chemical waste removal are strangely present in the top 20 most relevant.
07-09-2023	Scopus	(Storage OR Repositor* OR Stockpil* OR storehouse* Or Depot* OR Cache* OR Shelve* Or Pallet* Or Rack* Or Buffer*) AND (Polic* OR Approach* OR Code* OR Guideline* OR Protocol* OR Plan* OR Strateg* OR Organization* OR Program* Or Rule* Or Method*) AND (Production OR Manufacturing OR Fabrication OR Making OR Constructing Or Assembling) AND (Floor* OR Hall* OR Department* OR Domain* OR Facilit* OR Setting* OR Environment* OR Workstation*)	51.478	Added many asterixis to search more broadly. This search results in many irrelevant results, like manufacturing environments that differ too much from Ipskamp Printing's ones, data analyses of unrelated sectors or really specific applications of theory unrelated to this thesis. It is safe to say that from here on out the search query should be tweaked to get more high quality sources.
08-09-2023	Scopus	(Storage OR Repositor* OR Stockpil* OR storehouse* OR Shelve* Or Pallet* Or Rack* Or Buffer*) AND (Polic* OR Approach* OR Code* OR Guideline* OR Protocol* OR Plan* OR Strateg* OR Organization* OR Program* Or Rule* Or Method*) AND (Production OR Manufacturing OR Fabrication OR Making OR Constructing Or Assembling) AND (Floor* OR Hall* OR Department* OR Domain* OR Facilit* OR Setting* OR Environment* OR Workstation*)	50.429	Depot and cache are removed from the search query. This search resulted in only a few hits being removed and the top 20 most relevant hits is almost the same as the last search. Many data oriented sources and highly complex production environment sources are in this top 20 still.

08-09-2023	Scopus	(Storage OR Repositor* OR Stockpil* OR storehouse* OR Shelve* Or Pallet* Or Rack* Or Buffer*) AND (Polic* OR Approach* OR Guideline* OR Protocol* OR Plan* OR Strateg* OR Program* Or Rule* OR Method*) AND (Production OR Manufacturing OR Fabrication OR Making OR Constructing Or Assembling) AND (Floor* OR Hall* OR Department* OR Domain* OR Facilit* OR Setting* OR Environment* OR Workstation*)	49.325	Code and organization are removed from the search query. Again, not many sources are removed and most of the top 20 most relevant hits repeats itself.
08-09-2023	Scopus	(Storage OR Repositor* OR Stockpil* OR storehouse* OR Shelve* Or Pallet* Or Rack* Or Buffer*) AND (Polic* OR Approach* OR Guideline* OR Protocol* OR Plan* OR Strateg* OR Program* Or Rule* OR Method*) AND (Production OR Manufacturing OR Fabrication) AND (Floor* OR Hall* OR Department* OR Domain* OR Facilit* OR Setting* OR Environment* OR Workstation*)	36.327	Making, assembling and constructing are removed from the search query. This search resulted in quite a lot less hits and the top 20 most relevant ones are increasing in relevance. However, it is interesting to note that many of the top 20 most relevant hits are on semiconductor manufacturing. 1 source is saved for later research.
08-09-2023	Scopus	(Storage OR Repositor* OR Stockpil* OR storehouse* OR Shelve* Or Pallet* Or Rack* Or Buffer*) AND (Polic* OR Approach* OR Guideline* OR Protocol* OR Plan* OR Strateg* OR Program* Or Rule* OR Method*) AND (Production OR Manufacturing OR Fabrication) AND (Floor* OR Hall* OR Department* OR Facilit* OR Environment* OR Workstation*)	33.401	Setting and domain are removed from the search query. This search resulted in a relatively small reduction in hits and in the top 20 most relevant hits a lot of sources on semiconductors remained. There were a few new additions to the top 20, of which 1 was saved for later research.
08-09-2023	Scopus	(Storage OR Repositor* OR Stockpil* OR storehouse* OR Shelve* Or Pallet* Or Rack* Or Buffer*) AND (Polic* OR Approach* OR Guideline* OR Protocol* OR Plan* OR Strateg* OR Program* Or Rule* OR Method*) AND (Production OR Manufacturing OR Fabrication) AND (Floor* OR Hall* OR Department* OR Facilit* OR Environment* OR Workstation*) AND NOT Semiconduct*	32.667	AND NOT semiconduct* is added to the search query to remove sources concerned with this sector. There are less hits removed than expected, but the top 20 most relevant hits now contains 6 sources not seen in the top 20 before. Some of these new ones seem interesting, but not interesting enough to be saved for later research.
08-09-2023	Scopus	(Storage OR Shelve* Or Pallet* Or Rack* Or Buffer*) AND (Polic* OR Approach* OR Guideline* OR Protocol* OR Plan* OR Strateg* OR Program* Or Rule* OR Method*) AND (Production OR Manufacturing OR Fabrication) AND (Floor* OR Hall* OR Department* OR Facilit* OR Environment*) AND NOT Semiconduct*	30.924	Repository, stockpile, storehouse and workstation are removed from the search query. The top 20 most relevant results stayed the same except for 1 source, which is irrelevant to this thesis.
08-09-2023	Scopus	(Storage OR Shelve* Or Pallet* Or Rack* Or Buffer*) AND (Polic* OR Approach* OR Guideline* OR Protocol* OR Plan* OR Strateg* OR Program* Or Rule* OR Method*) AND (Production OR Manufacturing OR Fabrication) AND (Floor OR Floors OR Hall OR Halls OR Department OR Departments OR	17.983	Some asterixis have been removed of the synonyms of floor, to see if this improves the search results This search reduced the amount of hits greatly, but it impacted the quality of results heavily. Of the top 20 only 3 sources have the option to view the source

		Facility OR Facilities OR Environment) AND NOT Semiconduct*		at a publisher, which can be an indication of a bad source.
08-09-2023	Scopus	(Storage Or Buffer*) AND (Polic* OR Approach* OR Guideline* OR Protocol* OR Plan* OR Strateg* OR Program* Or Rule* OR Method*) AND (Production OR Manufacturing OR Fabrication) AND (Floor* OR Hall* OR Department* OR Facilit* OR Environment*) AND NOT Semiconduct*	29.745	Asterixis are placed back in the search query and shelves, pallets and racks is removed from the query. Again, no new sources came up in the top 20 most relevant sources
08-09-2023	Scopus	(Storage Or Buffer*) AND (Policy OR Approach* OR Guideline* OR Protocol* OR Plan* OR Method*) AND (Production OR Manufacturing OR Fabrication) AND (Floor* OR Hall* OR Department* OR Facilit* OR Environment*) AND NOT Semiconduct*	26.646	Strategy, program and rule is removed from the search query. This search resulted in more useful hits in the top 20 most relevant ones. Furthermore 1 source is saved for further research.
08-09-2023	Scopus	(Storage Or Buffer*) AND (Policy OR Guideline* OR Protocol*) AND (Production OR Manufacturing OR Fabrication) AND (Floor* OR Hall* OR Department* OR Facilit* OR Environment*) AND NOT Semiconduct*	3.893	Approach, plan and method are removed from the search query to see if specific sources on policy improvement exist. This search query is too narrow to receive effective results, because most of the top 20 most relevant hits were irrelevant to this thesis.

Table 14 Initial search query tweaking

B.7.2 Final searches on Scopus and Business Source Elite

The search query most optimal for this SLR was found in the previous section. This query is:

(Storage Or Buffer*) AND (Policy OR Approach* OR Guideline* OR Protocol* OR Plan* OR Method*) AND (Production OR Manufacturing OR Fabrication) AND (Floor* OR Hall* OR Department* OR Facilit* OR Environment*) AND NOT Semiconduct*

Semiconductors are specifically removed, because many of the most relevant hits were concerned with this sector, but these sources are irrelevant to this thesis, due to the fact that this manufacturing environment is too complex compared to Ipskamp Printing's production environment. Next to that there are no synonyms left that can be removed from the string without impacting the results negatively, therefore this query will be used for the final search on Scopus.

The title and abstract of the first 100 relevant sources will be evaluated and a selection will be saved to read for this SLR. From the search query tweaking and the final search, 13 potentially useful sources have been found. To search for more operations research (OR) specific results, a search using the same search query is also performed in Business Source Elite. This search did not result in any additional potentially useful sources, because the most relevant hits were the same sources as were found during the Scopus search.

B.8 Results of the Scopus search

After reading through most potentially useful sources, it was concluded that this search did not result in sources which could be used for this thesis. The reason for this is twofold: either the source is concerned with a warehouse storage policy, like the book chapter by Çevikcan, E. et. al.(2014) or it is concerned with the calculations for an optimal warehouse/storage system's size, like the paper by Zaerpour, N. et. al. (2013).

When a source is about a warehouse storage policy, it is irrelevant to this thesis, because the storage system at Ipskamp Printing is not used in the same way as the storage system of a warehouse is. At

Ispakamp Printing, there is no set number of products in storage that have to be picked from time to time, instead all products and half fabricates are unique and only stay in storage until they are used for the next step in production or until they are shipped out to the customer. The storage system at Ipskamp Printing could best be described as a buffer, instead of a storage system or stock. Next to that, the storage systems of warehouses are often times way larger than the system at Ipskamp Printing, which makes the improvements to a storage system proposed in the sources impossible or irrelevant for this specific case.

Sources on calculating a warehouse/storage system's size are also irrelevant to this thesis, because the size of the storage system is already determined and it is out of the scope of this thesis to add space to it. The main focus of this thesis is to reduce collection times through better and more efficient use of the current storage system, not the expansion of it. Therefore these sources are of no use to this thesis.

This search has resulted in leads to continue the SLR, which are the following three manufacturing process management methods: Just-in-time(JIT) manufacturing, Material requirements planning(MRP) and the theory-of-constraints(TOC) and by extension Drum-buffer-rope (DBR) methods. These three methods will be researched and compared in this SLR and thesis. The best one will be selected to form the basis for the theoretical part of this thesis' results.

B.9 Results of the literature research of JIT, MRP and TOC

The goal of this literature search is to find sufficient information on these three production management methods, such that they can be compared to each other. This comparison will be used together with the knowledge of the production process at Ipskamp Printing to decide on one method, which will be researched more in depth and (potentially) implemented at the company. First, a comparison of the three methods will be made and afterwards one of them will be selected for further research.

What is Just-In-Time manufacturing (JIT)?

- Just in Time manufacturing is an originally Japanese production management methodology. Its main concepts are the reduction or removal of buffers, stock and waste, cellular manufacturing and constant improvement to the production process. (Cheng and Podolsky, 1996)
- As the name suggests, JIT manufacturing wants to be just in time at every step of the process, from the delivery of raw materials to the shipping of finished products. In theory this means that no buffers or stock is required, thus reducing storage cost to (almost) zero and having more space on the production floor for actual production. In practice it is almost never the case that a production process has no buffers, but using this methodology most of them are significantly reduced or removed.
- Cellular manufacturing contains both a physical and a scheduling part. It is physical, because machines/workstations are laid out in such a way that for one or multiple very simillar product catergories all machines/workstation are placed in a production cell, making them easily reachable, thus reduing the time it takes to move between them. The scheduling part is that all products of a firm need to be categorised such that they can be allocated to one of the manufacturing cells and the workers are required to be able to operate multiple machines/workstations. (Kootanaee et. al., 2013)
- Constant improvement to the production process is mostly done by the workers, not the industrial engineers, when JIT is used. The workers identify a problem, however small it may be, and help in solving it. Implementing this mindset is in reality quite difficult, but when implemented, it ensures that the process is constantly updated and improved, which keeps the firm competative.

What is Material Requirements Planning (MRP)?

- Material requirements planning is a planning method most often used in production firms, which has two main outputs: the 'recommended production schedule' and the 'recommended purchasing schedule'. The calculations made for the MRP methodology are always based on realized demand, thus no (large) finished goods stock is kept.
- The recommended production schedule follows from the Master Production Schedule (MPS). The MPS shows what final parts and sub-parts and sub-assemblies are required at what time and thus at what time production on them has to start. The MPS combines multiple inputs of data namely; the Bill of Materials (BOM) of the final product, the lead time on production and delivery of required materials and parts of the final product and the current stock levels of materials and parts. (Ramya et. al., 2019)
- The recommended purchasing schedule also follows from the MPS. This schedule shows what materials and parts need to be purchased at what time to keep stock up to the required level and ensure the production process has enough input to keep producing. The recommended purchasing schedule can be changed according to the required levels of safety stock and the expected lead times of deliveries. (Ramya et. al., 2019)
- MRP is very useful in firms that have a set amount of products or product families, because it is easy and efficient to plan production over a certain time horizon.
- Using MRP and more specifically the BOM, a very useful overview can be made on what materials and parts are required when, even with very complex finished products.
- The MRP calculations can very easily be automated, given the BOM of each product is in a database.

What are the Theory of Constraints (TOC) and Drum-Buffer-Rope (DBR)?

- The TOC can be best described by the Five Focussing steps (5FS): (Goldratt and Cox, 1984; Goldratt and Cox, 1992)

1. Identify the system's constraint
2. Decide how to exploit the system's constraint
3. Subordinate everything ese to the above decision
4. Elevate the system's constraint
5. If in any of the previous steps a constraint is broken, go back to step 1

- From the TOC, the DBR methodology is born, in bulletpoints this is what the DBR does: (Duclos and Spencer, 1995)
    - The complete process is planned around the constraint, which is often 1 machine.
    - Due to the planning around the process' constraint, it's utilization is very high.
    - There is a buffer placed before the constraint, to absorb variability in the production process.
    - There is only material released to the steps before the constraint, if there is work being done at the constraint, this is to prevent an overflow of the buffer.
    - The drum is the pace of the process, which is determined by the pace of the constraint.
    - The rope is the act of choking the flow of material into the system to match the actual production of the constraint.
- From the DBR methodology, simple DBR (SDBR) is born which is: (Jun-Huei et. al., 2010)
    - Most of the SDBR's methodology is based on the buffer's size, expressed in time and the planned load concept.
    - The planned load concept is the accumiliation of the load on the capacity constraint resource(CCR), which in most cases is a machine, for all the firm orders requiring deliver in a set time horizon, often the standard lead time.

    - The due-date setting method sets internal due-dates and external due-dates, based on the buffer's size, work in process(WIP) and expected processing time of an order on the CCR.
- The SDBR usually assumes the CCR is in the middle of the order's production process, but some researchers found a way to use the methodology with orders where the CCR is at the front or back end of the process. (Jun-Huei et. al., 2010)
- (Urgent) order insertion is also possible with the SDBR. (Jun-Huei et. al., 2010)

Comparison between JIT, MRP and TOC.

Planning vs. improvement

All three methodologies have a planning part. MRP plans via the Master Production Schedule (MPS), JIT manufacturing plans the release of materials, half fabricates and finished products such that there are (almost) no buffers required in the production process and TOC plans all orders according to the constraint of the system. However, TOC and MRP both work with realised demand, while JIT manufacturing sometimes works with a demand forecast/planning. One downside of using MRP is that the methodology can give infeasible solutions, as it assumes that the realised demand can always be produced in the promised time frame.
A difference between MRP compared to JIT manufacturing and TOC is that MRP is purely a planning methodology, while JIT manufacturing and TOC are improvement methodologies next to their planning part. JIT manufacturing aims for continuous improvement of the production process, while TOC aims for the reduction and removal of its main constraint.

Implementation

TOC and MRP are easier to implement than JIT manufacturing. There are multiple reasons for this, the biggest two are:

1. TOC and MRP use buffers in the production system, which are often times already present in a firm, while JIT manufacturing tries to remove these buffers, resulting in layout and sometimes also flow changes. Due to the physical nature of the changes proposed by JIT manufacturing, it is a more difficult methodology to implement in a firm. The physical nature of JIT manufacturing is best recognised in the 'cellular manufacturing' part of the methodology (Kootanaee et. al., 2013). The TOC and MRP methodologies don't have these physical changes.

2. TOC and MRP focus on 1 thing in the production process, while JIT manufacturing focusses on the complete process and its improvement. TOC focusses on the main constraint of the process and tries to reduce and remove it, while at the same time planning the whole process around the constraint. MRP focusses on the delivery of finished products, according to realised demand. JIT manufacturing, however, focusses on improving the complete production process, which results in many more considerations and potential changes to the process.

Data requirements

All three methodologies require input data to be effective. MRP requires delivery and production lead times, realised demand numbers, product categorization and a BOM to create a planning. TOC requires data such as the KPI performance of the production process, machine/workstation utilization, buffer capacity and machine/workstation throughput time to identify the process' main constraint and plan according to it. JIT manufacturing combines the data requirements from the other two methodologies, such that the best overview of the complete production process can be made. With this overview a model will be made that aims to reduce buffers and implement cellular manufacturing.

Conclusion and methodology selection

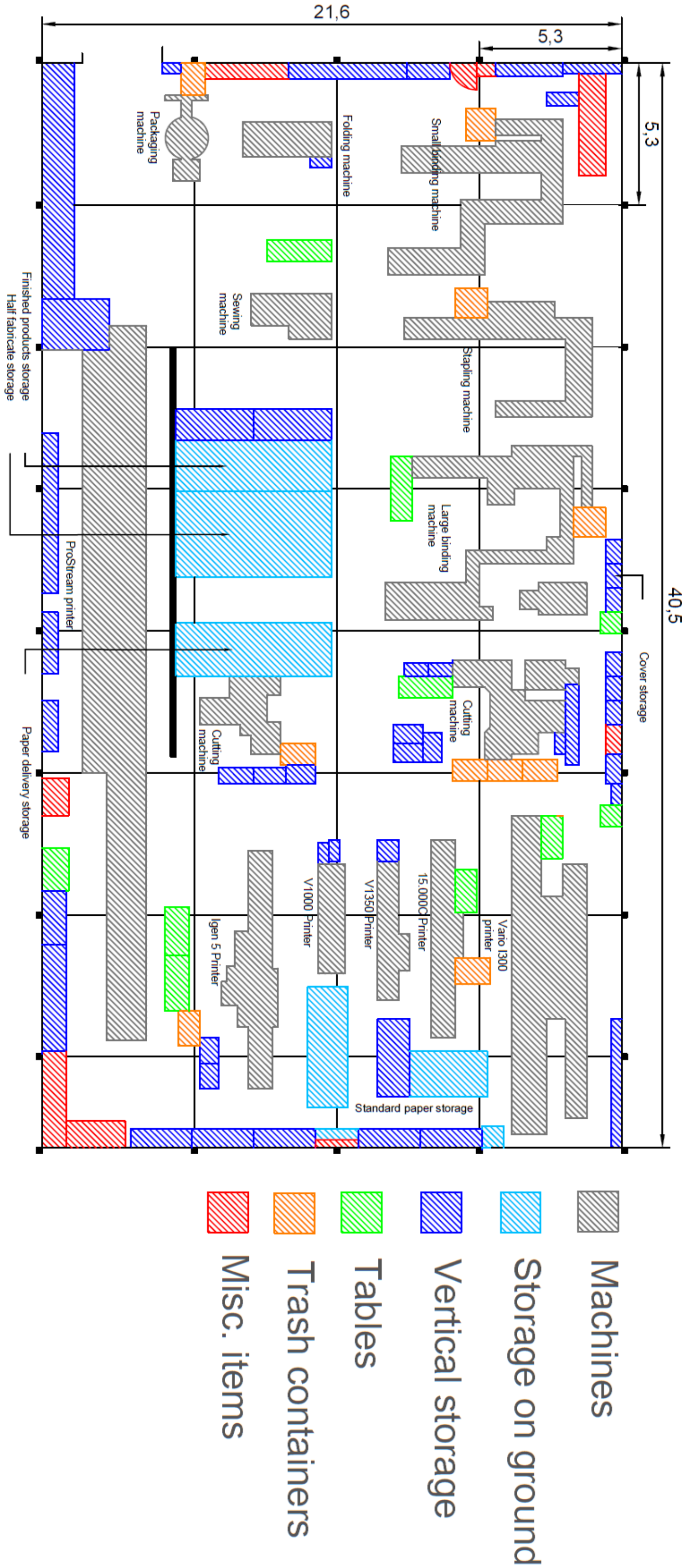
One insight from the research on Ipskamp Printing's storage system is that the production planning is vital to the performance of the production department. When the planning is not optimal, there is a lot of changeover time, low machine utilization, high buffer utilization and many orders are shipped out late. The high buffer utilization is the reason for this thesis, because due to the many different half fabricates in the buffer and the lack of visual identifiers, the collection times grow. If the planning is (more) optimized, the buffer utilization decreases, decreasing the number of different half fabricates in the buffer, thus decreasing collection times. Next to the buffer utilization decreasing, changeover time is reduced, machine utilization is increased and less orders are shipped out late.

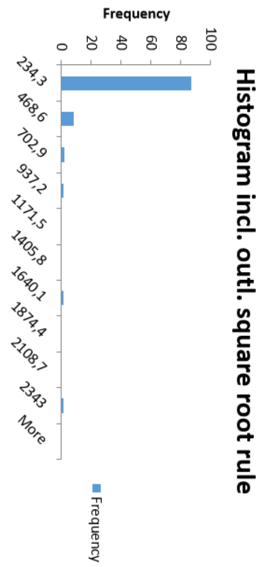
All three methodologies have a planning part and the TOC and JIT manufacturing also strive for improvement, something which Ipskamp Printing can use. From these two options there is one who is less suitable for implementation at Ipskamp Printing; JIT manufacturing. The reasons for this are as follows: Ipskamp printing experiences many urgent orders that need to be inserted to the already existing planning, somethings with which JIT manufacturing struggles to cope due to the small or non-existent buffers, there are too many product categories to effectively implement cellular manufacturing and implementing JIT manufacturing should also take the post-processing department into consideration, which is not done for this thesis. The production management methodology that will be recommended to Ipskamp Printing will therefore be the TOC, combined with a bit of MRP.

The choice for TOC is based on the following reasons: the limited number of production steps in the production department combined with the linearity of the production flow makes it easy to identify the main constraint of the process, the utilization of the constraint will be increased, the buffer will not overflow because of the drum and rope system and the buffer will be more strategically used. These reasons make implementing TOC easy and effective, because when the buffer is used more strategically, the collection times will be reduced due to a smaller number of different half fabricates. However, TOC will not be implemented on its own, MRP will play a role in improving the production process as well. Each order already has a partial BOM, consisting of the paper that is required for it. This BOM can be expanded with the amount of ink/toner, laminate and thread required for its production. Using this BOM and the production panning from the TOC methodology, a 'master purchasing schedule' can be set up. This will help in ordering paper, which is now often times done without it being necessary. Management should not completely rely on the master purchasing schedule, but keep an eye out for the stock levels of these materials, because sometimes an order needs to be (partially) reprinted, which means that more material is used than expected. This is easily done if at the end of a certain planning horizon the stock is visually checked.

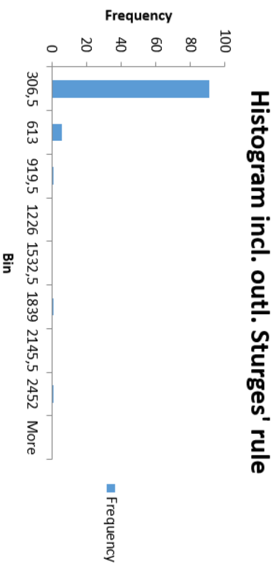
To conclude; the TOC should be implemented at the production department of Ipskamp Printing, firstly purely for planning with regards to the main constraint and secondly for reducing or removing this constraint from the production process. Next to that, MRP should be implemented to create a master purchasing schedule, which is concerned with the stock levels of raw materials.

Appendix C Enlarged graphs and figures

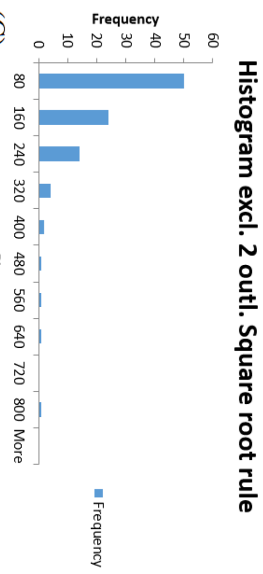




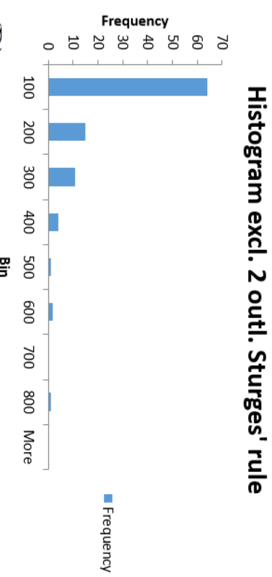
(A)



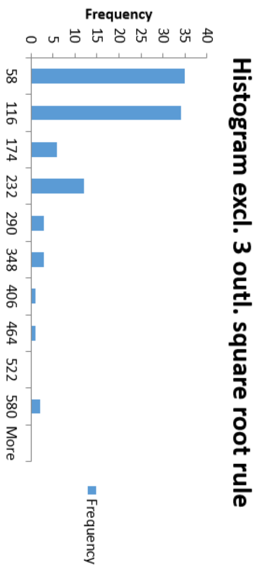
(B)



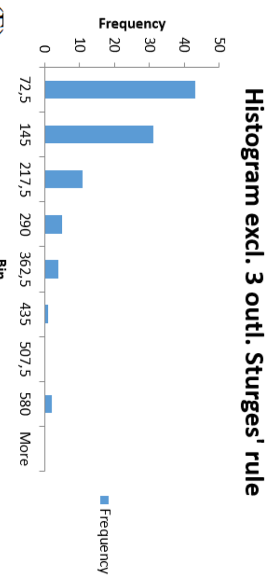
(C)



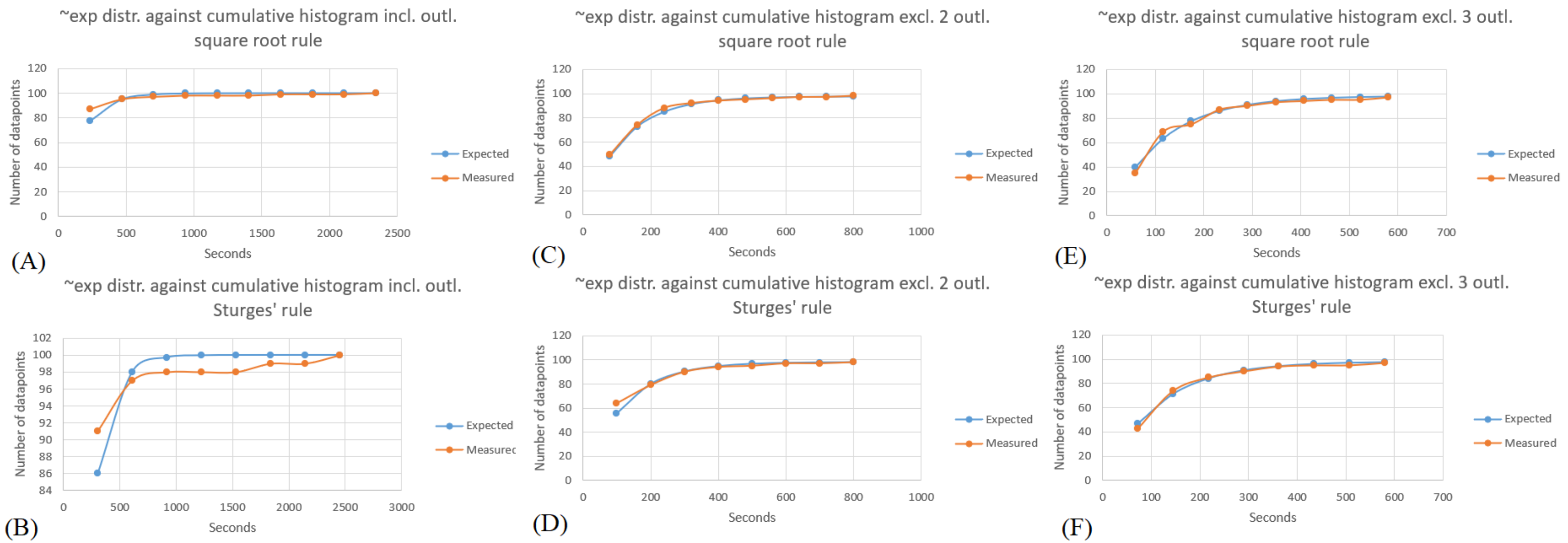
(D)



(E)



(F)



~exp distr. against cumulative histogram incl. outl.
square root rule
Number of datapoints
Seconds
Expected
Measured
(A)
~exp distr. against cumulative histogram incl. outl.
Sturges' rule
Number of datapoints
Seconds
Expected
Measurec
(B)
~exp distr. against cumulative histogram excl. 2 outl.
square root rule
Number of datapoints
Seconds
Expected
Measured
(C)
~exp distr. against cumulative histogram excl. 2 outl.
Sturges' rule
Number of datapoints
Seconds
Expected
Measured
(D)
~exp distr. against cumulative histogram excl. 3 outl.
square root rule
Number of datapoints
Seconds
Expected
Measured
(E)
~exp distr. against cumulative histogram excl. 3 outl.
Sturges' rule
Number of datapoints
Seconds
Expected
Measured
(F)