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Future-proof Layout Design Optimization for HMLV, MTO Manufacturing SME Companies: a Case Study

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Future-proof Layout Design Optimization for HMLV, MTO Manufacturing SME Companies: a Case Study

D. H. Spin
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Research Information

Master Thesis Graduation assignment:
Research whether a redesign of the lathe department can contribute to a more efficient manufacturing process, research how to better utilize the available workforce with the ageing of operators, and investigate what the best department layout is for Hankamp Gears by delivering a theoretical model and incorporating the lathe operators.

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Preface

Dear reader,

You are at the start of reading my master's thesis report, which is the final graduation assignment for my master's degree in mechanical engineering at the University of Twente. This graduation assignment is executed at Hankamp Gears B.V. which is a gear production company located in Enschede, The Netherlands.

I am thankful for the opportunity I got to do my graduation assignment at Hankamp Gears. It was not easy and I was truly challenged, but in the end, it was all worth it.

I would like to thank all employees from Hankamp Gears. Special thanks go to Wieteke and Pim, my supervisors from the university and company, respectively. Thank you for guiding and motivating me.

Enjoy reading this master thesis.

Dominiek H. Spin

Enschede, January 2025

Management Summary

A case study has been performed for a gear manufacturing company Hankamp Gears located in Enschede, The Netherlands. The main research question that has been answered was: "Is it possible to redesign a department such that it becomes future-proof within an SME manufacturing company that is characterized by organic growth and make to order (MTO), high mix low volume (HMLV) manufacturing?".
Within Hankamp Gears, in the coming seven years 4 out of 17 lathe operators (23,5%) will retire. Due to shortage of skilled operators on the labor market, in the worst case scenario Hankamp Gears cannot find new personnel. It is the task to research whether the same production rate can be achieved with fewer people. This has been researched by analyzing historical data and actively involving the personnel on the work floor.
By performing literature research, definitions of organic growth and future-proof were stated. Afer this, aspects of HMLV and MTO manufacturing were looked into as well as layout design algorithms. Furthermore, change management was taken into account. The literature research, although extensive, resulted in a research gap. By filling this research gap, this research adds value for Hankamp Gears, comparable companies and the research field regarding layout design of HMLV, MTO manufacturing companies.
Based on the production data from 2018-2023, articles of interest were selected by filtering. This resulted that out of 2387 unique articles produced, 1631 articles (68,3%) are of interest for this research and thus selected.
For these selected articles, the production numbers and diameters are taken into account. This resulted in an overview that showed the production numbers per article and per diameter. It was shown that 1,8% of articles represent 50,3% of production numbers. This relatively small percentage of articles has a diameter range of 10 - 120 mm.
It has been analyzed which machines in the past were used to produce these articles, representing 50,3% of total production numbers. It was found that often multiple lathes are chosen to produce the same article, resulting in the need for all lathes. From an analysis of machine usage, it followed that with 7 out of 14 lathes, the 1,8% of articles representing 50,3% of production numbers can be made as well. To extend the number of products, all products with this diameter range were analyzed regarding the usage of the 7 selected lathes. After verifying with the data and the operators, the complete range of products with diameter 10 to 120 mm can indeed be made with only 7 machines. By checking the maximum diameter of products made in the past for these 7 machines, the range was extended: 10 - 150 mm. To verify if machine capacity is enough, the VoCa (pre-calculated production hours) times have been analyzed. In conclusion, all chosen machines have enough time left (16% - 60%) after producing all products in the diameter range. This means that 37,8% percent of articles, representing 91,0% of production numbers, can be made with only 7 out of 14 lathes.
To gain insight in the maturity of the organization the operators and office personnel have been asked to fill in Continuous Improvement Maturity Model (CIMM) questionnaires. Maturity levels and People & Organization score average, however the scores are divided and spread among the personnel.
All lathe operators are involved by means of interviews and interactive 1-on-1 brainstorm sessions, in which the operators could create their own ideal lathe layout. The goal was to get to know based on which criteria the operators would create their ideal layout and if machine couples could be made. All relative distances per layout were calculated into scaling factors and put in a matrix. This resulted in several machine couples and groups. This matrix resulted in a visual 2D representation in which all machine locations relative to each other were shown, confirming the machine couples and groups.

To take into account all possible layout options, a programming script was made. By adding multiple constraints, all possible layouts that follow these constrains where shown as a result and outcome of the programmed code. The constraints were needed to decrease the number of possible outcomes, namely 1.3 trillion options. For visual inspection, each machine was represented by a colored 2D cube. In each layout, the colored cubes had a unique orientation, representing a 8 machine layouts. After practical adjustments, one final lathe layout meeting all constraints was the result. Also, other department of the complete workshop were rearranged to create enough space for the new lathe department. To actively test and validate the new layout, different simulations with several variables were performed. The articles, setup times and processing times together with the layouts, man/machine couples and different ultimate scenarios were simulated. January 2023 was the most active month, so that month was input for the simulation. Eventually, the redesigned layout resulted in a simulation time decrease of 18,7% (representing a production rate increase of 23,0%) compared to the initial simulated layout.
The conducted research resulted in a redesigned layout for Hankamp Gears shown in Figure 1. This was done by filtering articles, arranging the articles based on diameter and production number, decrease lathes needed to produce largest portion of production, creating a specialized cell, incorporating all lathe operators, creating machine couples, settings constraints, use a coding program to show all viable outcomes, adjust these outcomes to reality and simulate the final layout. This resulted in a redesigned and future-proof layout with one lathe department instead of multiple smaller departments.

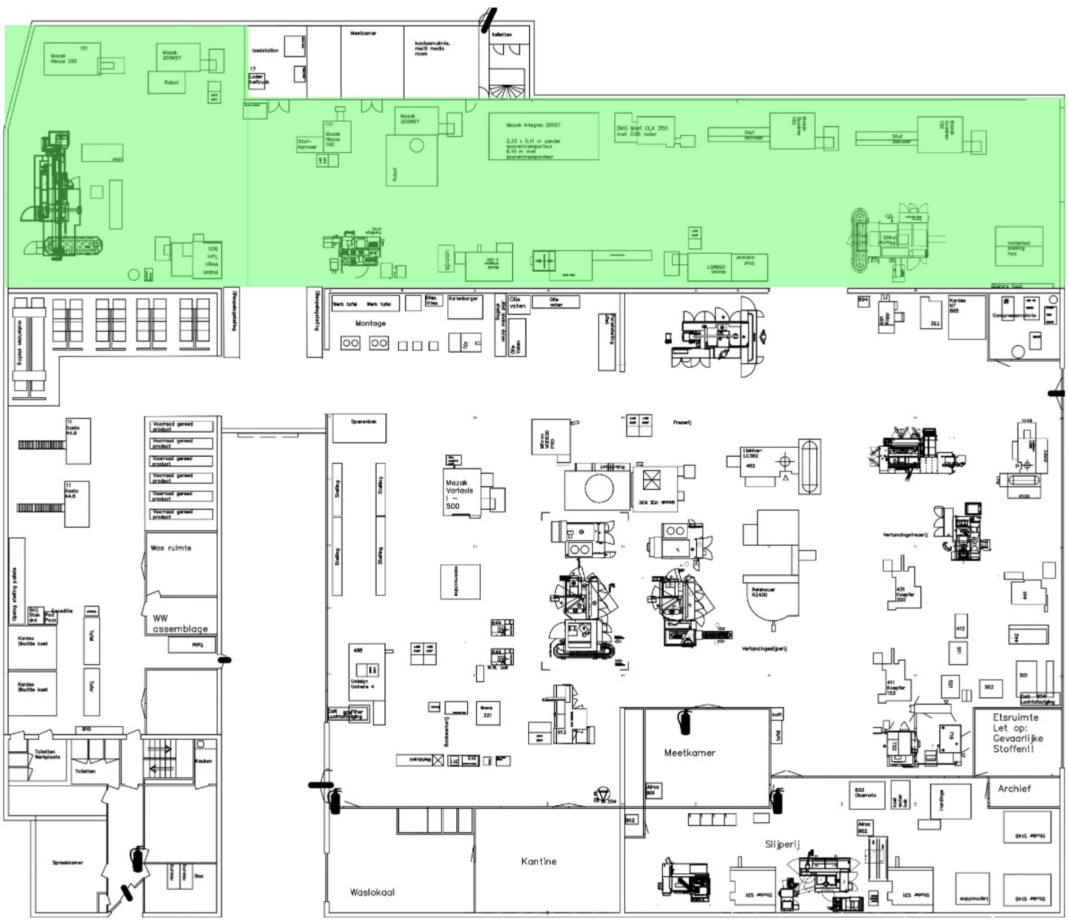

FIGURE 1: Redesigned workshop Hankamp Gears (lathe department is green).

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1 Introduction

As finalization of the Master Mechanical Engineering a case study was executed at Hankamp Gears situated in Enschede. The case study was performed to determine whether a workshop redesign could maintain an equal production rate with a decrease in available personnel. First, the company Hankamp Gears will be described (Section 1.1). Besides general company information, detailed company characteristics will be described shortly as well (Section 1.1.1). Once the company is known, the actual problem description will be stated (Section 1.2). Based on the problem description, one main research question and seven additional sub-questions were defined that will be elaborated on further (Section 1.3). Lastly, the performed step-plan that functions as a framework for upcoming chapters is discussed (Section 1.4).

1.1 Company Description

Hankamp Gears was founded in 1909 and has become an absolute expert in the production of high quality gears throughout the past 115 years. The produced gears are used in several industries such as aerospace, defense, mining, printing, food, energy, robotics, printing industry (digital and flexo) and pumps (both driving and pumping gears). Among customers of Hankamp are companies located in nearly all European countries but also outside Europe like Israel, USA and China. Hankamp Gears strives for high quality produced gears. This enables Hankamp to several achievements: First of all, to be a global player related to the gear production sector. Second, to create solutions related to different transmission inquiries. Lastly, to establish and maintain a proper relationship with partners and customers for the long-term. The building of Hankamp Gears is shown in Figure 2.

FIGURE 2: Hankamp Gears building.

The in-house production processes of Hankamp Gears are among others: milling, turning, gear hobbing, gear cutting, (gear) grinding (out/inside and surface), honing, spark erosion (wire), broaching and laser engraving. With Hankamp Gears machine park they anticipate and respond constantly to the latest trends in the metal sector. Furthermore, competing with other expert in the Netherlands is possible with a very modern gear grinding department consisting out of multiple CNC machines. With the aid of the modern CNC machinery and all experience, Hankamp Gears is specialized in the manufacturing of gears with tolerances from even $< 1M\mu$. For comparison, the thickness of a human hair is about $60M\mu$.

Hankamp Gears produces different types of products (Figure 3): straight (1) and helical gears (2) (diameter up to 600 mm), straight toothed inner gears (3) (diameter up to 300 mm), hardened and ground tooth flanges (external and diameter up to 400 mm), gear racks (4) (hobbed, shaped or ground; maximum length of 1000 mm), worm shafts (5) (single and multiple starts; maximum length of 600 mm), ground (hardened) shafts, ground external threads, gear segments and parts for fuel injection systems (with tolerances up to $2M\mu$). In some cases, Hankamp Gears includes the assembly of the gear parts, castings, bearings and seals (6).

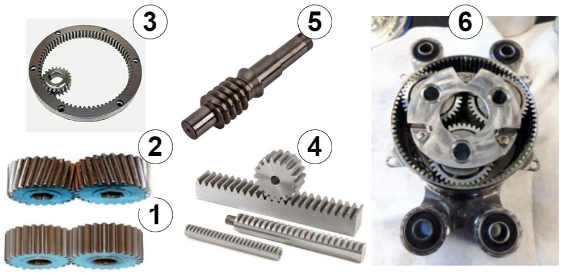

FIGURE 3: Examples of type of products that Hankamp produces. Due to confidentiality, numbers 1 - 5 are examples (not these exact products were produced by Hankamp Gears). Only number 6 is produced by Hankamp Gears itself.

To ensure quality, Hankamp Gears implemented Failure Mode Effect Analysis (FMEA) a few years ago with the main goal of identifying potential failures and act upon these to optimize production. Production is optimized when rejection of parts, cost and lead time are reduced and minimized which will benefit the customers. Part of the FMEA are process flows, control plans and risk analysis. Besides FMEA, also Statistical Process Control (SPC) is implemented to control and optimize the production process even though Hankamp produces small quantities (single parts) and midsize batch quantities. Furthermore, internal and periodical audits executed by Lloyds guarantee that Hankamp Gears meet the quality standards according to EN-ISO 9001:2000/AS9100 [1],[2]. Besides, Hankamp Gears is supported by an independent consultant to ensure that they meet current environmental demands and simultaneously ensure that staff members work in a comfortable and safe production area [3].

1.1.1 Company Characteristics

Now that the company description is known, it is time to dive deeper into some typical characteristics for Hankamp Gears. First of all, Hankamp Gears falls under the header Small and Medium-sized Enterprises (SME) since the company has fewer than 250 employees and their annual turnover is less than 50 million euros [4]. Second of all, Hankamp Gears is an Make To Order (MTO) and High Mix Low Volume (HMLV) manufacturing company. So, based on specific client requirements, parts are made to order. There are no standard parts, only unique parts are made according to the whishes and demands of the clients. The HMLV manufacturing indicates the total number of products consists out of relatively many different parts (high mix) with relatively low amounts of product numbers (low volume). Since Hankamp fabricates the parts in its own workshop, they are active in the Dutch manufacturing industry. Lastly, Hankamp Gears grew organically over the years. Relocating current machines and placing new machines is expensive and not always enough financial resources were available. When extending the workshop and

placing machines, no long-term plan or clear strategy was used. Rather, available space at the moment was leading when making decisions about where to (re)locate machines.
During the rich history of Hankamp Gears, the workshop has been enlarged more than once, resulting in more available space. Departments are distributed over the workshop, machines are located all over the place and the workshop seems messy. This is displayed in Figure 10 (Section 3). As of right now, Hankamp Gears realizes that action is required in order to change.

1.2 Problem Description

Now that both the company and the typical characteristics are known and understood, the real problem for Hankamp Gears can be understood in a better way. Hankamp Gears has its own workshop, consisting out of different departments and machines. Raw material enters the factory, passes several machines, undergoes different manufacturing steps and in the end a finished product is sent to the customer. The department of interest is the lathe department, where all different lathes are positioned and where operators work with these lathes. In here, a raw piece of material is turned into a gear blank (Figure 4).

FIGURE 4: Gear blanks.

There are several problems that needs to be addressed. First of all, machines have been replaced with new ones over the years which resulted in a production route that is not necessarily more efficient. This is an effect of organic growth over the years. Second of all, several lathe operators will retire in the near future. Combine this with an expected decrease of experienced lathe operators on the labor market and the true challenge for Hankamp Gears shows itself. An inefficient production route with an decrease in operators and a decrease in available, new, and experienced lathe operators on the labor market might have a negative effect if Hankamp Gears does not take any action. Operators will retire, meaning the company's number of operators decreases. This is a result of the Dutch ageing population that will continue to grow over the years [5]. As a result, the operators who will continue working at the company need to control even more lathes. This will make their jobs more challenging. With an increase in to be controlled machines and without a chance in work pace, the total production will take longer. Also, knowledge and experience will leave the company. All described problems result in the need for change. Due to the predictions of the labor market, in the worst case scenario Hankamp Gears will not gain any new lathe operators.
Based on these challenges, the question for Hankamp Gears arose whether a redesign of the lathe department could contribute to a manufacturing process that is more efficient. A higher efficiency indicates being able to handle the same amount of work or more, with fewer people. If this can be achieved, than the redesign is future-proof for Hankamp Gears. To investigate if this is all possible, the best lathe department is to be created.

This needs to be established by both a theoretical model and the incorporation of the lathe operators since the operators have to work in the new situation. This incorporation creates management of expectations towards the employees in the workshop. Furthermore, it needs to be determined if good machine combinations are possible in the new layout. Thus, the objective for Hankamp Gears is becoming future-proof for the upcoming seven years. The objective of this thesis is to redesign the lathe department such that the same production rate, or a higher production rate, can be achieved with fewer people to make the lathe department future-proof.

1.3 Research Question and Sub-Questions

Based on the company description, company characteristics and problem description, the following **research question** is defined:

- **Is it possible to redesign a department such that it becomes future-proof within an SME manufacturing company that is characterized by organic growth and make to order (MTO), high mix low volume (HMLV) manufacturing?**

This main research question is accompanied with 7 additional *sub-questions*:

1. *What possible factors can be taken into account regarding the redesign of layouts from MTO and HMLV manufacturing companies, according to literature?*
2. *How can the current situation be described in terms of layout, machines, operators, production steps and readiness for change?*
3. *Are all articles in the product portfolio of interest or can a distinction be made that separates possible articles of interest and articles not of interest?*
4. *Based on what criteria would operators redesign the lathe department and how would this redesign look like?*
5. *Is it possible to create machine couples and machine groups in the redesigned layout?*
6. *How to ensure that all possible layout options are taken into account?*
7. *How to validate the redesigned lathe department layout?*

1.4 Framework and Step-plan

To be able to answer the sub-questions and eventually the research question, a step-plan consisting out of 15 steps is used as can be seen in Figure 5. For the upcoming chapters, this step-plan functions as a framework. Chapters 2 - 7 go in depth about the executed steps. One or multiple steps were executed and needed to eventually answer each sub-question. For convenience of the reader, each sub-question will be answered at the end of each chapter to conclude the chapter. Sub-question 1 will be answered in Chapter 2, sub-question 2 in Chapter 3, sub-question 3 in Chapter 4, sub-questions 4 and 5 in Chapter 5, sub-question 6 in Chapter 6 and finally sub-question 7 in Chapter 7. After all sub-question are answered, the main research question can be answered and a recommendation for Hankamp Gears can be given to conclude the research, as is described in Chapter 8. The main research question, the sub-questions and the framework define the scope of this research.

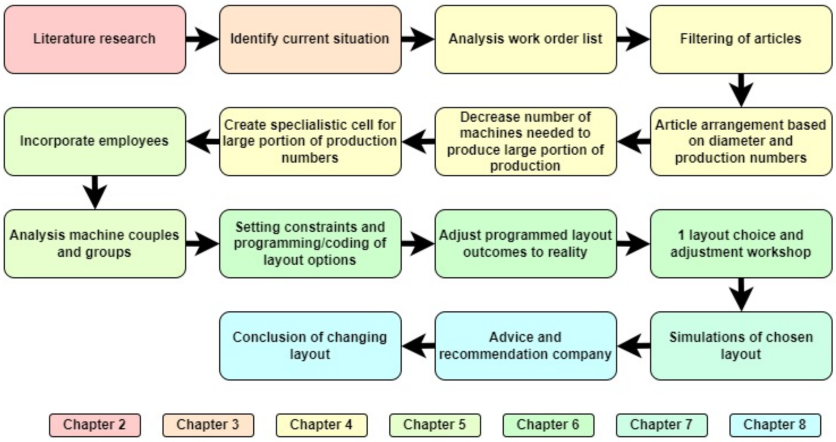

FIGURE 5: The 15 steps in the step-plan function as a framework for the upcoming Chapters.

2 Literature Research

The first main step to answer the main research question and solve the challenges for Hankamp Gears is to perform literature research. This forms a solid basis of knowledge and information, that can be used to further explore possible options to tackle the problem. To define which aspects to be looked at, the main research question (Section 1.3) is divided into 6 different parts, as enumerated below. For each part, the possibilities and reasoning whether resources are needed is explained:

1. **Is it possible to redesign a department**
   - Layout design methods are needed to identify if these can be used for the redesign of the workshop of Hankamp Gears. Literature about specifically lathe departments or other case studies of companies that have a lathe department can possibly help as well.
2. **such that it becomes future-proof**
   - A clear definition is needed to describe what exactly is so-called *future-proof.* If future-proof is not defined, the redesign cannot be validated.
3. **within an SME manufacturing company**
   - Hankamp Gears operates in the Dutch manufacturing industry and is an SME company. Although risks and opportunities of the Dutch manufacturing industry could possibly contribute to a future-proof layout (as well as the redesign), these are out of scope regarding this research. SME companies are based on number of employees and annual turnover, however turnover will not be taken into account any further.
4. **that is characterized by organic growth**
   - Organic growth caused the current layout of Hankamp Gears being not specifically made more efficient. The understand this cause, a definition of *organic growth* is needed.
5. **and MTO, HMLV manufacturing?**
   - Make To Order and High Mix Low Volume identify the type of manufacturing applied at Hankamp Gears. Possibly, literature can be found that specifies how MTO, HMLV manufacturing companies can be improved.

Moreover, since operators are involved, it has been chosen to also add literature about change management. This will aid in practice to create support, to get attention and to properly get the desired information from the operators. Here, literature how to handle a decrease in employees can be found as well.
First, definitions of organic growth (Section 2.1) are given. Second, future-proof definitions will be elaborated on (Section 2.2). Then, literature involving lathes specifically is short discussed (Section 2.3). This is followed by layout design methods, combining MTO and HMLV manufacturing (Section 2.4), in which layout generation methods are specified (Section 2.4.1). Afterwards, aspects and effects of change management are stated (Section 2.5). Based on the literature research, first the research gap is defined (Section 2.6). Afterwards, the relevance of this research is elaborated on further (Section 2.7). This Chapter will be closed by answering Sub-Question 1 (Section 2.8).

2.1 Organic growth

The definition of organic growth is often combined with financial aspects of a company. In literature, organic growth is defined as the opposite of acquisitive growth. Organic growth can be measured by means of an Organic Growth Index (OGI). The OGI takes into account capital invested, sales, cash flow from operations growth, core earnings, accounts receivable to sales, cash realization and mergers and acquisitions [6]. Furthermore, compared to acquisition growth, organic growth is more likely to represent genuine job creation. Also, organic growth indicates a smoother pattern of growth compared to acquisition growth. Lastly, organic growth often happens within small and young firms that operate in emerging industries [7].
Although, the financial aspect is not to be solely focused on. For Hankamp Gears, it had much more to do regarding growing in terms of available space. Furthermore in literature, organic growth is observed as a typical or natural way to grow were managerial abilities to use internal resources and processes efficiently are needed. This type of growth is achieved without buying existing business that is not part already of the company itself. Instead, it involves the natural growth of product sales and personnel [8]. Challenges involved with organic growth are a lowered flexibility for the company, the type of growth is a slow process and is trail and error [9]. Lastly, organic growth is referred to growth from a definite time window that arose from the existing business at the start of the defined period [10]. Regarding Hankamp Gears, available space was mainly an important factor regarding organic growth. Other found literature does describe this. Namely, layout modifications for production plants were triggered in the past at the moment there was a need for change. Because of this, companies grew in a way that was disordered and disorganized. If new equipment was bought, rearrangement of the current layout was a needed consequence to accommodate the new equipment. Often, based on space availability or convenient ways, departments were arranged [11].
This is comparable for the situation of Hankamp Gears. Not a long-term vision and strategy were used to arrange the layout. Instead, available space (due to extension of workshop) and convenience were leading during the arrangement of the layout. Over the years, this led to the current situation of Hankamp Gears. The workshop is disordered, disorganized, departments are separated at multiple smaller departments, machine are placed at mixed locations and there is by no means a clear overview anymore.

2.2 Future-proof

Now that it is clear how Hankamp Gears could grow organically in history, it is time to look towards the future. From the problem description described (Section 1.2), it is clear that the redesign of the lathed department needs to be future-proof for the coming seven years. In order to validate this, it needs to be clear how future-proof is defined.
According to the dictionary future-proof can be defined by a verb and adjective. Something is defined as future-proof if it will continue to be useful, or successful, in future if a situation changes (adjective). So, to future-proof the department, it needs to be designed and changed such that it will continue to be useful or successful in the future if the situation changes (verb) [12]. The situation of Hankamp Gears changes due to the decrease in operators that will retire in the near future. As an effect, the department needs to be redesigned and changed to still add value or be successful in the future.
From literature, future-proof related to (architectural) design can be defined as: something is made or planned such that it does not become ineffective for future use. Also, something is designed to be effective after possible changes that may occur in the future. Something is future-proof if it is both flexible and durable against future situations [13]. Furthermore, if a design can simultaneously resist the time to come and meet both needs of current and future generations, it is future-proof [14]. Besides, a design is future-proof when it is universal to a certain extent but also adaptable in case of insufficient universality [15]. Moreover, by ensuring a comparative transformability and anticipating future states, something can be identified as future-proof [16]. For Hankamp Gears, the redesign of the lathed department is identified as future-proof when the same production rate, or an increased production rate, can be achieved with less operators working in the newly redesign layout.

2.3 Resources Lathe Specific

At first glance, it was attempted to find literature specific about lathe departments. However, results were limited and the contents did not represent the actual research to be performed. For instance, work about turning operations was found, but this was to produce a computer aid for operation sequence planning in the early eighties [17]. Other outdated sources from the mid-eighties were found about either a theoretical analysis of dynamic behavior of lathe types or about a health hazard evaluation report from a company using lathes [18], [19]. More recent studies, such as a paper (2012) about production components for lathes, do exist in which lean manufacturing (LM) and cellular manufacturing (CM) are presented to optimize production. Although, this is not representable since the paper discussed a factory that has a consistent yearly order of lathes, has limited variation in components (only 8 lathe beds) and the number of operators is double the amount of the number of machines [20]. This all is not the case for Hankamp Gears: yearly orders are not consistent, there is more variation in components (1000+ articles with multiple production sequences) and per shift there are less operators than machines. A more recent article (2020) uses Method Engineering to increase productivity and decrease downtime for turning and grinding operations. However, these are the only operators to occur and the study was performed to improve the production of just 1 product by doing a time study for the production process and by changing the linear distribution of both lathe and grinding machine to a L distribution [21]. This is not comparable for Hankamp due to increased number of products with longer and variable production sequences. In the paper, all sub-tasks within an manufacturing operations are specified in seconds, such as cleaning the product. However, for Hankamp Gears only the production times for each production step are known from start to end and are less detailed.

2.4 Layout Design for MTO, HMLV Manufacturing

If a workshop layout is well designed, it comes with several benefits such as: reduced material handling costs, sufficient production capacity, no delays during work, efficient utilization of available floor space, efficient labor utilization, flexibility in terms of volume of and type of products, easy supervision and control, safety, ease of maintenance, high equipment utilization, improved productivity, reduction in hazardous situations for personnel and minimized material handling, time and costs. Several factors are of great importance regarding layout design: room for adjustments and expansion in the future, maximum flexibility, throughput, efficient utilization of space, ease of communication, promotional value, safety and lastly maximum accessibility. Type of layouts to be considered are process- , product-, fixed position- and cellular plant layouts [22]. Although, there are several challenges regarding facility layout design. Facility layout problems are dependent on: manufacturing systems, facility shapes, material handling systems, flow movement, devices, layout configurations, layout evolution, layout formulations, type of data used, objectives, constraints and resolution approaches [23]. Figure 6 shows the complexity of a facility layout problem.

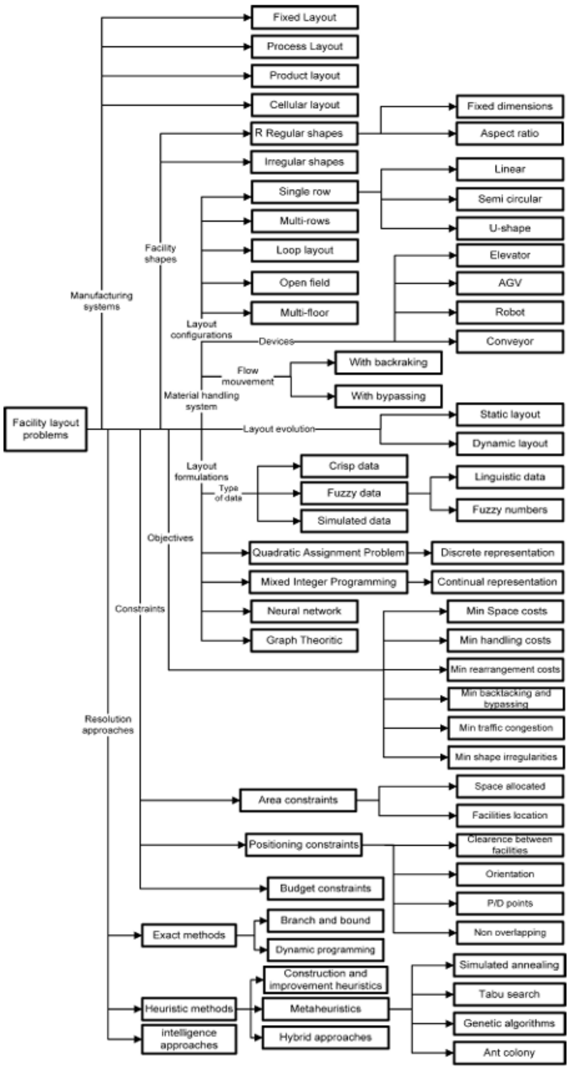

FIGURE 6: Layout problem overview [23].

Since Hankamp Gears strives for high quality produced gears and be a global player, World Class Manufacturing (WCM) is desired. To achieve WCM in MTO, it is advised to ensure skilled and flexible operators that have ownership of their own work. Second, design for products and processed need to be improved whilst improving supplier relationships. Third, simplifying the shop floor is advised. On the one hand, it is advices to focus on a cellular approach, but due to MTO a strategic decision could be made to keep a functional layout. Furthermore, available resources need to be used to their full potential and only after this investments regarding new resources or automation is needed. Next, quality needs to be improved and rework decreased. Furthermore, control systems and planning need to be up to date and appropriate regarding the production. Lastly, performance measurements shall be executed for benchmarking and continuous improvement. Quality, on-time delivery and product line flexibility are the most important performance measurements. Exploiting capacity, improving visibility, information flow and planning whilst continuing to improve are aspect that have impact on the change in MTO [24]. Often, the use of lean principals or the lean philosophy are described to improve MTO manufacturing. To implement lean principals in HMLV production, the following implementation flowchart is shown in Figure 7, where quality, volume, cost, shop floor and office are taken into account [25].

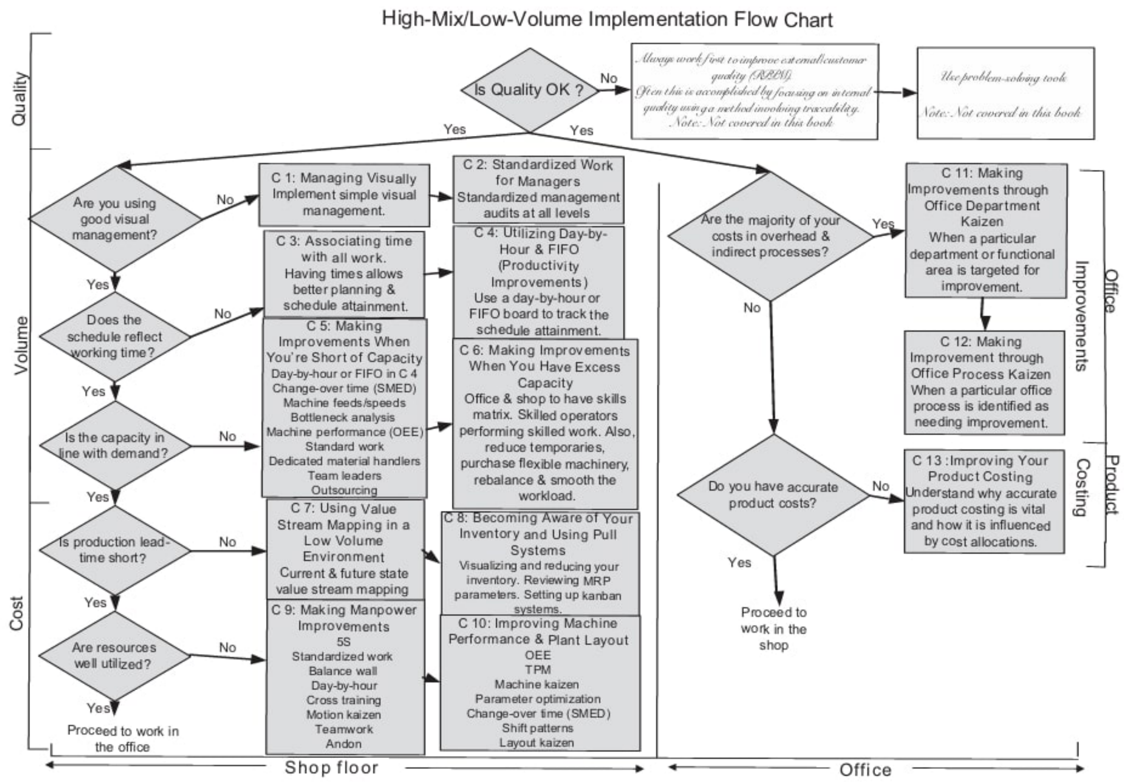

Figure 0-1. Implementation Flow Chart.

FIGURE 7: Flow chart for HMLV implementation.

There are several factors that possibly generate positive results regarding the implementation of the lean philosophy in MTO manufacturing. The philosophy needs to be attached to for two years at the minimum. Furthermore, open communication between employees and senior management is needed to ensure motivation. Here, a learning approach is needed as well as technique awareness and consistent support. Lastly, attitude is needed to create an improvement structure and to adapt to change. The Lean Manufacturing model, using a

Plan-Do-Check-Act procedure with the focus on the Do stage can be used to positively impact a MTO companies as in done in a case study for an Indian MTO company. Efficiency is improved, tool search time is decreased, on time delivery is increased and reprocessing is decreased for a metalworking company resulting in savings. The Do stage mainly focused on classification and order focused on 5S, application of visual control boards and apply work standardization [26]. Another case study focuses on Kaizen to extend the lean frontiers and to improve an Italian MTO manufacturing company with HMLV products. Here, a Kaizen framework is used to reduce production costs and to improve delivery time. Ten phases are identified: identification of problem, identification of project, current state mapping, setting a target, perform root cause analysis, define solution approach, perform rapid experiments, development completion plan, evaluation of impact of countermeasures and finally insights from the improvement. In the case study, by performing these phases, outcomes were that a mixed-model line could be used and that an area for certain production steps was decreased in sized and was allocated to a new position in the workshop [27]. According to case studies, plant layouts can be adjusted according to systematic layout planning to increase productivity [28], [29]. Doing so, space is properly utilized. Furthermore, material handling time, cost of labor and transportation is decreased. The Systematic Layout Planning Method is shown in Figure 8.

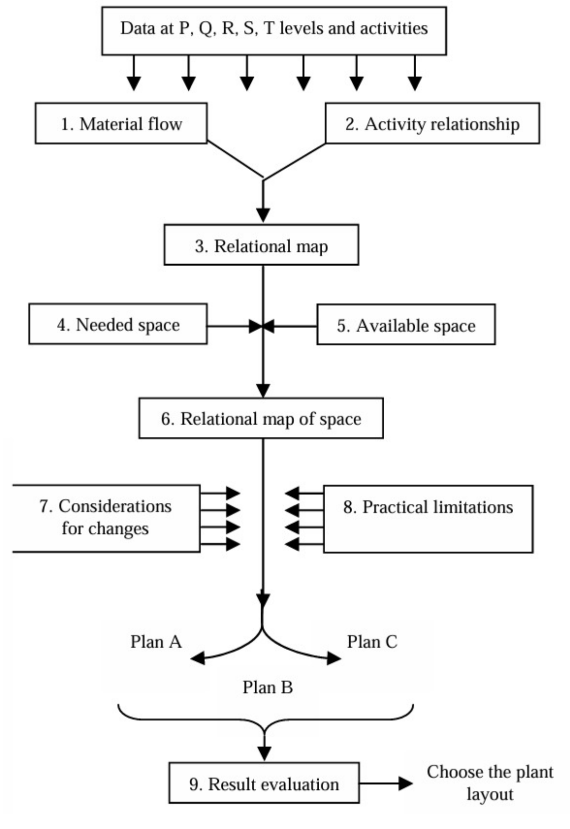

FIGURE 8: Systematic Layout Planning Method displayed with product (P), quantity (Q), route (R), support (S) and time (T) data as input [29].

2.4.1 Layout Generation Methods

Regarding resolution approaches, so to solve layout problems, there are three options. For exact methods (option 1), either branch and bound or dynamic programming can be used. Intelligence approaches (option 2) can be used as well. For heuristic methods (option 3), construction (CORELAP, ALDEP, COFAD) and improvement (CRAFT, FRAT, DISCON) heuristics can be used as well as hybrid approaches. Regarding meta heuristics, either simulated annealing, tabu search, genetic algorithms or ant colony are options. [23].
In terms of layout algorithms, a layout can either be improved or constructed. Improving algorithms try to optimize existing layouts whilst constructing layouts starts from nothing and builds op the layout. For constructing algorithms, it can either be that building dimensions are given and there are algorithms that tackle the challenge of not knowing the building dimensions. Modeling techniques are pairwise exchange method, graph-based method, CRAFT, BLOCK PLAN, MIP, LOGIC and MULTIPLE.
The following layout methods will be shortly summarized: Pairwise Exchange Method, Graph Based Method, CRAFT, BLOCPLAN, MIP, LOGIC and MULTIPLE [30]. For an en depth explanation, please refer to the used source. Furthermore, CORELAP, ALDEP, COFAD, FRAT and DISCON will be stated in short [31], [32], [33], [34], [35], [36]. Please refer to other sources if more details are wanted. For clarity of the reader, the sources will be stated again after the introduction of each layout method.
The Pairwise Exchange Method is used to redesign a layout based on a currently existing layout, thus an improvement type of algorithm. Often the algorithm implies a distance-based objective where departments of equal area are exchanged. All possible exchanges of locations are examined one at a time. The objective function is distance-based and based on total cost. The exchange pair that reduces the cost the most is selected. The result depends on the initial layout and thus cannot guarantee to give an optimal layout [30].
The Graph Based Method is a construction layout algorithm type, where often an adjacency-based objective is used. From a relationship chart, a relationship diagram can be made. By arranging different block layouts, the objective is to maximize the sum of arc weights. Here, adjacency only account for adjacent departments, it does not take into account distance and dimensional specifications are omitted as well [30].
CRAFT (Computerized Relative Allocation of Facilities technique) is a improvement-type layout. Centroids of departments are determined, after which rectilinear distances between all departments in the initial layout are measured, which is put in a distance matrix. To calculate the initial layout cost, entries from a from-to-chart are multiplied with corresponding entries in a unit cost matrix. All possible pairwise or three-way department exchanges are considered to maximize the cost reduction. This can be used for departments of different sizes and departments. Normally, CRAFT can only be used for rectangular buildings, although by using unused space (dummy departments), the shape of the building can be made rectangular [30].
BLOCPLAN arranges departments in bands, where both a relationship chart and from-to-chart function as flow input data. To calculate the cost, this can either be accomplished by a distance- or adjacency-based objective. The number of bands is limited to two or three whilst the band widths are allowed to vary. As a first step, all departments are assigned to the two or three bands. The proper band width is computed by dividing the total area of all department in the band by the building length. This is done for each band, after which the departments are arranged, resulting in a complete layout [30].
Mixed Integer Programming (MIP) can be used when a facility has a continuous representation and if all departments are rectangular, consisting out of several problem parameters (such as dimensions of building and limits of departments) and decision variables (such as

centroids of departments) [30].
LOGIC (Layout Optimization with Guillotine Induced Cuts) uses from-to-charts as input data for flow. Costs are implemented based on the distance-based objective function. Layouts are generated by continuously cutting horizontally and vertically, assigning different positions for departments [30].
MULTIPLE (Multi floor Plant Layout Evaluation) is originally created for multi-floor layouts, but by setting the number of floors to 1 and omitting lift requirements, MULTIPLE can be used for single floor layouts as well. MULTIPLE is comparable with CRAFT, although MULTIPLE can exchange two departments regardless whether they are adjacent or not [30].
CORELAP (Computerized Relationship Layout Planning) is a construction algorithm that uses relationship ratings as input. This is done to allocate positions to workstations. The allocation is based on Total Closeness Rating (TCR) for all departments, reducing total distance difference on shop floor and decreases costs of moving material compared to the original workshop layout [31].
Using ALDEP (Automated Layout Design Program), optimum layouts regarding organizational units are generated within restricted space availability. A method of scoring is used to develop a preference table consisting of weighting factors to display desired machine pairs. All generated layouts are scored and the best layouts are plotted [32].
COFAD (Computerized Facilities Design), starts with an initialization where material handling equipment are assigned and all moving costs are set. Then, for plant layout modules alternative move costs are calculated. Iterations of layout are made based on distances of departments, costs of transportation and total materials handling system costs [33].
FRAT (Facilities Relative Allocation Technique) is an algorithm that used a heuristic procedure. The number of facilities, a flow matrix and original facilities coordinates are input. By computing the differences of the longest and shortest distances between the center of two facilities and the total cost of possible trips, the position of the facilities is calculated. The distance is dependent on the travel flow pattern in the layout [34].
For the DISCON (Dispersion and Concentration) algorithm, facilities are assumed to have a circular shape. To measure the distances between the facilities, Euclidean distances are used [36]. Locations are to be found such that the cost per unit distance between facilities is minimized. In the dispersion phase, all circular facilities are put at one point and based on cost factors they are separated, since the facilities should not overlap. In the concentration phase, it is analyzed which pair of facilities are strongly connected. this is the case when the facilities are relatively close to each other when the dispersion phase is ended [35].

2.5 Change Management

Typically, change is part of the strategy of a company where strategic decisions, for example, are about changes in the environment of the business and about long-term direction of the organization. Mostly, change is hard due to the heritage of resources and as a result of organizational culture [37]. Change programs do effect the emotions of employees. Strongly present values and beliefs of people will resist change and once changed, people will experience a feeling of loss. Depending on the reaction of change, emotions will differ among people. Reactions to change can be passive resistance, embracement or active undermining (Figure 9). To allow change, people need to do three things: consider the change, take actions towards the change and collect knowledge about the change. To actually realize change, three significant challenges need to be overcome: receptivity, mobilization and learning. From a cognitive level point of view, employees might understand the need for change to let organizations survive. Nevertheless, emotionally the employees might have lost their trust regarding offers to change and the future of the company [38]. Both willingness to change and subcultural strength determine how an employee reacts towards cultural change, resulting in 9 different responses (Figure 9) [39]. The acceptance of organizational change is influenced by different leadership styles. Namely the perception of change of employees is influenced by the leadership style used by managers. The leadership styles can either be visionary, coaching, affiliative, democratic, pace-setting or commanding. Not only the leadership style, but also the openness to experience (either high or low) of employees influences the effects on acceptance or organizational change. These effects can be negative, possibly negative, possibly positive and positive [40]. The reason why people will not change may be due to being caught in a competing commitment. This is a subconscious and hidden goal that clashes with their stated commitments. So, valued employees do not have to be purposefully resistant to change. The immunity to change can be broken in three main steps, where the first step is diagnosing the competing commitment. Second, the big assumption needs to be identified. The big assumption is the way people view the world, which is woven in their lives, creating the deepest beliefs and assumptions. The last step is to test the big assumption, after which is can be replaced after consideration [41].

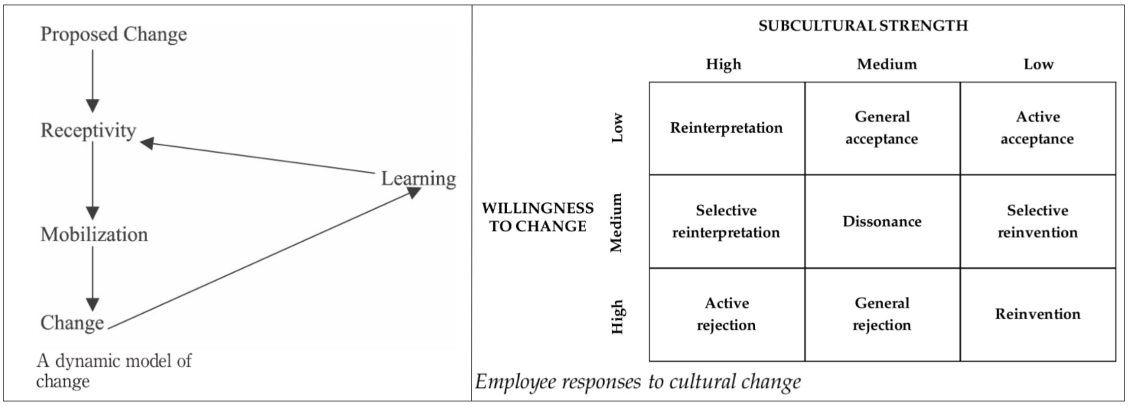

FIGURE 9: Dynamic model of change (left) [38] and 9 employee responses to cultural change (right) [39].

2.6 Research Gap

Now that several resources are collected, the next step is the identification of the research gap. In short, this can be described as: Currently, no method is available to make companies that are organically grown, are active in the manufacturing industry, have MTO production and have HMLV production, future-proof by redesigning a department in the workshop. In this specific context, organic growth is related to placing machines based on available space and convenience whilst future-proof implies redesigning the layout such that the same production rate can be achieved with fewer operators. This ensures that the layout is still successful and useful for current and future generations by anticipating the future state. Although several layout generation methods to exist, none of them are specifically designed to be used for complex HMLV and MTO manufacturing companies. The methods often minimize the costs, whilst for this case study cost is not the objective. The objective is production rate and usage of personnel. Moreover, in literature flow is often an input, whilst this is extremely challenging for a HMLV and MTO manufacturing since there are an incredible number of products with varying production times and processing steps. Another challenge of the current methods are the fact that they arrange different departments based on flow. This implies that for the production, several departments are used. In the case of Hankamp, the department is the lathe department, in which different lathes are placed. Rearranging the lathes based on flow will not work, since the products do not flow from lathe to lathe, but from lathe to other machines. The usage of personnel is also not taken into account in the sources. This thesis aims to fill this research gap by creating a new method to take into account: complexity of HMLV and MTO flow of products, incorporation of operators in the work floor, generating all possible layout configurations for one department, practical adjustments of a chosen layout and the validation of the chosen layout configuration. To the knowledge of the writer, this method is the first in its kind to describe how to solve this very complex problem by performing a case study.

2.7 Research Relevance

The research gap actually shows that there are no resources available that combine all the listed company characteristics together with the challenging problem. Due to all challenges listed, this research aims to create a theoretical framework on how to improve and future-proof companies identified by organic growth and make to order, high mix low volume manufacturing. To put this into practice, the research aims to redesign the lathe department of Hankamp Gears B.V. to make it future-proof by performing a case study. On the one hand, this case study is performed to gain valuable input and advice for Hankamp Gears B.V. Furthermore, this thesis aims to add value in the research field by exploring possibilities to improve and future-proof companies with a specific combination of specifications. This is not only done by literature research, but also by performing the case study to truly let theory meet practice and thus validate the research.
First of all, logically this research is relevant for Hankamp Gears itself. Since a case study is performed, Hankamp Gears will be examined in detail to solve the problems they have by redesigning the lathe department. Second of all, other SME companies, active in the Dutch manufacturing industry, that are organically grown, have HMLV and MTO production and will have less personnel in the near future, can benefit from this research. This research can inspire, guide and help such companies that face the same problems as Hankamp Gears. Lastly, this thesis is filling the described existing research gap. By filling this, value is added to the current existing research around specific types of companies that struggle to future-proof themselves.

2.8 Answering Sub-Question 1

What possible factors can be taken into account regarding the redesign of layouts from MTO and HMLV manufacturing companies, according to literature?
The first two factors to be taken into account are the definitions of organic growth and future-proof. Namely, organic growth caused the need for redesign of the layout to achieve a future-proof layout. To understand the cause, organic growth needs a definition. To set a goal and to validate this goal, a definition of future-proof is needed. No factors regarding specific sources about lathes need to be taken into account, since the contents of the found literature does not correspond to this case study. A layout design problem is complex and thus one or multiple challenges regarding layout design are to be considered and to be taken into account such as manufacturing systems, layout configurations, the objective and the used constraints. HMLV factor implementation can be taken into account in order to enhance the layout redesign. Also, a type of systematic layout planing method as is used in MTO manufacturing layouts, can be a factor to take into consideration. From

the layout generation methods, the objective of the redesign needs to be clear. Also, a method (such as an algorithm) needs to be considered to generate the layouts. These layouts need to be generated based on constraints, which need to be taken into account as well. Regarding change management, it is important to take into account emotions of employees, the resistance against change and the used leadership styles. All these factors and the literate research resulted in the proposed research gap and research relevance. In Chapter 3, the second step of the presented framework (Figure 5) will be discussed, namely the identification of the current situation of Hankamp Gears.

3 Current situation

Before the redesign is made, it is good to know how the current situation looks like at Hankamp Gears. To do this, the current layout will be examined (Section 3.1) together with the different production steps (Section 3.1.1) and the detailed lathe department (Section 3.1.2). Furthermore, a Continuous Improvement Maturity Model (CIMM) questionnaire has been handed out to the office and the workshop to adequately provide insight in the current situation in terms of continuous improvement and readiness for change (Section 3.2). Here, maturity levels (Section 3.2.1) as well as aspects regarding people & organization (Section 3.2.2) will be discussed. Also, an explanation for using different questionnaires is elaborated on (Section 3.2.3). Lastly, the results of the CIMM assessment will be given (Section 3.3). By shortly introducing box-plots (Section 3.3.1), the results of both office (Section 3.3.2) and workshop (Section 3.3.3) are discussed. This Chapter will be finalized by answering Sub-Question 2 (Section 3.4).

3.1 Current Layout

The current layout of Hankamp Gears with all its departments and different areas is displayed in Figure 10. Hankamp Gears has its workshop, consisting out of the following areas: bench working, sawing, lathe, expedition, measurement rooms, WW cell (consisting out of a lathe, honing machines, milling machine and grinding machine), gear milling, milling, gear grinding, grinding, assembly and common space. The raw materials enter the workshop, the raw materials go to the sawing department and after the material is cut is goes through the workshop. Depending on the product, the several departments are used to process the part, eventually leading to a finalized product. At the expedition, the product is packed and shipped to the customer. In Section 3.1.1 it will be explained shortly how complex the production process is and how important the lathe department is.

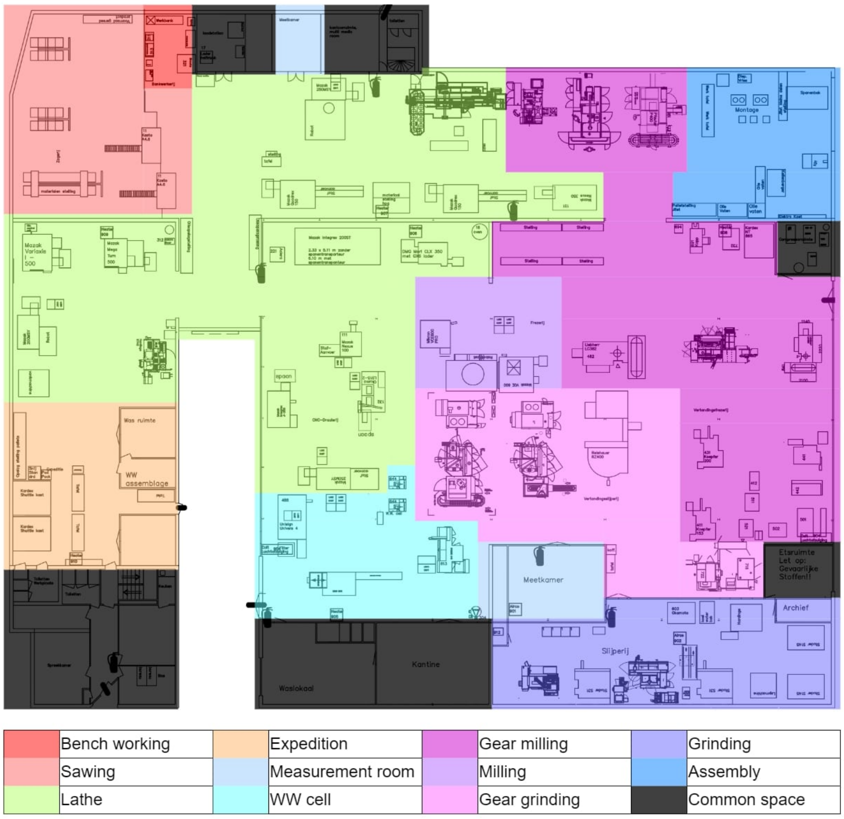

FIGURE 10: Current layout of Hankamp Gears including legend with corresponding color explanations.

3.1.1 Production Steps

Since the production is high mix low volume and make to order, there is no standard procedure of producing parts. Depending on the part to be produced and the requirements from the customer, different processing steps are needed to go from raw material to a finished product. When examining the production year 2023, there are already 162 unique combinations for the first 4 production steps. A total of 8 unique combinations represent a total of 49,67% regarding frequency. What can be seen is that a turning processing step (called *dr*) is most often combined with sawing (*za*) and gear milling (*twfz*). The other 50,33% frequency is part of the other 154 unique production sequences, which include turning as well. The Pareto chart of the production data from 2023, regarding unique processing sequences is shown in Figure 11. Since the production process is elaborated on and the importance of turning as a manufacturing step is clear, in Section 3.1.2, the lathe department will be explained.

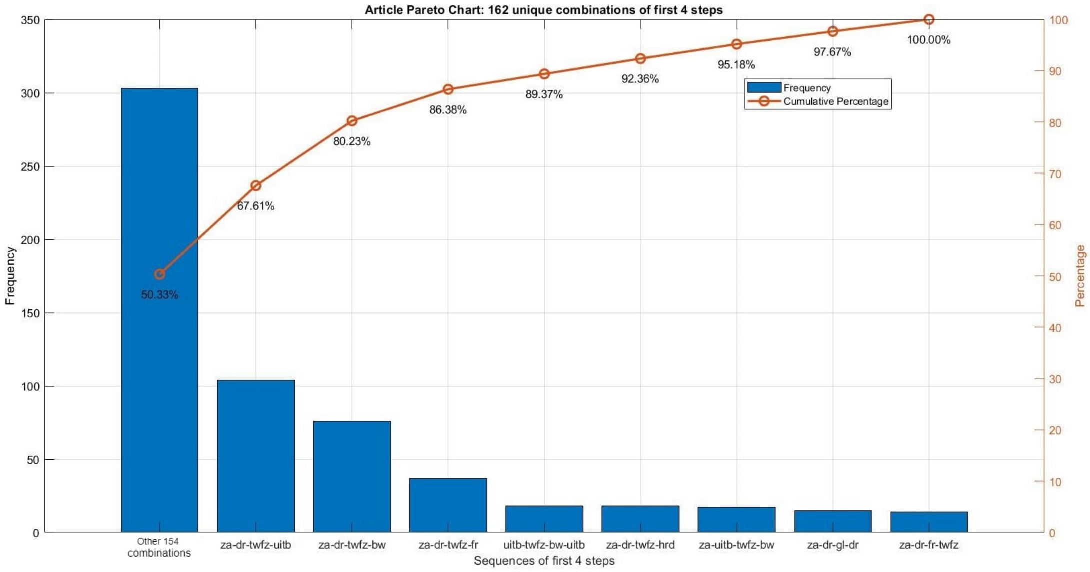

FIGURE 11: Pareto chart showing all 162 unique combinations of first four production steps for all products produced in 2023.

3.1.2 Lathe Department

The lathe department is distributed into four different segments: *DB*, *CR*, *DR* and *WW*, see Figure 12. In lathe department *DB*, there are 3 lathes, 1 milling machine and 1 spark-erosion machine. All three lathes are in use. In lathe department *CR*, there are 5 lathes, which are all in use. To the right of *CR*, there is also a small conventional machine. Although, this lathe is hardly used. In lathe department *DR*, there are 6 lathes. One of them will be removed in the near future due to age. In *WW*, there is 1 lathe present together with 2 honing machines, 1 milling machine and 1 grinding machine. In total, there are 17 lathe operators. In *DB*, 5 lathe operators are working: 2 in the morning shift, 1 in day shift and 2 in evening shift. In *CR*, there are 4 lathe operators: 2 in morning shift and 2 in evening shift. In *DR*, there are 6 lathe operators: 3 in morning shift and 3 in evening shift. In *WW*, there are 2 lathe operators: 1 in morning shift and 1 in evening shift. Now that the lathe department is detailed, it is time to measure the current performance of Hankamp Gears in terms of change and continuous improvement, as is done next in Section 3.2.

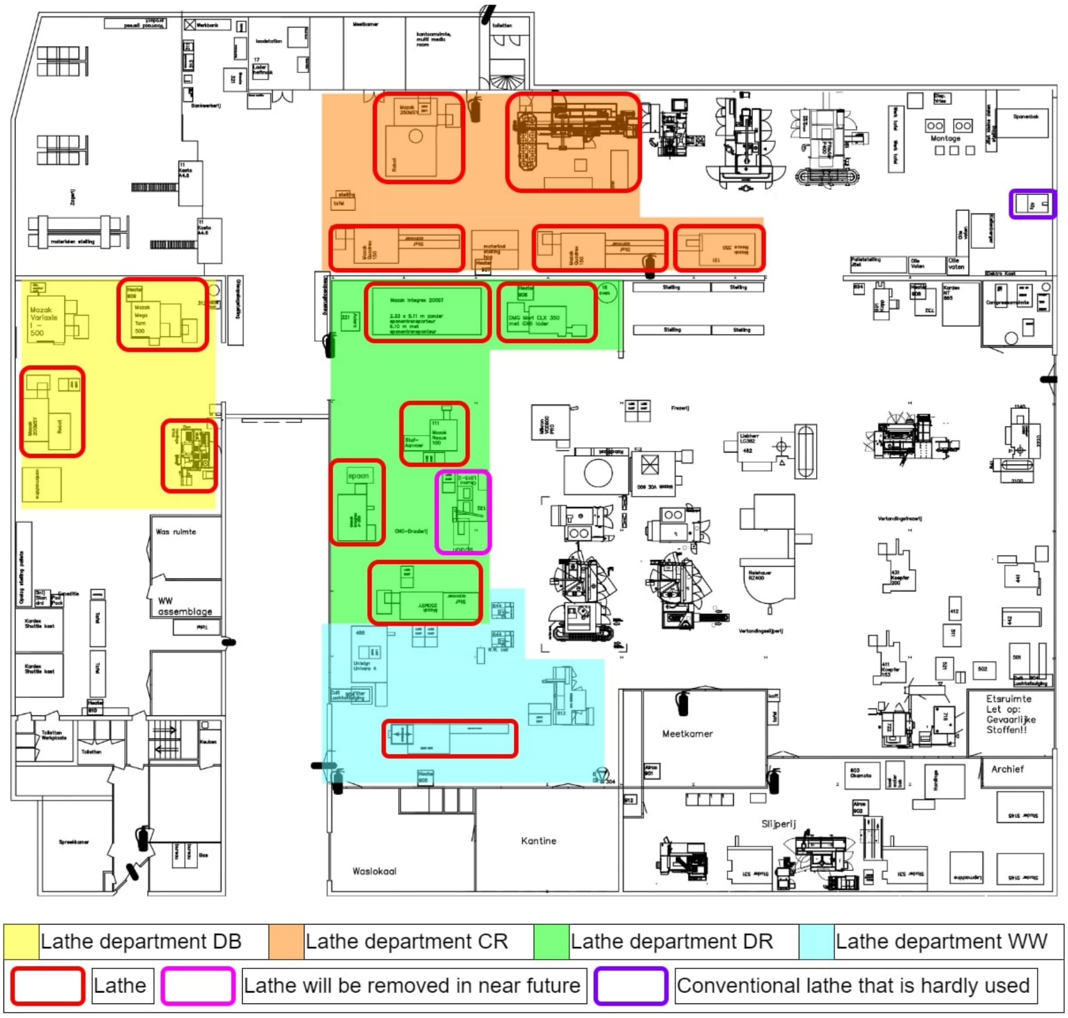

FIGURE 12: Lathe departments and locations of lathes.

3.2 Continuous Improvement Maturity Model Assessment

Redesigning part of a workshop, which possibly leads to improvements, can be a large change within a company. Regarding the current situation, the goal is to measure how mature and ready Hankamp Gears is for change. Another goal is to identify if employees agree with each other mutually. To do this, the Continuous Improvement Maturity Model (CIMM) assessment, a questionnaire, is used. Symbol [42], a company that provides consulting in areas of organizational development, continuous improvement, quality management and change management, developed the CIMM assessment. This assessment gives companies insights regarding their current situation, where the assessment forms a starting point to develop a continuous improvement program. When a company whishes to implement a lean or six sigma transformation, first the current maturity level should be determined. Depending on the maturity level, continuous improvement can be achieved by several methods. The CIMM combined best practices, techniques and different methodologies in one framework. This shows where a company stands on the development path of continuous improvement [43]. By knowing how mature Hankamp Gears is regarding change and improvements, this can lead to additional advice and recommendations that can be combined with redesigning the layout of the lathe department.

3.2.1 Maturity Levels

All five maturity levels are explained shortly [44]:
Level 1: Create a solid foundation.
The first level describes how to create a solid foundation for a company. This solid foundation can later be used to develop into the other levels. With a solid foundation, the company can eventually successfully execute improvement initiatives. In a solid foundation, there is a professional work environment with 5S (Sort, Straighten, Shine, Standardize, Sustain), there is standardized work, and there is a quality management system present.
Level 2: Create a continuous improvement culture
The second level is about creating a culture in which all employees are both proactively and constructively involved in the continuous improvement of the company. In such company culture, there is a bottom-up approach, where all employees are encouraged to initiate small improvement processes. Daily short stand-up meetings to discuss improvements, programs and goals, play a role to achieve all this.
Level 3: Create stable and predictable processes
The third level focuses on improving the logistics flow by making processes stable, efficient and predictable. Doing so, unsafe situations, unplanned backlog, increased waiting times, mistakes and quality issues are prevented. This level is about creating a stable environment where results and achievements are predicable.
Level 4: Create capable processes
The fourth level addresses reducing variation in a stable process. By decreasing variation, the process performance is increased. Complex quality issues are solved. Processes executed at this level are more top-down and performed by engineers and experts.
Level 5: Create world class products and services
Levels 1 - 4 had a reactive approach by improving the current situation. In the fifth and last level, the reactive approach is changed into a proactive approach. Here, the aim is to develop products and services that both meet all customer requirements and are flawless, without any mistakes, from the very first moment. Here, Product Lifecycle Management (PLM) and Design for Six Sigma (DfSS) are combined with the other techniques from levels 1 - 4 resulting in world class products ans services.

3.2.2 People & Organization

Besides the five maturity levels, the CIMM assessment also consists out of a category called People & Organization. This category describes five major components:
Strategy
The strategy component is about a clear direction and focus for the company. Furthermore, the vision, mission, core values, long-term strategy and clearly defined goals of the company are part of this.
Leading
The leading component is about the quality of the management within the company. Parts of management are functioning as an integer example for employees, strong leaders are present, creativity of employees is stimulated, focus projects are defined and measurements are adequately taken towards employees who do not perform well.
Openness
The openness component is about the open and transparency and action-orientated decisions. Also, it is about job satisfaction of employees and corporation of employees when making decisions in the company.
Learning

The learning component is about a learning company, where employees are inspired to get proper results and where making mistakes is seen as a opportunity to grow. It is also about complementary employees and development of competences for employees.
Agility
The agility component is about an agile and flexible organization. This can be achieved if employees see change as an opportunity, if a company can quickly adapt to market changes, if there is a self-managing organization with high degrees of responsibility, proper action is taken when results are not as desired and management can make decisions quickly.

3.2.3 Difference CIMM Questionnaire for Office and Workshop

The CIMM assessment is in the form of a questionnaire. The standard CIMM questionnaire consists out of 100 statements: 15 for each level and 25 for the category People & Organization. This was handed out to the office. Based on the statements and feedback from the office, it was decided to change the CIMM questionnaire for the workshop. The workshop had the same People & Organization statements, but different statements connected to Level 1 - 3. Level 4 and 5 were omitted. This decision was made to shine light into the more practical side of Hankamp Gears, by making statements based on levels 1 - 3 such that operators in the workshop could more easily answer the questions and give input, resulting in a different questionnaire and 95 questions. For that reason, only the People & Organization part can be truly compared to each other for office and workshop. In both questionnaires, everyone had the fill in a score, ranging from number 1 to 5. Both questionnaires that were handed out to the office personnel and operators from workshop can be found in Appendix 9.1 and 9.2, respectively. Each score had a different meaning:

- 1: not present/no knowledge about
- 2: started, limited in presence
- 3: applicable for number of areas, improvement possible
- 4: widely applicable, good
- 5: completely implemented and secured

To display the averages and spreading of the scores, box plots are used, as can be seen in upcoming Section 3.3.

3.3 Results CIMM Assessment

The collected results are used to approximate the maturity levels and to display possible mutual (dis)agreements between office and workshop employees. This will give Hankamp Gears a representation of how the employees think about change and how ready Hankamp Gears is regarding change and possible improvements by redesigning the lathe department. If it is known how the current situation scores on beforehand, this can be taken into account before and during the redesign phase. For example, if it is known that there is not a solid foundation yet, this can be a focus point before the redesign phase to enhance the redesign of the layout. Or, if it is known beforehand that operators believe they are not actively taken into account during important company decisions, this can be used as an action point. For instance, they can be more actively incorporated during company meetings during the redesign phase. Regarding the aspect of mutual (dis)agreements: if overall employees mutually agree with most statements, implementation of change might be easier to achieve compared to a situation where there are strong disagreements. If this is known beforehand, this can be used as input to get to know where these disagreements come from. By solving this and creating unity before the redesign starts, this might positively influence the view regarding change. So, by analyzing the current situation, this can result in valuable and mostly practical inputs for Hankamp Gears that can be used before and during the redesign phase.

3.3.1 Results Implementation Using Box-plots

Box-plots are used to visually display all scores, see Figure 13:

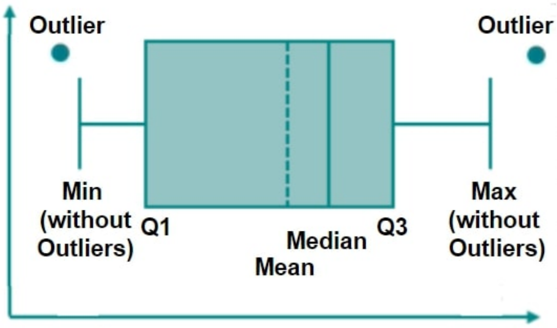

Figure 13: Box-plot visually explained [45].

The left side of the box is the first quantile (Q1) and the right side of the box is the third quantile (Q3), since the box displays interquartile range (IQR) of the data. The solid line represents the median and the dashed line is the mean. The T-shaped lines outside the box are called T-shaped whiskers, going up to factor 1.5 of the IQR (Q3 - Q1).
In Figure 13, the line from Min to Q1 represents the range of the first 25% of data, the IQR the middle 50% of data and the line from Q3 to Max represents the range of the last 25% of data (both without outliers). Any point further than the T-shaped whisker is called an outlier. The box, the range (Max - Min) and the Outliers will be used to analyze each maturity level and components.
For the office questionnaire, the 5 maturity levels (consisting each of 3 components) are stated. Furthermore, the category People & Organization consists out of 5 components. The average scores of each component and corresponding levels from the office are shown by means of box plots in Figures 14 - 19 (Section 3.3.2). For the workshop, the questionnaire was adjusted to validate practical insights. The categories are different compared to the office. There are 7 components, of which one component (Organized work environment 5S) is specified in 5 sub-components (Sort, Straighten, Shine, Standardize, Sustain). This is done since implementing 5S is the very first step regarding Level 1 in the maturity model [44]. The components from People & Organization are identical compared to the office questionnaire. The results are displayed in Figures 20 - 22 (Section 3.3.3).
From the office, only 5 out of 8 employees (62,5%) filled in the questionnaire, making this a relatively small dataset. Although a larger dataset (17 people) was used for the workshop (100% of lathe department employees), it occurred multiple times that certain questions were either not filled in at all or multiple scores were given for the same question. Occasionally, this happened for complete components as well. Furthermore, besides the People & Organization part, the questionnaires had similar components but different questions and statements, making it impossible to create a 1-to-1-comparison. Also, there are both uni- and multi-modal distributions. Taking all this into account, together with the goal to display possible differences between employees regarding different scores (meaning a relatively large spreading of scores), it has been chosen to not dive deep into statistics. For example, calculations and analysis of skewness of datasets or performing in depth statistical analysis are omitted. The box-plots were mainly used to quickly display the differences in given

answers and to focus on the average scores and their spreading (difference in highest and lowest scores). For that reason, it was also decided to not adjust the box plots for skewed distributions [46]. This results in approximations of performance regarding maturity levels mainly based on spreading and averages. So, mainly the averages, the IQR and the total range will be taken into account. In conclusion, the analysis of the data will mainly function as an approximated and practical starting point and eventually recommendations for Hankamp Gears to be used before and during the redesign phase.

3.3.2 Results Office

In Figure 14, the scores regarding Level 1 and its components are shown. Quality Management is the 1st component, Standardized Work is the 2nd component and Professional Work Environment is the 3rd component. For the level and for all components, no outliers are present. The mean values in ascending order: 3rd component (2,96), level 1 (3,11), 1st component (3,12) and 2nd component (3,24). The IQR in ascending order: 1st component, level 1 and 2nd % 3rd component. The spread (difference highest and lowest value, excluding outliers) in ascending order: level 1, 1st component, 3rd component, 2nd component. The 2nd and 3rd component show a wider spread and IQR compared to the 1st component and level 1. The averages are relatively close to each other. Based on the analysis, it is approximated that a solid foundation is applicable for a number of areas and improvement are possible. Overall, the office agrees about quality management, but the opinions are more divided regarding standardized work and a professional work environment.

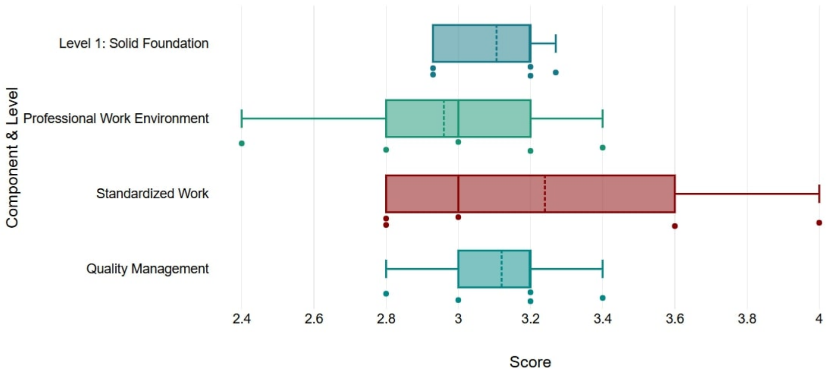

FIGURE 14: Office - Level 1 and components results.

In Figure 15, the scores regarding Level 2 are shown. Work in Progress and Visual Workplace is the 1st component, Short-cyclical Improvements is the 2nd component and Kaizen Events and Go to Gemba is the 3rd component. For the level and for all components, no outliers are present. The mean values in ascending order: 3rd component (2,72), level 2 (3,01), 2nd component (3,08) and 1st component (3,24). The IQR in ascending order: 1st component, level 2 & 3rd component, 2nd component. The spread in ascending order: level 2, 3rd component, 1st component, short-cyclical improvements. The 1st and 2nd component show a wider spread compared to the 3rd component and level 2. The IQR are comparable, where the main biggest difference is between the 1st and 2nd component. The averages are around 3, with the 2nd component an exception closer to 2,5. Based on the analysis, it is approximated that the continuous improvement culture is applicable in a number of areas. Overall, the office opinions about work in progress and visual workplace and about kaizen events are somewhat divided. Regarding the short-cyclical improvements, there is a strong mutual disagreement.

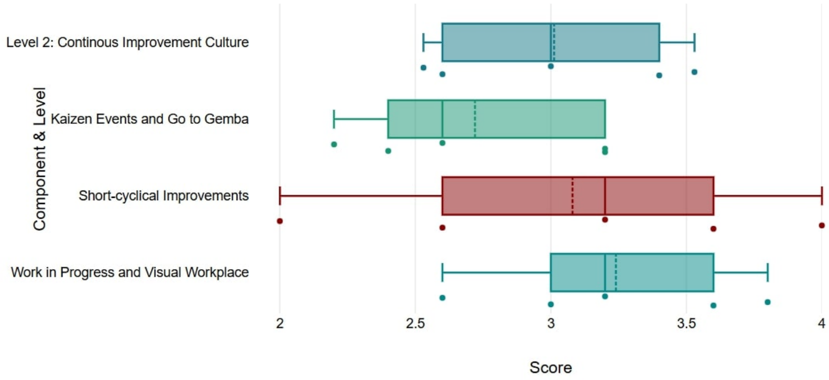

FIGURE 15: Office - Level 2 and components results.

In Figure 16, the scores regarding Level 3 are shown. Risk Management and First Time Right is the 1st component, Elimination of Waste is the 2nd component and Lean Management is the 3rd component. For the 2nd component, there is one higher outlier and for the 3rd component there is one lower outlier. The mean values in ascending order: 1st component (2,64), 2nd component (2,72), level 3 (2,76) and 3rd component (2,92). The IQR in ascending order: 2nd component, 1st component & level 3, 3rd component. The spread (without outliers) in ascending order: 2nd component, 3rd component, level 3 and 1st component. The IQR of the 1st and 3rd component and of level 3 are comparable, but the 3rd component has a low outlier. The IQR is relatively smaller, although the complete IQR is below the average since there is one high outlier. The spreading and outliers indicate that the opinions are divided regarding the components of level 3. Whilst Lean Management is closer to being applicable for a number of areas, is Elimination of Waste closer to being just started. Risk Management is in between and overall is Level 3 applicable for a number of areas, with room for improvements.

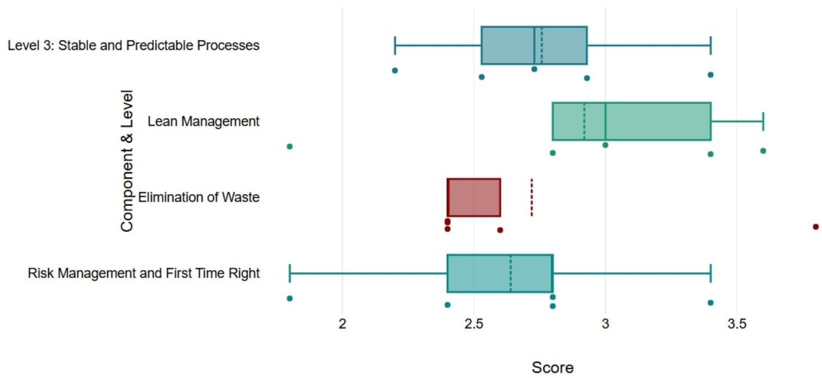

FIGURE 16: Office - Level 3 and components results.

In Figure 17, the scores regarding Level 4 are shown. Lean Six Sigma Organization Culture is the 1st component, Reduction of Variation (Six Sigma) is the 2nd component and (Big) Data Analysis is the 3rd component. For the 1st component, there is one high outlier. For the 2nd component and level 4, there are one low and one high outlier. The mean values in ascending order: 1st component (1,68), 2nd component (1,84), level 4 (2,08), 3rd component (2,72). The IQR in ascending order: 2nd component, level 4, 1st component, 3rd component. The spread (without outliers) in ascending order: 2nd component, level 1, 1st component, 3rd component. (Big) Data Analysis has a large spread, whilst the other components have outliers, so the opinions are divided among the office employees. Overall, (Big) Data Analysis scores best of the components in between being started and being applicable for a number of areas. Reduction of Variation is close to being started whilst the Lean Six Sigma Organization Culture is closer to being not present. Overall, capable processes are started, but limited in presence.

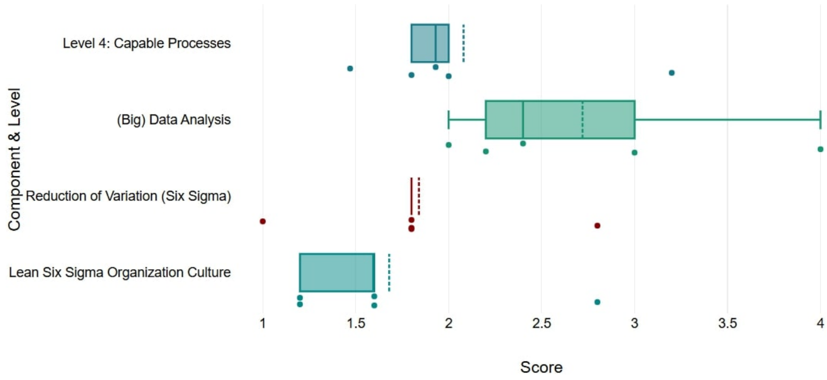

FIGURE 17: Office - Level 4 and components results.

In Figure 18, the scores regarding Level 5 are shown. Product Lifecycle Management (PLM) is the 1st component, Design for Excellence (DfX) is the 2nd component and SMART Industry / Organization 4.0 is the 3rd component. Only for the 3rd component there is one lower outlier, there are no other outliers in the dataset. The mean values in ascending order: 1st component (2,64), 2nd component (2,80), level 5 (2,89), 3rd component (3,24). The IQR in ascending order: 3rd component, level 5, 2nd component, 1st component. The spread (without outliers) in ascending order: 3rd component, 2nd component, level 5, 1st component. The IQR of 2nd and 3rd component and level 5 are comparable in size, whilst the IQR of the 1st component is relatively large. SMART Industry scores best whilst DfX is under and PLM is widely spread. Due to the spreading of the components and the outlier of SMART Industry, the ranges are high and the opinions are divided. SMART Industry is applicable for a number of areas, whilst the other components are closer to being started and being limited in presence. Overall, world class products and services are applicable for a number of areas with possible improvements.

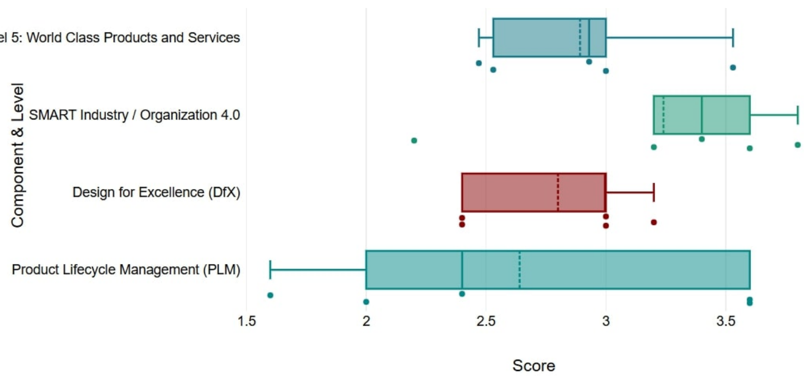

FIGURE 18: Office - Level 5 and components results.

In Figure 19, the scores regarding the category People & Organization are shown, consisting out of the following 5 components: Strategy, Leading, Openness, Learning and

Agility. No outliers are present. The mean values in ascending order: Agility (3,28), Learning (3,36), Leading (3,52), Category People & Organization (3,53), Strategy (3,68) and Openness (3,80). The IQR in ascending order: Leading, Learning & Agility & Category, Openness, Strategy. The spread in ascending order: Leading, Category, Strategy, Learning, Agility, Openness. Leading has the lowest IQR, Learning, Agility, and Category have equal IQRs and Openness and Strategy have relatively large spreading. For all components, the spreading is relatively large. All components, based on the spread, are between being started and being widely applicable. Overall, the category People & Organization scores as applicable, but the opinions regarding the components are widely divided between the office personnel.

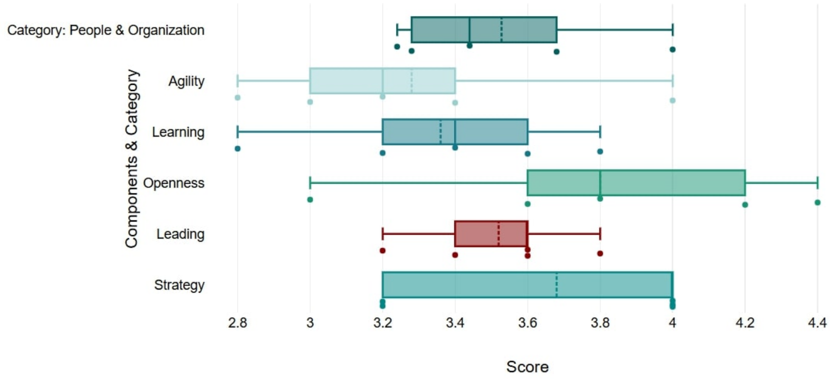

FIGURE 19: Office - People & Organization results.

3.3.3 Results Workshop

In Figure 20, a detailed overview of an Organized Work Environment (5S) is shown, where all components (S1 - S5) are taken into account. S1 has 2 low and 2 high outliers and S2 has 2 low outliers. The mean values in ascending order: S5 (2,84), S2 & S4 (3,06 both), Organized Work Environment (3,16), S1 (3,38), S3 (3,56). The IQR in ascending order: S1, Organized Work Environment, S2 & S3, S5, S4. The spread (without outliers) in ascending order: S1, S3, Organized Work Environment, S2, S4, S5. The IQRs of S1, S2, S3 and the Organized Work Environment are comparable in size, whilst S4 and S5 show a relative larger IQR. Although S1 has the lowest spread, it has the most outliers. The scores clearly display the divided options in the workshop. The 5S components vary from being started and limited in presence to being widely applicable and good in use. Based on the averages, IQRs and spreading, the first three steps of 5S (S1, S2 and S3) are best developed, whilst the other two upcoming steps (S4 and S5) show a wider spread and divided opinions. Overall, 5S is applicable for a number of ares with possible improvements, yet spreading is large and outliers are present.

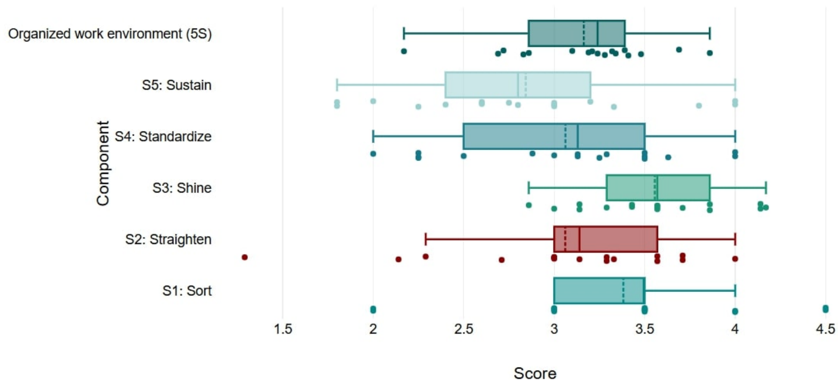

FIGURE 20: Workshop - Components 5S results.

In Figure 21, the other components from the questionnaire are shown. Standardized Work and Documentation is the 1st component, Quality Management is the 2nd component, Evaluation and Audits is the 3rd component, Short Interval Management is the 4th component, Root Cause Analysis is the 5th component and finally Continuous Improvement is the 6th component. The 2nd and 5th component both show 1 lower outlier. The mean values in ascending order: 4th component (2,61), 1st component (2,93), 3rd component (2,98), 5th component (3,06), 6th component (3,08), 2nd component (3,11). The IQR in ascending order: 2nd component, 5th component, 1st component, 4th component, 6th component, 3rd component. The spread (without outliers) in ascending order: 2nd component, 1st component, 5th & 6th component, 4th component, 3rd component. Based on solely the averages, each component is applicable for a number of areas with possible improvements. However, looking at the IQRs and large spread, the opinions are divided. Based on the spread, evaluation and audits and short interval management range from being not present to being widely applicable. Other components lay between being started and being widely applicable.

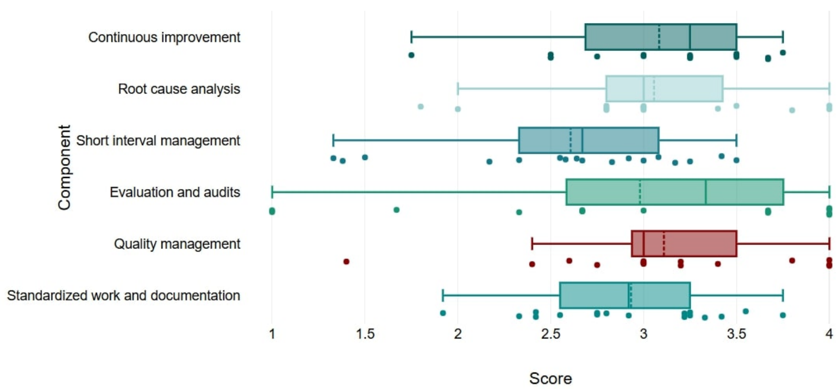

FIGURE 21: Workshop - Other components results.

In Figure 22, the category People & Organization is examined with 5 components: Strategy, Leading, Openness, Learning and Agility. The questions in this category and components are identical to the ones in the office questionnaire. Strategy, Openness, Learning, Agility and People & Organization have one low outlier with the lowest score possible (1) since the questions had to be answered by giving scores of 1, 2, 3, 4 or 5. The mean values in ascending order: Leading (2,52), Agility (2,78), People & Organization (2,83), Strategy

(2,89), Learning (2,91) and Openness (3,01). The IQR in ascending order: Openness, Learning, People & Organization, Agility and Strategy & Leading. The spread (without outliers) in ascending order: Openness, People & Organization, Strategy & Learning & Agility, Leading. On average, the components are close to being applicable for a number of areas. Although, by the wide spread, the opinions in the workshop are divided. For Leading, the range is between not being present to being widely applicable. The other components show options just being started and limited in presence up to being widely applicable. Compared to the results of the office, the workshop is more spread. The maxima of the scores of office are comparable to the maxima of the workshop, but the values of the minima of the office are present in the IQR of the workshop. This can be partly declared by a larger sample size (5 for office and 17 for workshop), but it can also be that workshop thinks more critically about components related to people & organization.

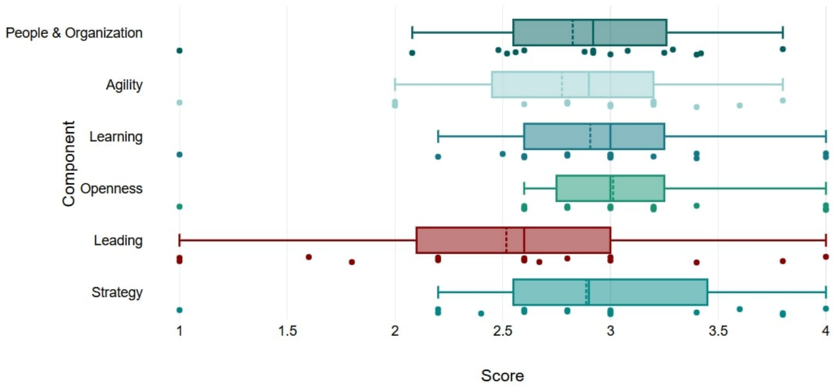

FIGURE 22: Workshop - People & Organization results.

3.4 Answering Sub-Question 2

How can the current situation be described in terms of layout, machines, operators, production steps and readiness for change?
Hankamp Gears has a workshop which can be divided into 11 departments and common space, In each department are machines placed that execute a production step. Since the manufacturing of Hankamp Gears is HMLV and MTO, there is no standard production process. To get an idea, the production sequences from previous production year (2023) was analyzed. This showed that there are already 162 unique combinations regarding the production sequence of the first four production steps. The cumulative percentage of 8 steps was 49,67% and 50,33% was for the other 154 sequences. Mostly, a turning production step is combined with sawing and gear milling. 6 out of 8 production sequences showed a turning step and in the other 154 orders turning was mostly a production step. This indicated the importance and high occurrence of turning in the production step. The lathe department is of interest for this literature research and is divided into 4 smaller departments. In total, 16 lathes are distributed over the smaller departments. Not only lathes, but also other machines are present in 2 out of 4 departments. A total of 17 lathe operators in morning shift, day shift and evening shift are distributed over the lathe department. From a CIMM questionnaire and analysis of the results, Hankamp Gears scores average (3 on scale 1 - 5) on all 5 maturity levels and components related to People & Organization. This would imply that these maturity levels and components are applicable for a number of areas and improvement is possible. Although, when taking into account spreading and outliers of scores, the opinions from office personnel and operators on the

workshop are clearly divided, ranging from scores 2 (started, limited in presence) to 4 (widely applicable, good). Next, in Chapter 4, the analysis of the product data will be discussed.

4 Product Data Analysis

The product data from the previous 5 years of Hankamp Gears is analyzed. First, the work order list is explained (Section 4.1). Then, it is explained how articles of interest were filtered (Section 4.2). A discussion about how these articles were arranged is presented afterwards (Section 4.3), in which more information about half of the production numbers will be stated as well (Section 4.3.1). Next, the method used to decrease a number of lathes to produce articles representing a large portion of production numbers is stated (Section 4.4). This will be extended by taking into account a range of diameters (Section 4.5). The decreased number of lathes needed will be validated (Section 4.5.1) and lastly simplifications of this validation are shared (Section 4.5.2). This Chapter is concluded by answering Sub-Question 3 (Section 4.6).

4.1 Work Order List Explanation

Now that the problem definition and the current situation are known, the next step is to solve the problem step by step. The first step is to analyze historical production data. This production data is in the form of a work order overview. Data from the past five years is used in this research. The used data was retrieved from the ERP system of Hankamp Gears. To properly show and explain the data set, an example is shown in Figure 23. This comes from the actual work order list. Due to confidentiality, the codes of the article number, work order, material article number and used material are changed and thus not the actual codes. This is done as well in the remaining of this report. Furthermore, Figure 23 is separated into two table fragments under each other, where in reality these two table fragments are connected and thus next to each other (indicated by black arrows). This is cut for readability reasons. Table 1 explains what data is present in the data sheet.

Art.nr.	Werkorder	Samenstelling	Bewerking	Bewerking code	Bewerking omschrijving	Aantal	Insteltijd_VoCa
12345-678-90	987654-3-2	0	10	za	Zagen	1000	0,25
12345-678-90	987654-3-2	0	20	dr25a	Draaien 250 staf	1000	2
12345-678-90	987654-3-2	0	30	tf200	Tandwielfrezen K200/KHLC150H	1000	1,5
12345-678-90	987654-3-2	0	40	bw	Bankwerken	1000	0,1
12345-678-90	987654-3-2	0	50	uw35	w3 Harden	1000	0,1
12345-678-90	987654-3-2	0	60	ho	Honen	1000	1
12345-678-90	987654-3-2	0	70	slv	Slijpen Vlak	1000	0,25
12345-678-90	987654-3-2	0	80	mem	Meetkamer met meetrapport	1000	0,25
12345-678-90	987654-3-2	0	90	exp	Expeditie	1000	0,1

Productieuren_VoCa	Insteltijd_NaCa	Prodcutieuren_NaCa	Materiaal art.nr.	Materiaal	Lengte (m)	Begin datum	Eind datum
0,45	0,5	1,2	ABCD12345.67	12xBcXyZ3	0,015	17-3-2021	17-3-2021
40,5	3,63	44,02				23-4-2021	3-5-2021
40,5	0,37	40,8				26-5-2021	2-6-2021
0,1	0,1	0,02				8-6-2021	8-6-2021
2	0,15	2,5				15-6-2021	15-6-2021
22,5	3,25	18,44				18-6-2021	24-6-2021
11,25	0,25	9,5				29-6-2021	29-6-2021
1	0,35	0,8				29-6-2021	29-6-2021
0,2	0,1	0,3				29-6-2021	29-6-2021

Figure 23: Example of work order list for one article.

TABLE 1: Description of data categories present in the analyzed work order overview.

Data	Description
Art.nr.	Code that describes each unique article to be produced
Werkorder	Code that describes job traveler, that is coupled on article numbers
Samenstelling	Number that describes whether article is sub-assembly or main assembly
Bewerking	Number that describes the order of manufacturing steps
Bewerking code	Abbreviation of the manufacturing step, describing which machine is needed
Bewerking omschrijving	Description of the manufacturing step
Aantal	Number that describes what the production amount
Insteltijd_VoCa	Pre-calculated (VoorCalculatie) number that describes how many hours it should take to set-up the machine
Productieuren_VoCa	Pre-calculated (VoorCalculatie) number that describes how many hours it should take to produce all articles at the machine
Insteltijd_NaCa	Number that describes how many hours it took in practice to set-up the machine (NaCalculatie)
Productieuren_NaCa	Number that describes how many hours it took in practice to produce all articles at the machine (NaCalculatie)
Materiaal art.nr.	Code that describes each unique material used for production
Materiaal	Description of the material used
Lengte (m)	Length in meters of the used bars of material
Begin datum	Starting date of production
Eind datum	End date of production

With aid of Table 1 an explanation can be given of Figure 23:

- From *Art.nr.* it can be seen that there is one article, namely *12345-678-90.*
- From *Werkorder*, it can be seen that the article is connected to a work order called *987654-33-2.*
- From *Samenstelling* all *0* can be seen indicating that this part is a complete assembly already. If the number would have been for example *1*, it would be a sub-assembly of another article.
- From *Bewerking* nine columns can be seen, going from *10* to *90.* The lowest number, in this case *10* is the first manufacturing step, followed by *20* and going to eventually *90.* These numbers give the order of manufacturing steps.
- The abbreviations for each manufacturing steps can be seen at *Bewerking code.* Not only is this an abbreviation for the manufacturing step, it is also at the same time the code for the to be used machine. For example, for the second step the *Bewerking code* is *dr25a.*
- From *Bewerking omschrijving* follows that *dr25a* means *Draaien 250 staf.* So, the manufacturing step is turning on a lathe. The machine, the lathe in this case, is *250 staf.*
- The column *Aantal* clarifies that *1.000* articles need to be produced.
- From *Insteltijd_ VoCa* the pre-calculated set-up times in hours of each machine are found. So, for the lathe *Draaien 250 staf* it should take *2* hours to set-up the

machine.

- From *Productieuren_ VoCa* the pre-calculated production time in hours of each machine are found. Again, for the lathe *Draaien 250 staf*, it should take *40,5* hours to produce all *1.000* parts.
- From *Insteltijd_ NaCa* follows that the actual set-up time in practice was *3,63* hours.
- From *Productieuren_ NaCa* the total time it took to produce all *1.000* parts was in practice *44,02* hours.
- From *Materiaal art.nr.* follows that the material article number was *ABCD12345.67* (not actual code) and the material used was *12aBcXyZ3* (not actual code).
- From *Lenght (m)* it is clear that the material was cut to *0.015 meters*.
- From *Begin datum* it can be seen that the manufacturing was started on the 17th of March 2021.
- From *Eind datum* it can be seen that the last manufacturing step was finished on the 29th of June 2021.

4.2 Filtering Articles of Interest

Now that there is a clear understanding regarding the work order list, it is time to narrow down the number of articles to be considered for this research. The example given in Section 4.1 was of only one article, whilst over the past five years 2387 articles have been produced. It might be that not all articles are of interest, so a filtering of articles is the first step. The filtering procedure is displayed in Table 2.

Table 2: After filtering of articles, 1631 out of 2387 articles are of interest for this research.

# of articles	Filtering explanation
2387	All unique articles produced in period 2018-2023
2068	Remaining articles after removing articles that do not require a lathe
1854	Remaining articles after removing articles that used a redundant lathe
1631	Remaining articles after removing articles that will not be produced in future

Since the lathe department needs a redesign, the first logical step is to select only articles that use turning as a manufacturing step. Articles without turning as a manufacturing step do not use a lathe and are thus not of interest.
Now that is known which articles used a lathe, it is important to make a distinction between the used lathes in the past. In Figure 24, all unique machines codes (*Bewerking code*) with their descriptions (*Bewerking omschrijving*) are shown. In total, there are 16 different codes of which 3 codes need special attention. Lathe *dr230* will be retired in the coming months, so this lathe will not be taken into account in the new layout. However, the articles produced on this lathe do need to be taken into account, since another lathe needs to be chosen to produce these parts. Furthermore, according to Hankamp Gears both Lathes *dc* and *dex* are exceptions, so articles made by these lathes do not need to be taken into account.

Bewerking code	Bewerking omschrijving
drint	Draaien Integrex
dr230	Draaien 230
dr35a	Draaien 350 auto
drj200	Draaien int. j200
dr200	Draaien 200msy
dr100	Draaien 100
dr25a	Draaien 250 staf
dr250	Draaien 250

Bewerking code	Bewerking omschrijving
drww	Draaien WW staf
dc	Draaien conventioneel
drq	Draaien Quadrex
dex	Draaien Extern uitb.
dr20a	Draaien 200 auto
drha	Draaien gehard assen
dr500	Draaien 500
dr350	Draaien 350

FIGURE 24: All lathe codes with their description. Red codes need special attention.

Since the work order list is from the past five years, the historical data needs a critical check: it needs to be assured which articles will be kept in production and which articles will not be produced anymore in the future. After a discussion with the account manager from Hankamp Gears, certain types of articles are to be removed from the list: the so called 3C-articles. These type of articles will not be produced in the future and are thus not of interest. The remaining of the articles is approximated to be a realistic product portfolio for the upcoming seven years in accordance with the account manager.
Figure 25 displays the filtering process visually. This also shows the importance of the filtering of articles since 31,7% of articles are not of interest for this conducted research. Once the extensive filtering process of all produced articles is completed, it is time to go more in depth regarding the selected articles of interest.

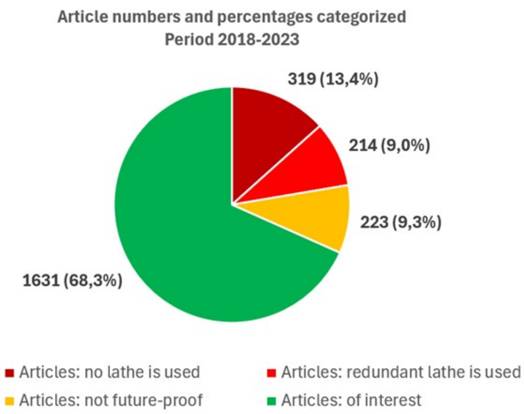

FIGURE 25: Categorized articles with their corresponding number of articles and percentages based on the initial 2387 articles. Only 68,3% (1631 unique articles) are of interest for this research.

4.3 Arranging Articles Based on Diameter and Production Numbers

Now that actually all the articles of interest are known by filtering the work order list based on applicable lathes, the next step is to arrange these articles. This is done by combining the diameter of each material combined with the production numbers. Material arrives in bars to the sawing department, the bars are cut to length and then proceed to the next production step. The diameter of the material, together with the required production steps and capacity of lathes determine which lathe is chosen to manufacture the article. All lathes have a maximum diameter they can handle and each lathe has its own technical capabilities and limitations.

Knowing the diameters and production numbers gives more insight in the lathe production steps. From the material article number and material, the diameter can be derived. In Figure 26, an example is given. Again for confidentially, the actual material article number and type of material are omitted and changed by alternative codes:

Materiaal art.nr.	Materiaal
99999025	x9XxXxXxXx99 99-9 Rond 025 (XXXX 999 Xx)

Figure 26: Diameter can be arranged based on material article number and type of material.

The last numbers of the material article number (*Materiaal art.nr.*) show in this case *025*. Furthermore, the description of the material name (*Materiaal*) states *Rond 025*. This implies that the diameter is 25mm. Since all articles to be considered in this research are known, this procedure of determining the starting diameter of all articles can be repeated. This gives insight in all the different diameters. Then, the articles together with the diameters can be compared to the production numbers.

4.3.1 Half of Production Numbers

Per article, the total number of production numbers was summed. This was arranged, starting with the highest total production numbers, followed by articles with the lower production numbers. Table 3 shows an important insight:

Table 3: Percentage of articles with percentage of production numbers.

# of articles	% of all articles	Production numbers	% of all production
29	1,8%	367.698	50,3%
1601	98,2%	363.842	49,7%

The 29 articles with the highest production numbers, represent 50,3% of total production numbers. This means that only 1,8% of all articles (29 out of 1631) represent about half of the total production numbers. The Top 29 articles with the highest production numbers vary from 53.061 pieces (Part1, green bar) to 3208 pieces (Part29, pink bar), as can be seen in Figure 27. All diameters of each Top 29 articles are shown in Figure 28.
It was a starting point to start looking at the the very few articles that represent half of production numbers. Since there were only a few articles, it was easier to analyze them. In a later stage, it was looked into if this percentage of production numbers could be increased, which was the case as can be read in Section 4.5.

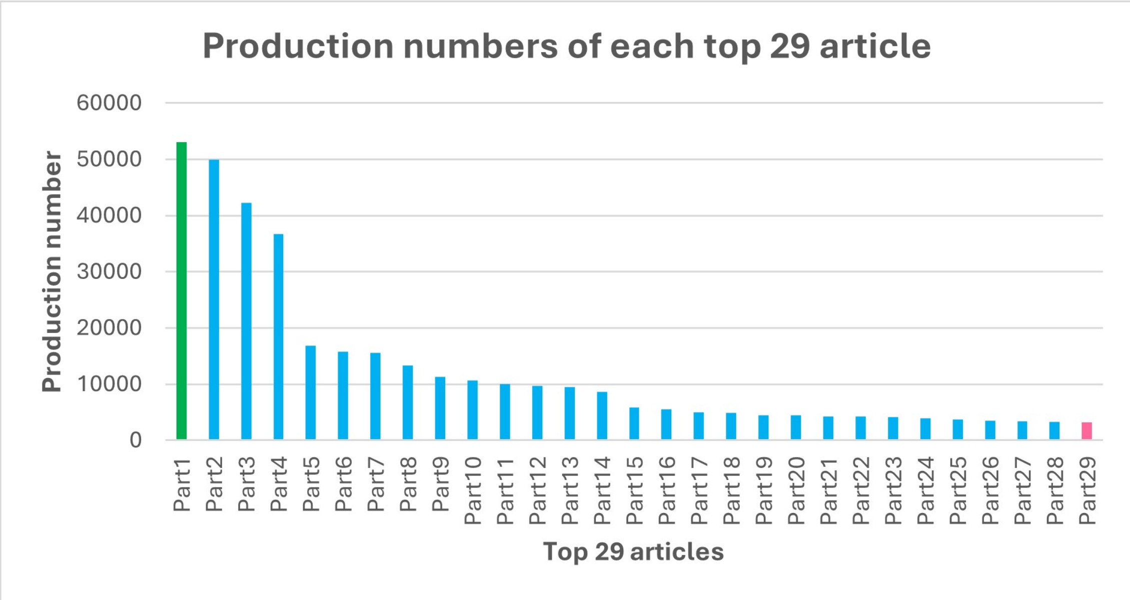

Figure 27: Top 29 articles with highest production numbers.

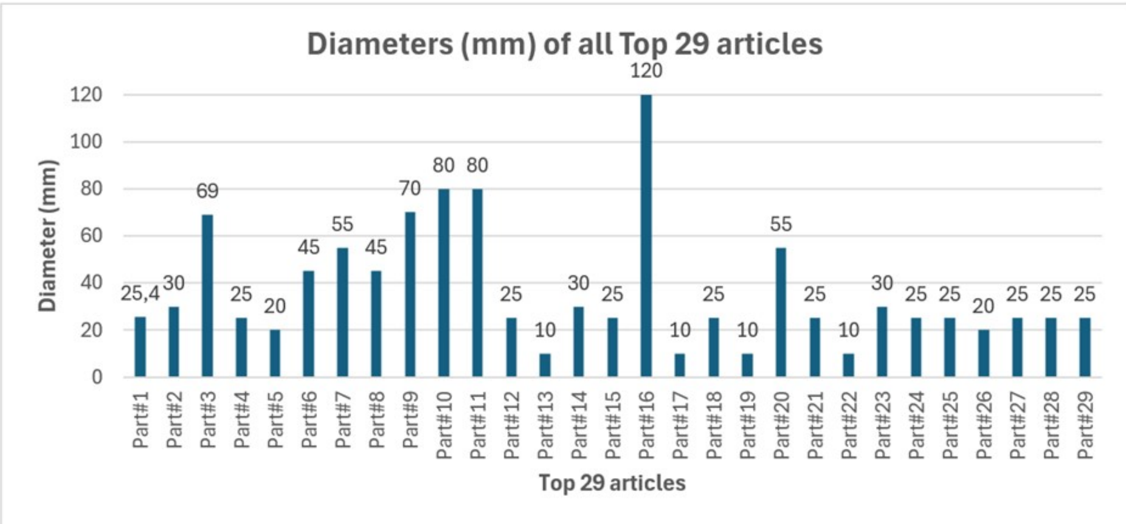

Figure 28: Top 29 articles with their corresponding diameters (mm).

4.4 Decrease Number of Lathes Needed for Top 29 Articles

To start with, first the Top 29 articles are analyzed since these parts represent about half of the total production numbers. It is a possibility that in the past different lathes were assigned to the produce the same part, depending on the article, work order and machine capacity. For example, if a part had to be produced before a certain deadline and a lathe on which it was made normally had no capacity left, another lathe would be used. Since the amount of people will decrease due to retirement, it would be potentially positive if the number of lathes needed to produce the parts would decrease as well. Doing so, the effect of less people could possibly be compensated by also needing less lathes. With this philosophy in mind, the goal was to decrease the number of lathes needed to produce the Top 29 articles. Then, with a minimum number of machines, at least 50,3% of the production numbers can be produced with less operators. For each Top 29 article, unique sequences of manufacturing steps were looked into. In Figure 29, part of the work order list of Part1 is shown. So, by using a minimum number of lathes to produce a relatively low amount of articles (Top 29), still at least half of production numbers can be produced with less operators. The other half of production numbers, representing 98,2% of articles then can be distributed over the other lathes. So, a distinction of lathe usage is made, as can be seen in Table 4.

Art.nr.	Werkorder	Samenstelling	Bewerking	Bewerking code	Bewerking omschrijving
Part1	111111-2-3	0	10	za	Zagen
Part1	111111-2-3	0	20	*dr25a*	***Draaien 250 staf***
Part1	111111-2-3	0	30	tf200	Tandwielfrezen K200/KHLC150H
Part1	111111-2-3	0	40	bw	Bankwerken
Part1	111111-2-3	0	50	uw35	w3 Harden
Part1	111111-2-3	0	60	ho	Honen
Part1	111111-2-3	0	70	mem	Meetkamer met meetrapport
Part1	111111-2-3	0	80	exp	Expeditie

Art.nr.	Werkorder	Samenstelling	Bewerking	Bewerking code	Bewerking omschrijving
Part1	999999-8-7	0	10	za	Zagen
Part1	999999-8-7	0	20	*dr100*	***Draaien 100***
Part1	999999-8-7	0	30	tf200	Tandwielfrezen K200/KHLC150H
Part1	999999-8-7	0	40	bw	Bankwerken
Part1	999999-8-7	0	50	uw35	w3 Harden
Part1	999999-8-7	0	60	ho	Honen
Part1	999999-8-7	0	70	mem	Meetkamer met meetrapport
Part1	999999-8-7	0	80	exp	Expeditie

FIGURE 29: Part1 has different work orders and thus different manufacturing steps (**black**), resulting in different routing for the same article. In this case, the difference in manufacturing steps is the chosen lathe (red). In the past, both lathes *dr100* and *dr25a* were used.

From Figure 29, it becomes clear that in the past not one, but two lathes were used to produce the part. This means, that both lathes could produce the part. To decrease the number of lathes needed in production, it was counted how often lathes *dr25a* and *dr100* were used. The lathe that was used most of the time, was chosen. For Part1, looking at all work orders and all unique manufacturing steps, lathe *dr25a* was used most often and thus chosen. In this case, by only assigning articles to lathe *dr25a*, not two lathes but only one lathe is needed for production. To check if there would be no overcapacity, the machine hour capacity was looked into as well in Section 4.5.1. This procedure was repeated for all Top 29 articles and the result is shown in Table 4:

Table 4: Type of lathes used before and after selection procedure for Top 29 articles.

13 (out of 14) lathes used before procedure	dr100, dr200, dr20a, dr230, dr250, dr25a, dr35a, dr500, drha, drint, drj200, drq, drww
Only 6 lathes used after procedure	dr100, dr20a, dr250, dr25a, drint, drq

4.5 Decrease Number of Lathes Needed for Range of Diameters

The fact that the number of needed lathes for the Top 29 articles is decreased is a good start, but not good enough. Regarding the layout, the original idea was to place these lathes closely together. By doing this, a specialized cell is created. The idea was to design this specialized cell such that with a minimum number of operators, this specialized cell is operated. By doing so, with fewer people, at least 50,3% of the production numbers can be made. Although the assumption was validated that the filtered articles are a proper representation of the product portfolio for the upcoming 7 years, this is only based on 1,8% of the articles (Table 3). Imagine that still a portion of the articles is not made in the future anymore, then the specialized cell is based on less than 50,3% of the production numbers. To create more assurance, more articles are needed to create a higher redundancy rate.
To do this, the known diameters from the Top 29 articles (Figure 28) are used. The range is 10 - 120 mm. Instead of only choosing the Top 29 articles in this diameter range, all articles are chosen. Again, for each unique diameter, it was checked with the same selection procedure what lathes were used in the past. By repeating this procedure now with all unique diameters, the same lathes could be used as well. That means that in theory, all articles with a range of 10 - 120 mm can be manufactured with the six selected lathes. After that, per selected lathe the maximum diameter of articles were checked. From this scan, the range of diameters increased up to 150 mm. This means that 37,8% of articles with a range of 10 - 150 mm (representing 91,0% of all production numbers) can be produced by the six selected lathes. At least, in theory. Such a statement needs validation.

4.5.1 Validation Decreased Lathes

The first actual validation is already in the work order list: if in the work order a lathe is used in the past, this means that this lathe is applicable. To make sure this is indeed the case and that the lathes are varied enough to produce articles with a range of diameters, the technical service manager was incorporated. The range of diameters was stated, together with the group of six different lathes. During a discussion with the technical service manager of Hankamp Gears, indeed it was confirmed that this range of lathes are varied enough and applicable to produce articles with the given range of 10 - 150 mm.
The second validation was to check machine capacity. If the number of lathes needed is decreased, the needed machine hours of the chosen lathes is increased. A check was needed to calculate whether the lathes still have enough capacity in machine hours to produce all articles. Within the given diameter range, per unique diameter it was looked at what articles have such unique diameter. Then, per article, all unique manufacturing sequences from the past including lathes were analyzed. After this, depending on the chosen lathe from the group of six lathes, the capacity was compensated for regarding setup and production times. See Figure 30 for an example:

1X-2234
za - **dr100** - dc - wwa - bw - slbuauto - frun - frun - slbuauto - bw - mem
za - **dr100** - frww - bw - mez - frww - mez
za - **drq** - uw32 - bw - slbuauto - frun - frun - slbuauto - bw
za - **drq** - uw32 - bw - slbuauto - frun - frun - slbuauto - bw - mem
za - **drq** - wwa - bw - slbuauto - frun - frun - slbuauto - bw - mem
za - **drww** - uw32 - bw - slbuauto - frun - frun - slbuauto - bw - mem
za - **drww** - uw32 - slbuauto - frun - frun - slbuauto
za - **drww** - uw32 - slbuauto - frww - frww - slbuauto

FIGURE 30: Article *1X-2234* with it's 8 unique manufacturing sequences from the past of which 2 sequences used lathe *dr100* (yellow), 3 sequences used lathe *drq* and 3 sequences used lathe *drww*.

Each abbreviation, such as *za* is a manufacturing step and machine. In this example, article *1X-2234* has 8 unique sequences of manufacturing steps. From these sequences, three lathes are used. For this article, lathe *drq* was selected to produce the part (pink), since this lathe is part of the six selected lathes. This means that lathe *dr100*, who is also part of the six selected machines (yellow), gets more capacity since article *1X-2234* is now only to be produced on lathe *drq*. The same holds for lathe *drww* that is not part of the six selected lathes (white): this lathe gets more capacity, since the article is not produced at this lathe anymore. So, the production numbers regarding article *1X-2234* decrease to 0 at lathes *dr100* and *drww*. But, these production numbers are added to the already existing production numbers at lathe *drq*. In Figure 31 this can be shown:

Dia	Productieuren_VoCa	Insteltijd_VoCa	Instel+Prod_VoCa	Aantal	Aantal NIEUW	Ratio aantal N/O	NIEUW_Instel+Prod_VoCa
15							
1X-2234	101,64	21	122,64	1525	3611	2,37	290,66
111.11	30	3	33	300	x	x	x
222.22	30	3	33	300	x	x	x
XY987-65432	13,33	1	14,33	100	x	x	x
A478442	13	3,5	16,5	150	x	x	x

FIGURE 31: For lathe *drq*, 5 articles (article of example is green) with diameter 15mm (blue) are produced with corresponding Setup times (*Insteltijd_ VoCa*) and Production times (*Productieuren_ VoCa*).

So, by checking all lathes used in the past and summing these production numbers of article *1X-2234*, in this case the old production amount (*Aantal*) was 1525. Since other lathes are not used anymore (*dr100* and *drww*), this production number increases to 3611. The ratio (2,37) of new production numbers compared to old production numbers was multiplied with the total VoCa time (setup and production). In this case, the total time increased from 122,64 hours to 290,66 hours. All other articles have no time increase, since they were already planned on lathe *drq*. This procedure was repeated for each article in the range of 10 mm - 150 mm.
In the period 2018-2023, in total 12.600 hours are available per machine, see Table 5:

TABLE 5: During period 2018-2023 the number of available hours was 12.600 for a machine.

Hours/week	Weeks/year	Years/period	Total hours
63	40	5	12.600

Previously, 6 lathes were selected. Actually, in total there are 7 lathes, since Hankamp Gears owns two identical lathes, namely lathe *drq*. So, based on Table 5, the total available hours per type of lathe from period 2018-2023 are shown in Table 6:

TABLE 6: Total available hours during period 2018-2023, specified per selected lathe.

Type of lathe	# of lathes	Total available hours 2018-2023
DRQ	2	25.200
DR250	1	12.600
DR100	1	12.600
DR25A	1	12.600
DRINT	1	12.600
DR20A	1	12.600

The total increased production hours for the six selected machines (selection procedure, Figures 30 and 31) were compared to the maximum capacity of the machines (Table 6). This functions as a validation to check if, besides the technical capabilities of the lathes, the articles can be made by the lathes in terms of available production hours. This is displayed in Figure 32:

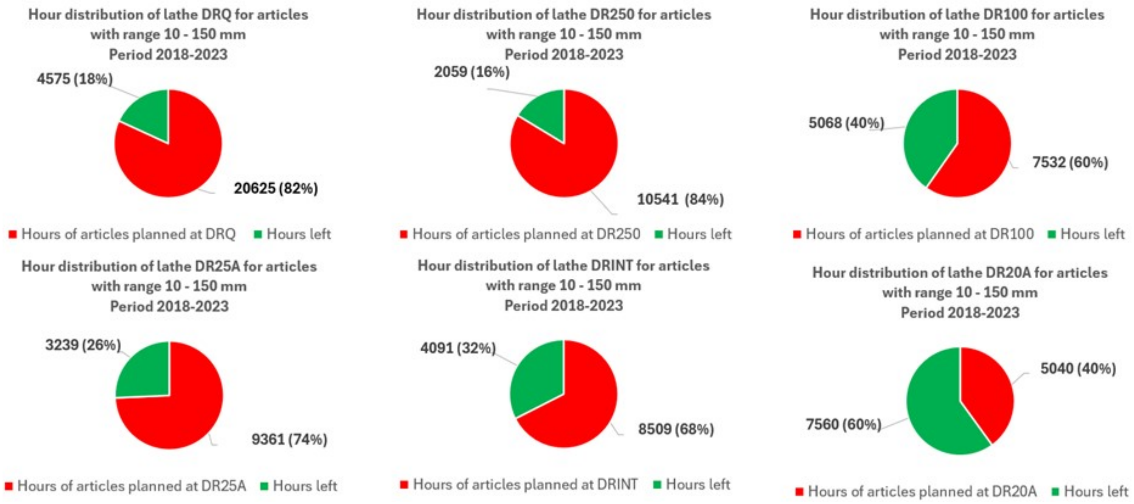

FIGURE 32: Machine hour distribution for six types of lathes selected.

From Figure 32 it becomes clear that all selected lathes have enough machine hours capacity to produce all parts selected. Now, it is validated that based on machine capabilities and machine production hours, the selected 37,8% of articles (representing 91,0% of production numbers) can indeed be manufactured on the six selected lathes. Since Hankamp Gears owns two identical lathes *drq*, the number of lathes needed and used is seven. It was checked too if all other 62,2% of articles, representing 9,0% of production numbers, can be made on the other machines regarding capacity. The result can be seen in Figure 33 that concludes that also the other lathes have enough capacity for the production of all the other articles. These articles have a diameter bigger than 150 mm.

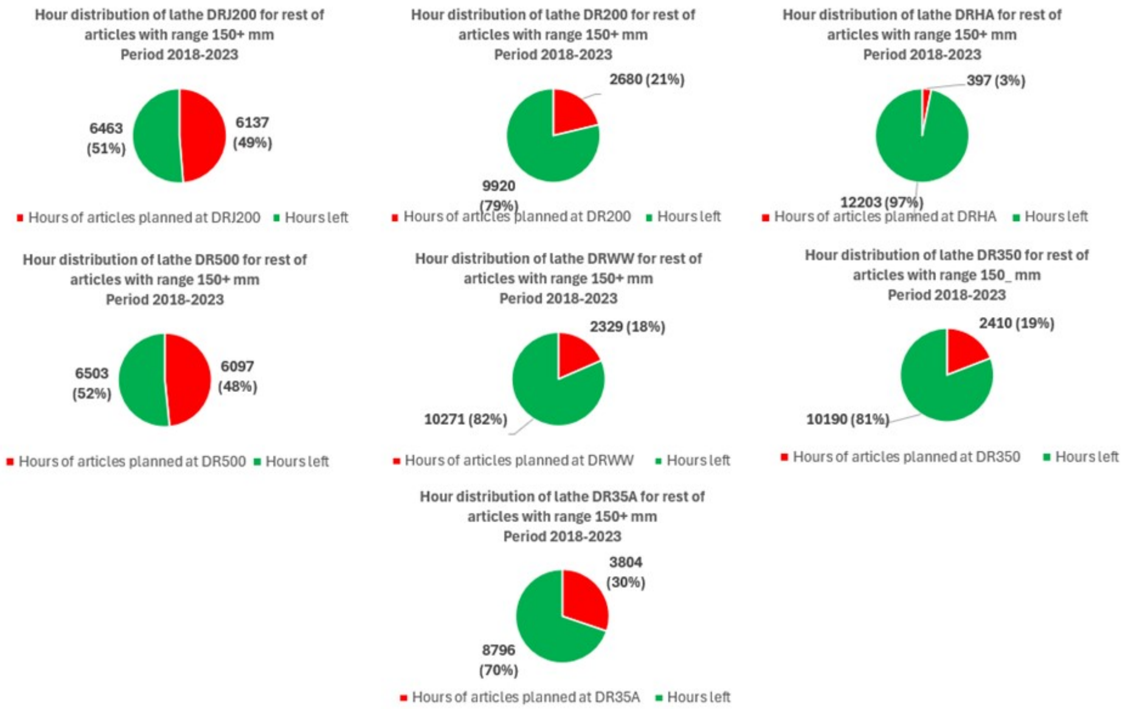

FIGURE 33: Machine hour distribution for other 7 types of lathes that produce the rest of the 9,0% of articles, representing 62,2% of production numbers.

4.5.2 Simplifications in Validation

In the validation process, several simplifications were made, which explain why only half of lathes (7 out of 14) are needed to produce 91,0% of production numbers. First of all, by selecting less lathes, the setup time decreases. For example, if before three lathes were selected at the same time and now one lathe, the setup time decreases. In that case, not three lathes need to be setup thus costing setup hours, now only one lathe is to be setup. Furthermore, the VoCa times are used and not the NaCa times (Table 1). VoCa times are based on different calculations performed by Hankamp Gears together with implementing calculation tools, their experience, expertise and by taking into account comments and practical experiences from the operators. That makes the VoCa time a theoretical realistic production time. The NaCa times are the actual times from practice. The NaCa and VoCa times are most of the time not identical. In some cases, NaCa times are faster than the VoCa times, but they can take longer as well. This is dependent on many factors, like operator efficiency, number of operators available, maintenance of machines, performance of machines and clocking behavior. Productivity of operators can change each day, resulting in different operator efficiencies. Due to free days or calling in sick, the number of operators available can change. Over time, machines might give errors, need to be checked, need maintenance or break down. If an operator forgets to clock in or out or shows inconsistent clocking behavior, the NaCa times are not representative anymore since these NaCa times are based on the clocked times via de computer system of Hankamp Gears. All these reasons make the NaCa times less favorable to use compared to the VoCa times. During the validation, it was simplified that all operators are always present, they work as efficient as they can, machines do not break down or need maintenance and the VoCa times are all met. These simplifications certify why each lathe has overcapacity (Figures 32 and 33).

4.6 Answering Sub-Question 3

Are all articles in the product portfolio of interest or can a distinction be made that separates possible articles of interest and articles not of interest?
No, not all articles in the product portfolio were of interest. The product portfolio from the previous 5 years, period 2018-2023, was used in this research. The product portfolio could successfully be understood and analyzed by understanding the work order list. Out of all articles produced from 2018-2023, 68,3% (1631 articles) is of interest for this research since articles that do not require a lathe, use a redundant lathe or will not be produced in the future are removed. The articles of interest were filtered based on diameter and production numbers, resulting in a Top 29 article list representing 1,8% of articles and 50,3% of production numbers. These 29 articles have a diameter range of 10-150 mm. To extend the production number percentage, all articles with the given diameter range were analyzed. All articles with diameter range of 10-150 mm, representing 37,8% of articles and 91,0% of production numbers, can be produced using only 7 out of 14 lathes. This was the result of an analysis by checking which lathes were used for which diameters and articles in the past. For that reason, these 7 lathes will be placed in a specialized cell to concentrate on producing a large portion of production (91,0% of production numbers), whilst the other 9,0% of articles representing 62,2% of production numbers with diameter larger than 150 mm will be produced by the other 7 lathes. All lathes are checked regarding production hour capacity and each lathe has overcapacity. These conclusions were achieved by data analysis. Next, in Chapter 5, the lathe operators are incorporated by organizing brainstorm sessions.

5 Incorporation Lathe Operators

A great first step regarding the redesign of the layout was performed by analyzing the work order list, filtering the articles of interest, arranging the articles based on diameter and production numbers, decreasing the number of lathes needed to produce 91,0% of production numbers and validating the selected lathe cell. With this philosophy, if these lathes would be placed in a cell and the number of operators is minimized in this cell then with fewer people Hankamp Gears can at least keep producing 91,0% of their production numbers. The next step is to incorporate the lathe operators of Hankamp Gears. Brainstorm sessions were organized to actively incorporate the lathe operators in a quick and above all practical manner. First, details about the organized brainstorm sessions are stated (Section 5.1). Second, more information regarding participation is explained (Section 5.2). Then, an analysis of each held conversation is stated (Section 5.3). In this analysis, distances between machines in the made layouts (Section 5.3.1), scaling factor matrix (Section 5.3.2), machine couples (Section 5.3.3) and a machine orientation based on averaged scaling factors (Section 5.3.4) are discussed. Lastly, this Chapter is concluded by answering Sub-Questions 4 (Section 5.4) and 5 (Section 5.5).

5.1 Brainstorm Sessions

The goal was to get to know how operators would redesign the layout. Based on what criteria would they place the machine? Would they make machine couples? Should certain machines be close to each other? Do they want one lathe department or multiple smaller lathe departments as is done now? Once that would be known for each operator, the next main question was if there would be similarities between the made layouts and if machine groups could be made.

The operators are helpful, but also practical and above all busy men. To encourage them to take part in this research, a practical and easy way was found to let them think about the redesign of the layout. The layout was printed on paper. Using that scale, machines were cut out of carton after which the cartons were put on magnets. By placing the printed layout and magnets on a whiteboard, machines can be moved around the printed layout creating. This way, for each operator it is rather easy, straight-forward, and quick to visualizes how they would design their own ideal lathe department layout. This enhanced their creativity and encouraged them to participate. Figure 34 shows the first version. Later, the layout was left partly blank and the cartons were put on magnets.

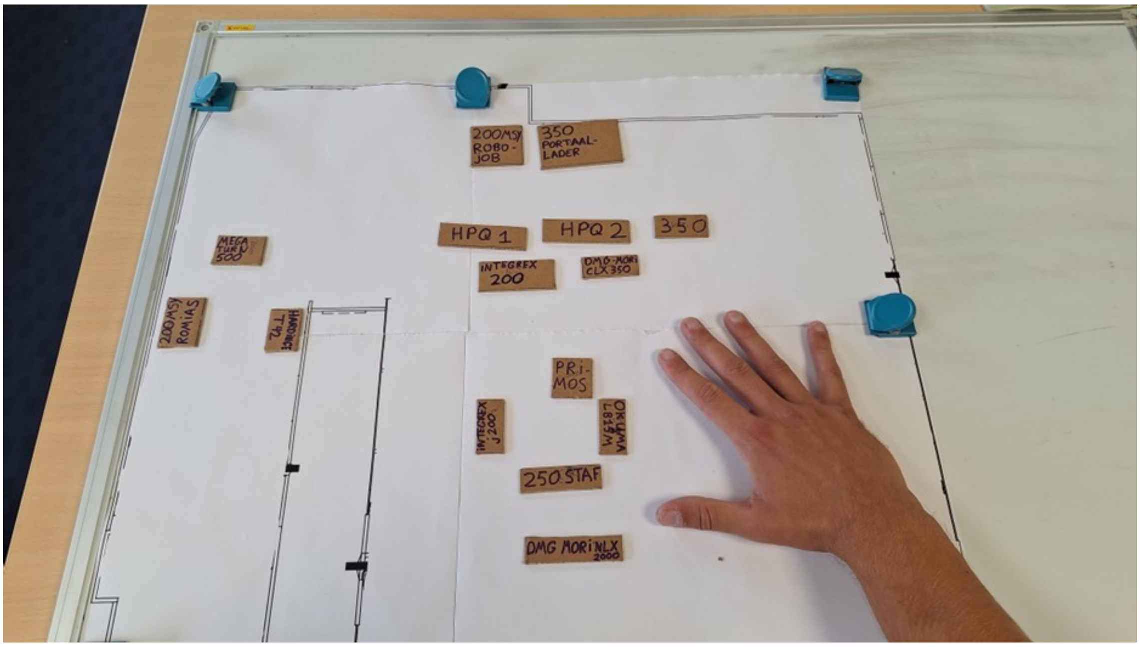

FIGURE 34: First version, complete blank layout was printed and put on whiteboard together with scaled cartons representing machines with their names written on. Machine locations are from the current layout. Hand for scale.

After setting up the whiteboard with the layout, machines and magnets, brainstorm sessions could be held with the operators. Part of the layout was made blank, representing space to rearrange the lathes. All other machines (not lathes), were omitted as well as one wall. This was done to enhance creativity and simplify the problem. By doing so, operators only had to focus on the lathes, which is exactly what is desired.
All 15 lathe operators at Hankamp Gears were given the opportunity to participate in this brainstorm session. Each brainstorm session was performed 1 on 1, so without the other lathe operators. The reason behind this was to not let the lathe operators be influenced by other operators. To ensure safety for the operators and to make sure everyone was honest and open, the results collected were anonymous. No names regarding made layouts were displayed or given. By using a practical way, the whiteboard with magnets and carton boards was brought to the workshop and at the location the operator was working at that moment, the brainstorm session was held. This graduation assignment was explained shortly together with the goals of this brainstorm session. Also, it was asked if operators would give permission to sound-record this brainstorm session. All operators were given a chance to participate, give their opinions and truly speak up.

5.2 Participation and Permission

A total of 17 lathe operators were working at Hankamp Gears during the start of this Master's thesis. Based on that number, the future-proof concept was made: if 4 out of 17 leave the company due to retirement, then with 13 operators Hankamp wishes to keep the same production by a redesign of the layout. Although, not 17 lathe operators but only 15 participated during the time of the brainstorm sessions. That is because 2 lathe operators left the company. The outcomes regarding collecting information from all 15 of the operators is summarized below. To start with, the participation of lathe operators is listed below. To ensure anonymity for the lathe operators, not their names but simply numbers ranging from 1 to 15 are used:

- Operators 1 - 15 agreed to participate in this brainstorm session
- Operators 1, 3 - 9 & 11 - 14 gave permission to make a voice recording of the conversation
  - Since the conversations of Operators 2, 10 & 15 were not voice recorded, handwritten notes were made instead
- Operators 1, 3 - 12 & 14 made a layout using the whiteboard

5.3 Analysis Conversations

First, the conversations were analyzed. For the conversation noted by hand, the most important points were summarized. For the voice-recorded conversations, each conversation was transcribed. Then, the transcription was read and summarized. It was the goal to get to know the logic behind making layouts by operators and mainly knowing if certain machines should be placed close to each other and why that would be the case. If that is known, then for the future-proof layout certain machine groups or couples can possibly be made. Table 7 summarizes the analysis of all conversations during the brainstorm session for each operator.

From the analysis, the following was perceived:

- Although not all operators made a layout, every operator shared their thoughts and opinions about redesign
- Each created layout from the operators was unique layout: no layout was exactly the same
- One large lathe department is desired over multiple, smaller lathe departments spread across the workshop
- Lathes that produce large diameters need to be close to each other
- Lathes with comparable operating systems need to be close to each other
- Lathes with barstockfeeder need to be close to each other
- A balance between lathes operated by hand and lathes that are less labor intensive/can be used automatic is needed
- Machine couples can be made based on placed machines (see Section 5.3.1)

Table 7: Summarized comments of each Operator regarding redesign of the lathe department based on conversations held during brainstorm sessions.

Operator	Results
1	Combine lathes operated by hand (labor intensive) with lathes that are least laborious.
2	**No layout was made**, yet comments were given. Importance lays in rotating of people, team work, standardized setup instructions, flexibility, having one lathe department and address each other regarding one clear work standard.
3	Large diameters and heavy articles close to each other. Lathes with barstockfeeder close to each other. Other lathes: distribute lathes operated by hand with automatically operated lathes.
4	Large diameters close to each other, comparable operating systems close to each other, least laborious lathes close to each other and combination with barstockfeeder lathes.
5	Comparable operating systems close to each other, barstockfeeder lathes close to each other, lathe *drha* next to lathe *dr500*.
6	Comparable operating systems close to each other, large diameters close to each other.
7	Barstockfeeder lathes close to each other, large diameters close to each other, comparable lathes close to each other, diameters with hardened final machining close to each other: lathes *drha* and *dr20a*.
8	Automatic lathes close to each other and combined with lathes operated by hand, large diameters close to each other, specialistic work close to each other, comparable lathes/operating systems close to each other.
9	Lathes that are used for final machining close to each other, combination automatic and hand, combination barstockfeeder lathe and hand lathe.
10	Large diameters close to each other, lathes *drint* and *drj200* close to milling department, comparable operating systems close to each other, lathes by hand combined with automatic lathes.
11	Barstockfeeder lathes close to each other, robots/automatic lathes close toe each other, spread rest of lathes in department, comparable lathes/operating systems close to each other.
12	Similar lathes/operating systems close to each other, automatic close to each other.
13	**No layout was made**, yet general comments were made. More room for material storage and central storage point.
14	Comparable manufacturing steps close to each other, comparable lathes close to each other, barstockfeeder lathes close to each other, robot lathes close to each other, specialistic work close to each other.
15	**No layout was made**, yet comments were given: exact layout too difficult to state, think about difference in machine types namely barstockfeeder lathes, automatic/loader and lathes operated by hand. Two options. Option 1: sets of loader and hand lathes with Machine/Operator (M/O) ratio 2/1. Option 2: barstockfeeder lathes combined with loaders/automatics with M/O ratio 3/1.

5.3.1 Distances Between Machines in Made Layouts

The next step was to analyze the made layouts on the whiteboard with the magnets and cartons. Since each layout was different from each other, somehow possible similarities needed to be researched. To do this, it was decided to measure all distances from center to center of each machine. This was done for all layouts. By doing so, per layout, it was known which machines were placed closest to each other. To help the operators, the codes of lathes used earlier (see Figure 24) were changed to the actual names of the lathes. The names of the machines are better known by the operators rather than abbreviations used in the work order list. The comparison between the codes used for the lathes and the names used in the brainstorm session are displayed in Table 8:

TABLE 8: Previously used lathe codes with their corresponding names used in the brainstorm sessions.

Lathe code	**Lathe name**	**Lathe code**	**Lathe name**
drint	INTEGREX 200	dr35a	350 PORTAALLADER
drj200	INTEGREX J200	dr200	200 MSY ROMIAS
dr100	PRIMOS	dr25a	250 STAF
dr250	200 MSY ROBOJOB	drww	DMG MORI NLX 2000
drq	HPQ1 and HPQ2	dr20a	DMG MORI CLX 350
drha	HARDINGE T42	dr500	MEGATURN 500
dr350	350		

To properly explain what has been done with the operators, one layout is chosen to give an example. All made layouts by the operators can be found in Appendix 9.3. For each layout, every machine (carton board) was marked with a dot in the center of the carton board. Then, all possible relative distances (from dot to dot) of each machine were measured with a ruler. Figure 35 displays a distance measured for one of the made layouts between two lathes:

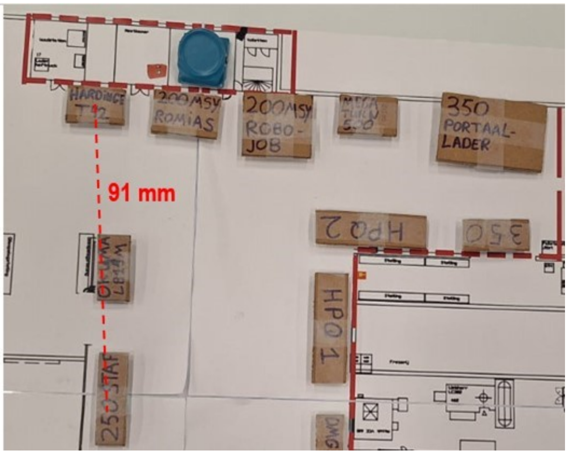

FIGURE 35: Part of layout made by Operator 3, where the relative distance from lathes *250 STAF* and *HARDINGE T42* is 91 mm.

A distance matrix was made to display all distances between all machines. Figure 36 displays the completely filled in matrix, where all distances between all machines in mm are shown (in this case as an example for layout of Operator 3):

	PRIMOS	200 MSY ROBOJOB	250 STAF	DMG MORI CLX350	200 MSY ROMIAS	DMG MORI NLX2000	INTEGREX 200	MEGATURN 500	HARDINGE T42	INTEGREX J200	350 PORTAALLADER	HPQ 1	HPQ 2
350	144	78	130	165	104	88	129	57	131	166	33	58	41
PRIMOS		126	31	61	122	69	74	141	121	32	162	87	114
200 MSY ROBOJOB			100	173	28	108	152	28	56	158	67	66	45
250 STAF				90	92	71	93	117	91	62	144	71	94
DMG MORI CLX350					175	79	44	181	179	39	192	117	148
200 MSY ROMIAS						119	161	57	28	153	95	81	68
DMG MORI NLX2000							46	109	133	83	114	44	73
INTEGREX 200								154	171	69	157	90	119
MEGATURN 500									83	170	40	65	36
HARDINGE T42										153	123	100	93
INTEGREX J200											123	100	93
350 PORTAALLADER												77	49
HPQ 1													31

FIGURE 36: Distance matrix of layout from Operator 3. For example, distance between lathes *250 STAF* and *HARDINGE T42* is 91 mm (pink colored).

In the distance matrix, different colors can be seen. Conditional formatting was used, where the lowest values get a green color and the highest values get a red color. This was implemented to make it easier to manually visualize if patterns were present. The color scale is displayed in Figure 37:

28	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	192

FIGURE 37: Conditional formatting color scale used for layout of Operator 3, where lowest value is 28 mm and highest value is 192 mm.

5.3.2 Scaling Factor Matrix

This procedure, so measuring each relative machine and filling in the distance matrix, was repeated for all made layouts. The idea was to compare the distance matrices to search for any patterns or similarities. However, in order to do that the distance matrices need to be changed into scaling factor matrices. The reasoning for scaling factors was, as the name suggests, because of scaling. Each taken photograph of the layout has a different scale. Each whiteboard was located at the workbench next to the machine whilst the operator was at work. When taking pictures, there was no fixed distance between the whiteboard and the mobile phone which took pictures. The effect is that each photo has a different scale as can be seen in Figure 38. To compensate for the differences in scale and to make a fair comparison between the matrices, all distance matrices were changed into scaling factor matrices.

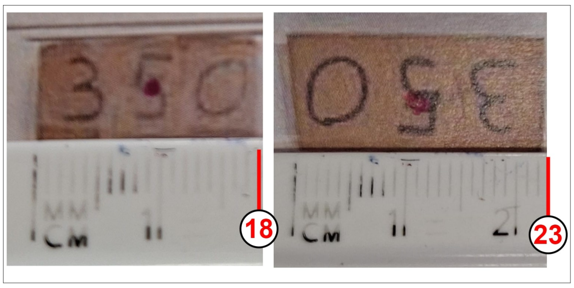

FIGURE 38: Two carton boards (machine *350*) are compared were the scale difference is clear: the machine on the left has a length of 18 mm, whilst the same machine on the right has a length of 23 mm.

Equation 1 states how the scaling factor (SF) is calculated and the corresponding variables are found in Table 9:

$$SF = 1 + \frac{(d - d_{min}) * 99}{d_{max} - d_{min}} \tag{1}$$

Table 9: Variables explanation of Equation 1.

SF	d	d_{min}	d_{max}
Scaling Factor	distance	minimal distance	maximal distance

By using Equation 1, the lowest distance in the distance matrix is transformed in the lowest scaling factor, namely 1. The highest distance in the distance matrix is transformed in the highest scaling factor, namely 100. All other distances are in between 1 and 100. By filling in the values from Figure 36 (Distance Matrix) in Equation 1, the Scaling Factor Matrix is the result as can be seen in Figure 39. Now indeed the lowest distance value (28) is transformed in Scaling Factor 1, the highest distance value (192) is transformed in Scaling Factor 100 and the initial value of 91 mm in transformed in 39,0.

	PRIMOS	200 MSY ROBOJOB	250 STAF	DMG MORI CLX350	200 MSY ROMIAS	DMG MORI NLX2000	INTEGREX 200	MEGATURN 500	HARDINGE T42	INTEGREX J200	350 PORTAALLADER	HPQ 1	HPQ 2
350	71,0	31,2	62,6	83,7	46,9	37,2	62,0	18,5	63,2	84,3	4,0	19,1	8,8
PRIMOS		60,2	2,8	20,9	57,7	25,8	28,8	69,2	57,1	3,4	81,9	36,6	52,9
200 MSY ROBOJOB			44,5	88,5	1,0	49,3	75,9	1,0	17,9	79,5	24,5	23,9	11,3
250 STAF				38,4	39,6	27,0	40,2	54,7	39,0	21,5	71,0	27,0	40,8
DMG MORI CLX350					89,7	31,8	10,7	93,4	92,2	7,6	100,0	54,7	73,4
200 MSY ROMIAS						55,9	81,3	18,5	1,0	76,5	41,4	33,0	25,1
DMG MORI NLX2000							11,9	49,9	64,4	34,2	52,9	10,7	28,2
INTEGREX 200								77,1	87,3	25,8	78,9	38,4	55,9
MEGATURN 500									34,2	86,7	8,2	23,3	5,8
HARDINGE T42										76,5	58,3	44,5	40,2
INTEGREX J200											58,3	44,5	40,2
350 PORTAALLADER												30,6	13,7
HPQ 1													2,8

Figure 39: Scaling Factor Matrix of layout from Operator 3. SFs of 1, 39,0 and 100 are circled red.

In Sections 5.3.1 and 5.3.2, an example was given for one operator, namely Operator 3. The procedure described in this example was done for all 12 operators. This resulted in 12 different distance matrices, which were transformed into 12 different scaling factor matrices. All these 12 different scaling factor matrices were combined into 1 scaling factor matrix. Now, in one matrix, all scaling factors, from each machine combination, from each operator, were visible. For readability, this complete matrix can be found in Appendix 9.4. To properly explain how this combined scaling matrix works, part of the combined scaling matrix will be shown and explained, see Figure 40. Each number in the matrix represents the Scaling Factor of each operator. Since Operators 1, 3 - 12 and 14 made a layout, this order is used:

	PRIMOS												200 MSY ROBOJOB											
350	25,2	71,0	89,4	60,0	55,7	90,4	90,8	74,6	48,7	15,0	38,3	59,8	23,0	31,2	54,9	27,2	8,7	76,6	43,2	80,3	52,3	100,0	64,4	52,4
PRIMOS													13,7	60,2	20,5	63,6	36,1	8,2	38,6	4,8	44,0	79,0	73,3	27,0
200 MSY ROBOJOB																								

Figure 40: Part of Combined Scaling Matrix is shown. Scaling Factors are explained as an example for lathes *350* and *PRIMOS*. Each Scaling Factor is from a different Operators.

From Figure 40, the example is about the Scaling Factors of lathes *350* and *PRIMOS*. From the layout made by Operator 1, the Scaling Factor of both lathes is 25,2 , so the lathes are placed relatively close to each other. Operator 11 placed these lathes even closer to each other, with the lowest Scaling Factor of 15,0. On the other hand, Operator 4 and

Operator 7 gave almost the highest SFs (89,4 and 90,4 , respectively) whilst Operator 8 gave the actual highest SF number, namely 90,8. So, these operators placed these lathes furthest away from each other. For each lathe combination, each scaling factor from each operator is known. Now, it is time to see if machine couples and similarities can be found, which will be described next in Section 5.3.3.

5.3.3 Machine Couples

Now that all Scaling Factors are known for each lathe combination made by all operators, possibly similarities can be found resulting in lathe couples. The lowest Scaling Factors are the most interesting: the lower the Scaling Factor, the closer two lathes are placed at each other. Since the combined Scaling Matrix displays results of all operators, it is easier to compare were most or even all operators made similar choices regarding machine placement. Not only the actual Scaling Factor values but also the color scheme helps to visualize if these patterns exist. At first glance, lathe combinations with mostly green columns were looked at in combination with relatively low values displayed in green columns, see Figure 41 (which is part of the total combined scaling matrix):

	HPQ 2											
HPQ 1	15,9	2,8	6,0	14,1	12,9	5,2	8,3	12,4	14,6	15,0	14,6	9,7

	DMG MORI NLX2000											
DMG MORI CLX350	40,1	31,8	4,9	3,9	7,7	1,0	4,3	14,3	8,1	70,9	5,1	41,2

	350 PORTAALLADER											
350	30,2	4,0	6,6	6,1	5,1	9,4	11,6	11,8	13,4	84,9	46,6	23,3

	200 MSY ROMIAS											
200 MSY ROBOJOB	84,1	1,0	2,1	81,1	21,6	5,2	5,0	72,1	5,7	9,2	4,6	1,0

	INTEGREX J200											
INTEGREX 200	38,4	25,8	11,6	2,5	5,1	8,8	4,3	72,7	48,7	15,6	17,6	61,0

	HARDINGE T42											
MEGATURN 500	93,4	34,2	1,0	1,0	32,5	73,6	14,2	43,5	1,0	8,6	11,7	2,9

FIGURE 41: Mainly green and low number SFs from the Combined Scaling Factor Matrix are found for six lathe combinations.

The most striking machine combination is lathe *HPQ1* & *HPQ2*: in the Scaling Factor Matrix, the entire column is colored green. So, all operators placed these machines extremely close to each other. Also values close to 1 or around 10 - 15 are found.
Lathe combination *DMG MORI CLX 350* & *DMG MORI NLX 2000* shows mostly green values, with also a bit yellow and on one occasion orange. Yet, looking at the values of green, one value is even 1,0 and others are very close to 1.
The same can be said about lathe combination *350* & *350 PORTAALLADER*. Mainly green, then yellow/greenish and one orange/red value. Still, the values in green are all very low and mostly close to 1.
Another lathe combination is *200 MSY ROBOJOB* & *200 MSY ROMIAS*. Although a bit more orange/red is shown, there is still a lot of green with very low values in green: even

two times 1,0.
Combination of lathes *INTEGREX 200* & *INTEGREX J200* also show mostly green, followed by yellow/orange colors. Again, the values in green are low and close to 1 or around 10.
The last interesting and striking combination is described by lathes *MEGATURN 500* & *HARDINGE T42*. Although there are higher red/orange values, the rest is yellow and mainly green, with even three times SF of 1.
Figure 42 states how often ranges of SF values appear, together with the found lathe combinations. The analysis so far thus resulted in 6 different machine combinations. These are visible too in a more in depth analysis by making a 2-dimensional layout based on the average combined SF matrix, see Section 5.3.4.

Lathe combination	1 ≤ SF ≤ 20	20 < SF ≤ 40	40 < SF ≤ 60	60 < SF ≤ 80	80 < SF ≤ 100
HPQ 1 & HPQ 2	12	0	0	0	0
DMG MORI CLX 350 & DMG MORI NLX 2000	8	1	2	1	0
350 & 350 PORTAALLADER	8	2	1	0	1
200 MSY ROBOJOB & 200 MSY ROMIAS	8	1	0	1	2
INTEGREX 200 & INTEGREX J200	7	2	1	2	0
MEGATURN 500 & HARDINGE T42	7	2	1	1	1

FIGURE 42: SF values of the found machine couples are counted with different ranges of SF.

5.3.4 Layout Based on Average Scaling Factor Matrix

Now the made machine couples are based on the combined SFs of the machine combinations. Still, it would be interesting if a 2D visualization of the layout could be made based on all SF Factors. For example, now the machine couples are made based on the SF factors of the two machines, but here all other SFs were not taken into account. The next step was to take all SFs into account to generate a 2D plane. To do so, the combined Scaling Factor Matrix from Figure 109 was averaged. So, for each machine combination, the average SF of all operators' SFs were taken. This also confirms the made machine couples, since these averages are the lowest. This resulted in the following Averaged Scaling Factor Matrix, see Figure 43. Although lathe couple *PRIMOS* & *DMG MORI CLX 350* also have a relatively low average value (26,0) this is no chosen couple. On one hand, *DMG MORI CLX 350* formed a stronger couple with *DMG MORI NLX 2000*. Furthermore, the values of combinations of *PRIMOS* & *DMG MORI CLX 350* were more spread as can be seen in Figure 109. Figure 44 is the 2D visualization of Figure 43.

	PRIMOS	200 MSY ROBOJOB	250 STAF	DMG MORI CLX350	200 MSY ROMIAS	DMG MORI NLX2000	INTEGREX 200	MEGATURN 500	HARDINGE T42	INTEGREX J200	350 PORTAALLADER	HPQ 1	HPQ 2
350	59,9	51,2	48,4	54,9	57,2	53,0	52,6	29,9	49,1	55,4	21,1	47,8	42,7
PRIMOS		39,1	34,8	26,0	43,2	34,4	34,4	58,7	50,3	34,0	67,1	35,3	43,7
200 MSY ROBOJOB			50,0	55,2	24,4	46,7	37,3	49,5	42,5	54,4	36,4	44,4	45,1
250 STAF				41,4	47,1	29,8	49,8	44,3	43,5	46,8	55,8	33,4	30,5
DMG MORI CLX350					57,0	19,4	39,6	67,6	51,6	32,9	63,0	49,8	59,1
200 MSY ROMIAS						54,4	49,5	40,8	49,1	52,5	50,0	40,1	40,3
DMG MORI NLX2000							35,3	58,1	39,6	39,5	51,9	40,2	46,5
INTEGREX 200								51,2	40,7	26,0	50,2	37,2	44,5
MEGATURN 500									26,5	54,6	36,3	42,1	35,7
HARDINGE T42										51,5	43,7	44,3	46,6
INTEGREX J200											59,2	38,5	46,3
350 PORTAALLADER												54,8	46,3
HPQ 1													10,9

FIGURE 43: For each machine combination, the average of all SFs of all operators are taken and displayed. The chosen lathe combinations also have the lowest average values, see red rectangles.

Figure 44 represents a 2D (X,Y plane) layout were each coordinate of each machine relative to each other is displayed. The programming script using Python can be found in Appendix 9.5. From this graph, all machine locations relative to each other, based on all average SFs, is shown.

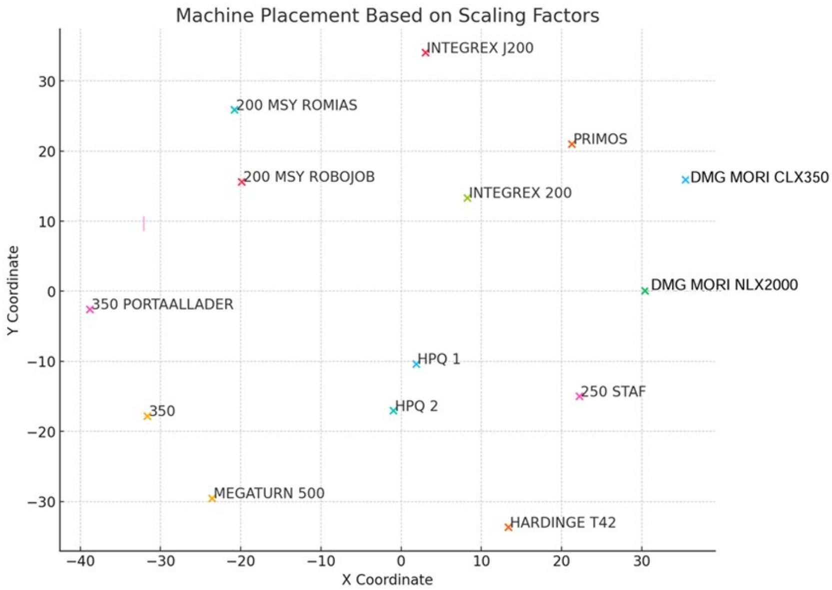

FIGURE 44: 2D (x,y) plane were machine placement based on all average SFs is shown.

From here, still the made machine couples can be seen. Furthermore, the earlier selected group of seven lathes are also closed in a group. Figure 45 shows this with colors to visualize these statements. Each chosen lathe couple can be seen by the colored rectangles.
Some machines are very close in their machine couples, as can be seen in the green and orange machine couples. Machines in other machine couples, namely the blue and purple couples, are a bit further away from each other, but are also remote from the other couples. Still, the machines in the yellow and red machine couple are relatively close to each other. Lathe PRIMOS is mainly close to these machine couples, whilst 250 STAF is more separated.
Distances are increased between the earlier made machine couples, since now the locations are based on all SFs (averaged) instead of only the SFs present for a machine couple. The specialized cell with previously selected machines is also clearly visible: all these 7 lathes are close to each other, such that an area can be circled (pink) to separate the other machines.

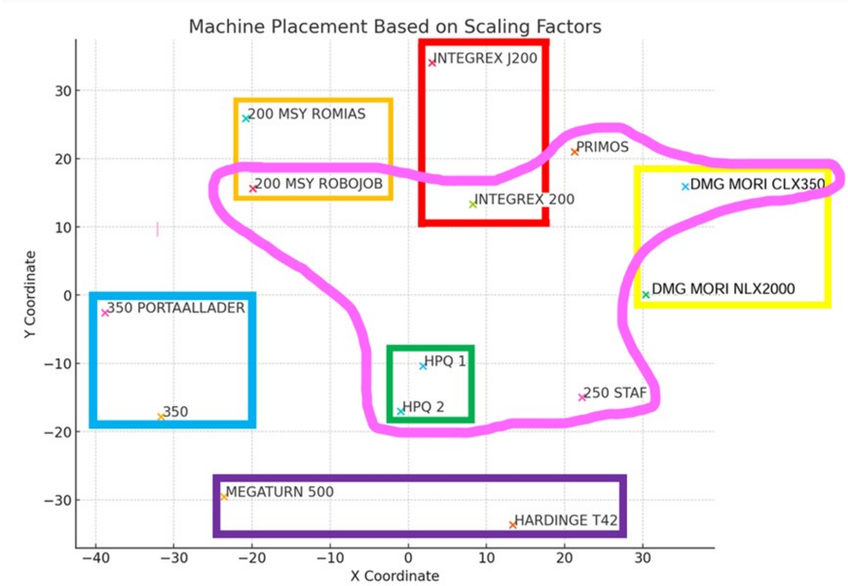

FIGURE 45: Machine couples (green, yellow, blue, orange, red, purple) and machines in specialized cell (pink) are visible in the Machine Placement 2D plane.

Another interesting insight from this 2D plane is the following: the machines that produce articles with large diameters (yellow), a barstockfeeder lathes (orange), comparable machines (purple and pink) and machines with similar operating systems (blue) can be grouped as well. Only PRIMOS is not part of any group. These groups correspond with Table 7. See Figure 46:

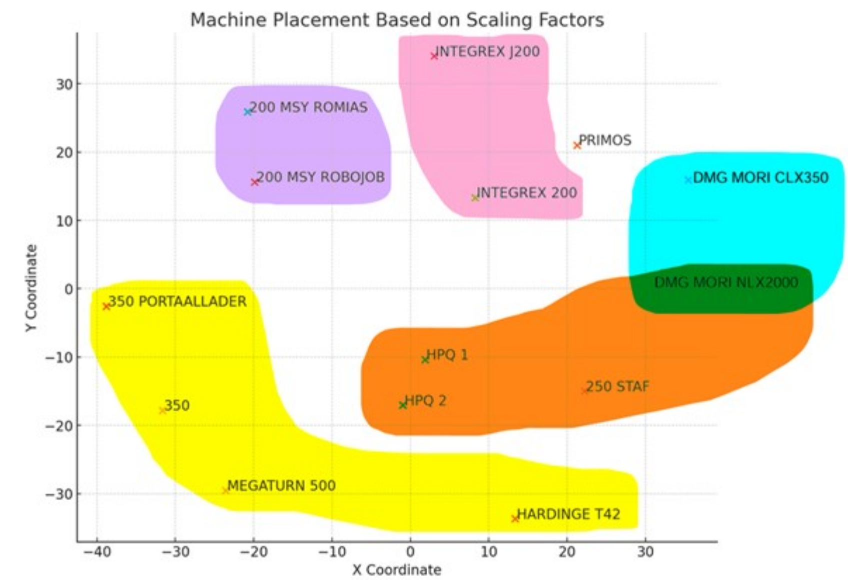

FIGURE 46: Machines can also be grouped together by large diameters (yellow), barstockfeeder lathes (orange), comparable lathes (purple) and similar operating systems (pink and blue).

5.4 Answering Sub-Question 4

Based on what criteria would operators redesign the lathe department and how would this redesign look like?

The Operators had several criteria regarding a redesign of the lathe department. Accordingly, they preferred one large lathe department in the future instead of multiple smaller lathe departments as is done right now. One large department was in favor since this gave mainly more overview of what everyone was doing. This would advance flexibility and helping each other would also be easier to do. Currently, this is a challenge since the departments are separated by walls, so there is no overview of what is going on and since each operator works in another department, the operators are grouped and not flexible. They rather keep staying in their own department and at their own machines. Furthermore, operators wanted a balance between lathes that are operated by hand and lathes that can be automatic or are less labor intensive. This would improve working with a larger M/O ratio. Lastly, they wanted lathes that produced large diameters close to each other. Also, they wished that lathes with comparable operating systems were placed close to each other. Moreover, barstockfeeder lathes were desired to be placed close to each other. To get to know how operators would make their layouts, an interactive brainstorm session was held. Here, operators could create their own layout by shifting magnets with machines on it across the current layout, which was printed out and put on a whiteboard. These layouts were photographed and analyzed after the brainstorm sessions.

5.5 Answering Sub-Question 5

Is it possible to create machine couples and machine groups in the redesigned layout?

Yes, it was possible to create machine couples and machine groups in the redesigned layout. The first machine group that was made was a specialistic cell. In this cell, 7 lathes were placed that are capable of producing 91,0% of production numbers, representing 37,8% of all articles. The lathes that are in this cell: 200 MSY ROBOJOB, INTEGREX 200, PRIMOS, DMG MORI CLX 350, 250 STAF, HPQ1 and HPQ2. This cell was created based on the decreased number of lathes to produce all articles with a diameter up to and including 150 mm. The other machine groups were lathes that produce articles with relatively large diameters, barstockfeeder lathes, comparable lathes and lathes with similar operating systems. Within these machine groups, 6 machine couples were found: 350 PORTAALLADER & 350, MEGATURN 500 & HARDINGE T42, HPQ 1 & HPQ 2, 200 MSY ROMIAS & 200 MSY ROBOJOB, INTEGREX J200 & INTEGREX 200 and DMG MORI CLX 350 & DMG MORI NLX 2000. These groups and couples were found by measuring all relative distances between all machines in each layout. These distances were transformed into scaling factors. Based on the lowest scaling factors, for each operator it could be identified which machines were placed close to each other. The machine groups (and couples) were made visible by taking the average of all scaling factors for all machine combinations.

Next, in Chapter 6 these insights were used as a staring point to come up with actual layout options by writing a programming script, setting constraints, running the script and analyzing the outcomes of the script.

6 Programming Layout Outcomes

By incorporating the lathe operators, it is clear that certain machine couples and groups are desired to be placed in one large lathe department. Furthermore, a specialized machine cell can be created to produce the largest portion of production numbers. With this information, it is time to actually start designing layout options. To make this process efficient and to check all possible layout options, it was chosen to write a programming script that checks all possible layout options based on created constraints. Based on modeling the layout by machine locations (Section 6.1) it became clear that without constraints 1.3 trillion layout options were possible (Section 6.1.1). By setting constraints, these options can be reduced and by programming all possible options can be visualized. After setting the constraints, the model setup is described (Section 6.2) as well as the analysis of the layout outcomes (Section 6.2.1). A first layout outcome is the result. After making practical adjustments, the final lathe department is created (Section 6.3). This also effects the layout of the rest of the workshop. This results in one finalized layout design for Hankamp Gears, including a new lathe department and rearrangement of other departments and machines (Section 6.4). The additional costs for this redesign are shortly elaborated on as well (Section 6.5). To conclude this Chapter, Sub-Question 6 is answered (Section 6.6).

6.1 Approximation Layout as 9x3 Table

For the programming script (see Appendix 9.6), first the space for the new lathe department layout needs to be approximated. From the operators, it became clear that one lathe department is desired. By making an approximate layout, space for machines to be placed can be created which is needed for the programming script. The layout of the workshop can be approximated as a 9x3 table, resulting in (9*3=) 27 boxes, see Figure 47. A distinction is made between 15 boxes were machines can be placed (green) and 12 boxes where machines cannot be placed (red). Green boxes are based on already existing locations of machines, whilst red boxes are based on already existing rooms, space allocated for other machines/storage, entrance for operators, walking paths and areas outside the workshop. Later, after the model has finished with creating layouts, the outcomes will be compared to actual dimensions and layouts will be fine-tuned and changed. It was first a priority to create possible outcomes by modeling, since there are more than 1.3 trillion options without any constraints.

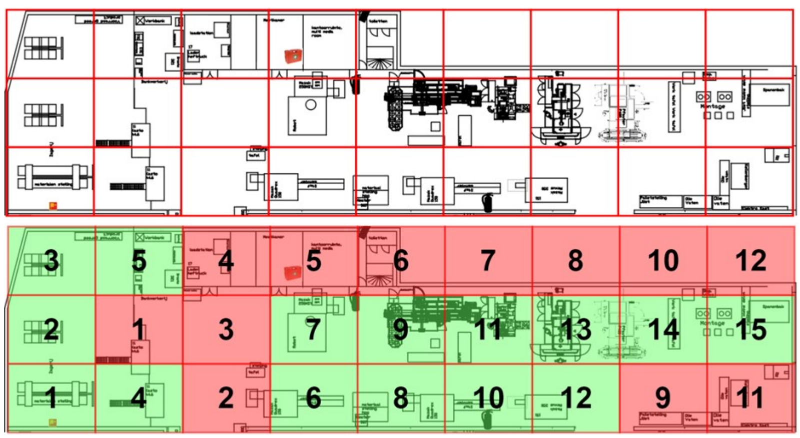

Figure 47: Layout can be approximated as a 9x3 table with 15 possible machine locations (green) and 12 impossible machine locations (red).

6.1.1 Creating Constraints

There are 14 machines (M), see Figure 44. These need to be placed on 15 possible machine locations (L_M), see Figure 47. The number of outcomes without constraints ($O_{NoConstrains}$) is calculated using Equation 2:

$$O_{NoConstraints} = L_M * M! = 15 * 14! = 15! = 1.307.674.368.000 \quad (2)$$

There are over 1.3 trillion options without any constraints. First of all, this is impossible to all check and change where possible. And even if this would be possible, the computation time would be a problem. The programming script (Section 6.2) generates a layout approximately every 0.05 seconds, equaling over 2070 years to generate all outcomes. It is no surprise here that constrains are absolutely necessary to make this code successful in generating layouts. To describe the constraints in a clear way, first each lathe name is given a number displayed in Table 10. This is done for readability in the to be described constraints.

Table 10: Each lathe name gets a lathe number for readability in the upcoming constraints.

Lathe name	**Lathe #**	**Lathe name**	**Lathe #**
HPQ1	L1	200 MSY ROBOJOB	L8
HPQ2	L2	200 MSY ROMIAS	L9
250 STAF	L3	PRIMOS	L10
DMG MORI NLX 2000	L4	350 PORTAALLADER	L11
DMG MORI CLX 350	L5	350	L12
INTEGREX 200	L6	MEGATURN 500	L13
INTEGREX J200	L7	HARDINGE T42	L14

Now that each lathe name is shortened to a lathe number, it is time to present the table of constraints (Table 11). There are 8 constraints (C#) with different corresponding machines (Lathe #), locations (Location #) and reasoning (Reason). To describe Location #, Figure 48 is used.

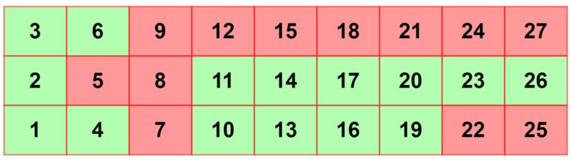

Figure 48: Boxes to represent the locations described in Constraint Table 11.

Table 11: Explanation of set constraints.

C#	Lathes	Constraint	Reason
1	L1-L14	Cannot be placed at locations 5, 7 - 9, 12, 15, 18, 21 - 22, 24 - 25, 27	Predefined impossible locations to place machines
2	L1-L2, L6, L11-L13	Cannot be placed at locations: 3, 6	No gantry crane present
3	L1-L9, L11-L12	Cannot be placed at location: 11	Not enough space between doors
4	L1-L4, L6, L11	Cannot be placed at location: 14	Not enough space between doors
5	L1&L2, L4&L5, L6&L7, L8&L9, L11&L12, L13&L14	Each pair (indicated with &) needs to directly touch each other	Earlier made machine couples
6	L1-L3, L5-L6, L8, L10	Cannot be placed at locations: 1 - 4, 6, 10, 13, 16	To force specialized machine cell
7	L1-L14	Lathes cannot overlap each other	Only 1 machine can be placed per location
8	L1-L14	Lathes cannot be placed out of bounds	Lathes need to be placed within approximated work place

6.2 Setup Model

A programming script was made to visualize all possible layout options. Machines are allocated to possible locations based on set constraints. The script calculates all different possibilities of machine configurations within a given area, representing a layout option. The script loops through all the constraints. As soon as one constraint is not met, the possible layout is removed and the loop starts over again. By adding constraints, the number of possible outcomes is drastically decreased, which makes it easier to add corrections to the layouts later. Furthermore, the computational time drastically decreases.
First, the model is setup. The blue rectangle represents the boundary of the approximated workshop. Each red box is a box were no machine can be placed as described earlier. After that, the script creates boxes that exactly fit in the blue area. Each filled box represents a machine with an own color. Later, the initial blue frame will be filled with the colored boxes. See Figure 49. In the end, the code displays all layout options that meet all the constraints.

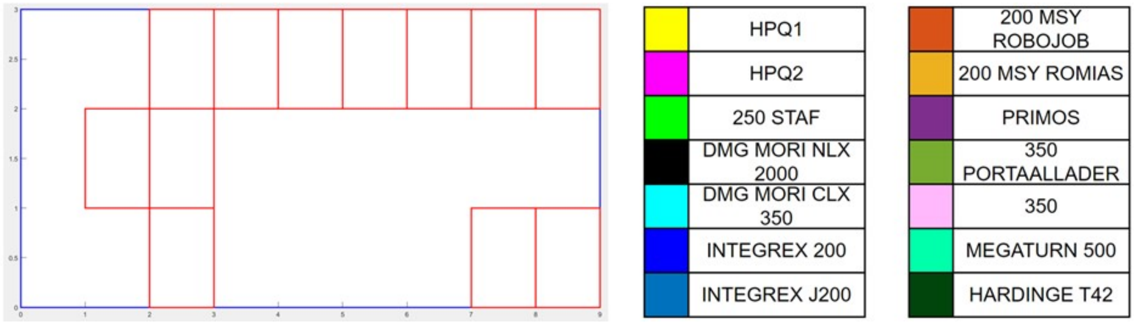

FIGURE 49: Initial frame with (left) were machine combinations will be displayed. Each machine has its own name and color (right).

6.2.1 Analysis Layout Results from Layout Loop Script

After running the code a total of 8 layouts were presented. These are all displayed in Figure 50.

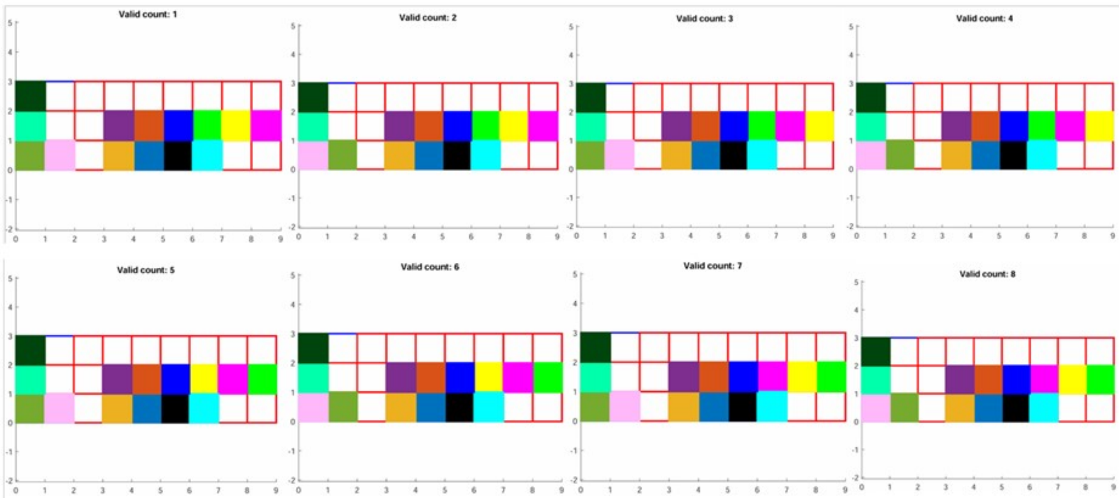

FIGURE 50: In total, 8 valid counted layouts were the result of the written coding script.

From these 8 layouts, one first redesign of the layout was made. To do this, first the left parts of each valid counted layout were analyzed, then the right side was compared to each other. Both the different options (2) for the left side and the different options for the right side (4) are displayed in Figure 51.

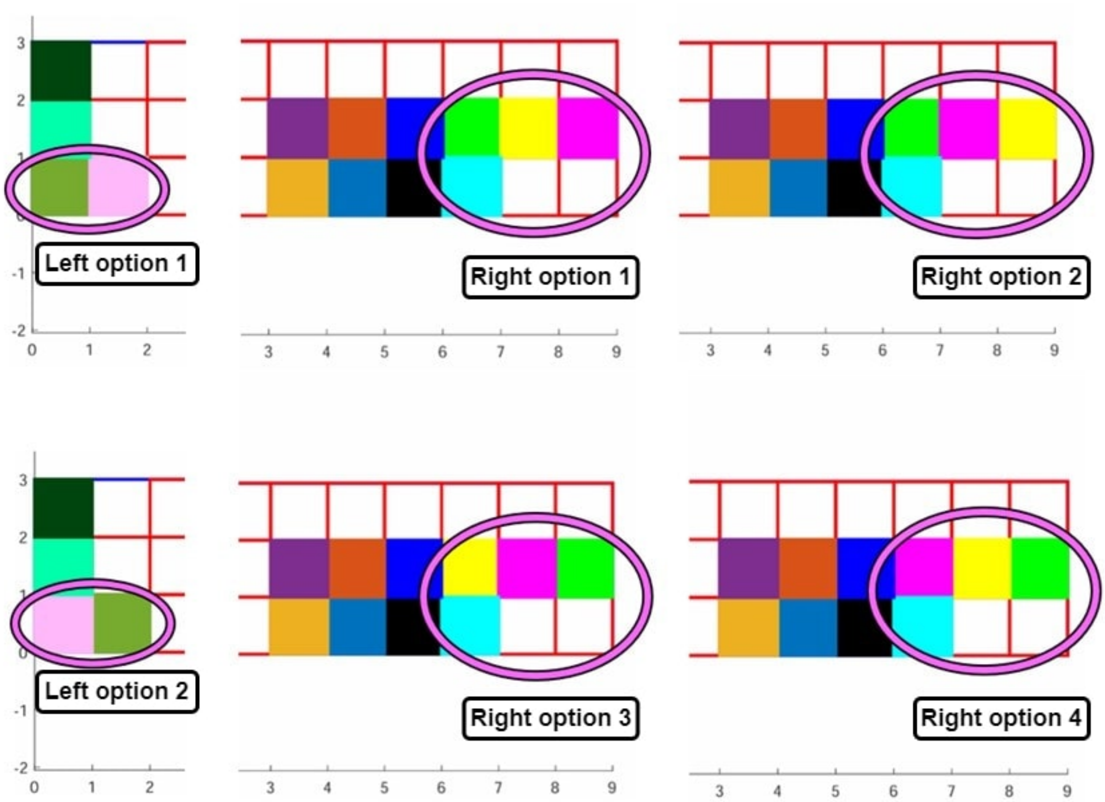

FIGURE 51: Differences for the left and right side are made visible by pink circles.

Left Side
For the left side, the difference lies in the locations of lathes 350 PORTAALLADER and 350 (pink circles in Figure 50), whilst the rest of the machines have no different options. This results in 2 options. The right side of Figure 49 can be used for the color scheme of each machine.
For the two lathes (*350* and *350 PORTAALLADER*), there are actually 4 different options in stead of 2. This is possible based on the physical orientation of the lathes in the workshop. The whiteboard with cartons was used to quickly check these orientations and thus 4 options, see Figure 52.
Option 1 and 2 are impossible, since there is not enough room for the lathes to be placed: they touch each other and they are nearly overlapping with the right side of the wall. Option 3 and 4 are left, where option 3 is chosen. In option 4, lathe *350* is blocking sight of the operator at *350 PORTAALLADER*. Based on the carton board shape, this could be said about *350 PORTAALLADER* as well, but this carton is cut in a rectangle based on the longest dimensions. In reality, *350 PORTAALLADER* is not blocking the sight of the operator when the operator works at *350*. So, option 3 is chosen.

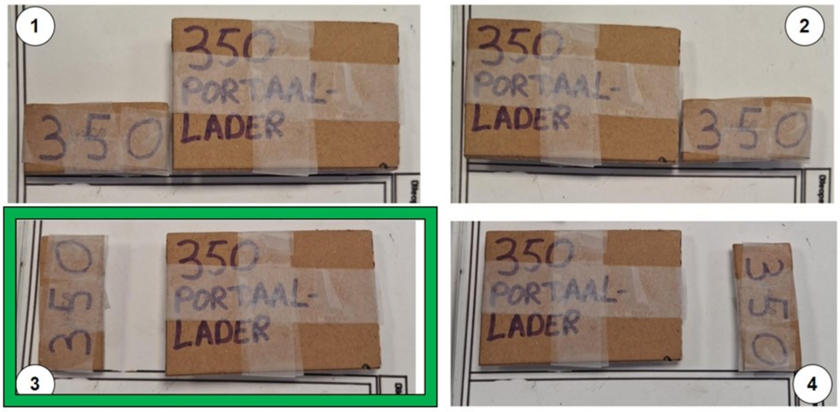

FIGURE 52: Carton board on whiteboard is used to check dimensions and orientations of machines to be placed. Option 3 is chosen.

Right Side
For the right side (Figure 50), the positions of lathes HPQ1, HPQ2, 250 STAF and DMG MORI CLX 350 are different (pink circles), whilst the other lathes have no different options (again, see Figure 49 for color scheme). This results in 4 options.
Again the whiteboard with cartons is quickly used to check for dimensions and orientation of the machines. The difference of the right side is based on how the machines HPQ1, HPQ2 and 250 STAF are placed relative to each other. The cartons show that these machines are very close to the wall, see Figure 53. At this location, there is a overhead door present which needs more space than is the case right now.

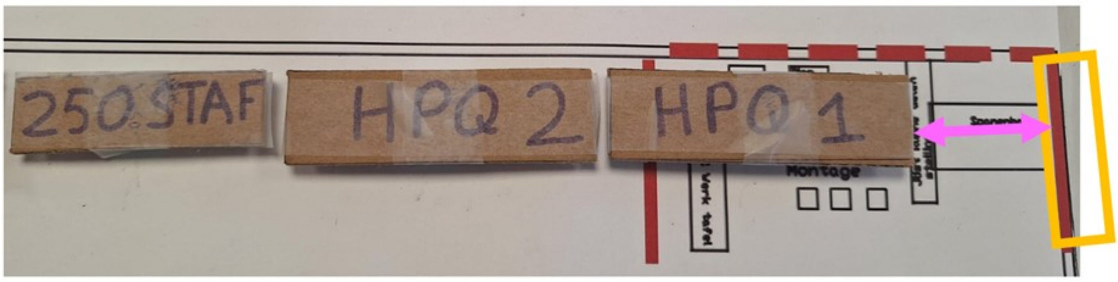

FIGURE 53: No matter which orientation is chosen, the distance between machines (pink arrow) and overhead door (orange) is too small.

It is clear that the 4 different options need to be changed since more space is required due to the overhead door. The solution to achieve more space is a clockwise rotation of the 4 lathes. This is shown in Figure 54.

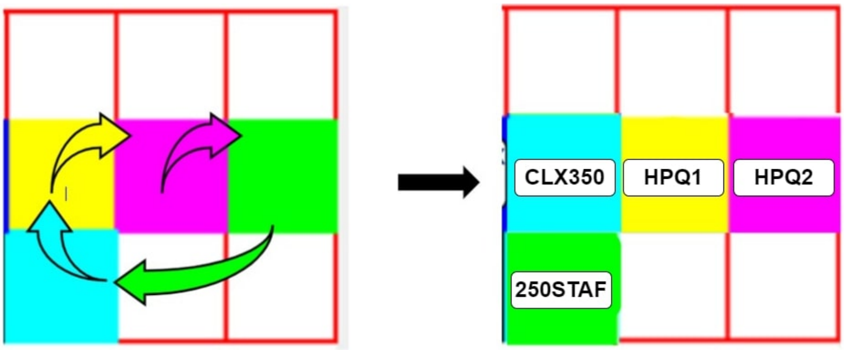

FIGURE 54: Lathes can be rotated clockwise.

By rotating clockwise, DMG MORI CLX 350 is placed in the row of HPQ1 and HPQ2. Since DMG MORI CLX 350 is a smaller and compacter machines, more room is created near the overhead door. This is displayed in Figure 55:

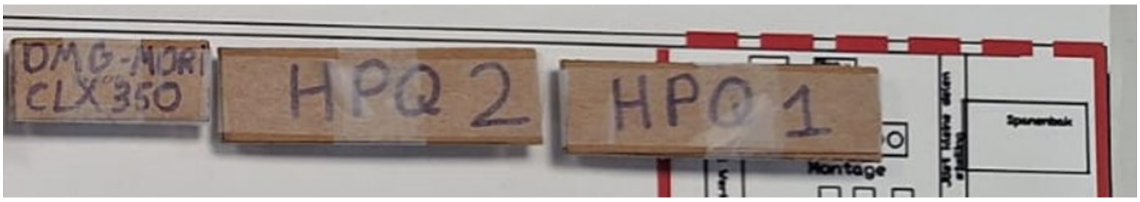

FIGURE 55: Carton board is used to visualize influence of placement of smaller DMG MORI CLX 350 in the row of HPQ1 and HPQ2.

Not only does this solve the space problem at the overhead door, another advantage is present. With this rotation all barstockfeeder lathes are grouped as well, which is a wish of the operators too based on conversations during the brainstorm sessions. This results in the adjusted layout in Figure 56.

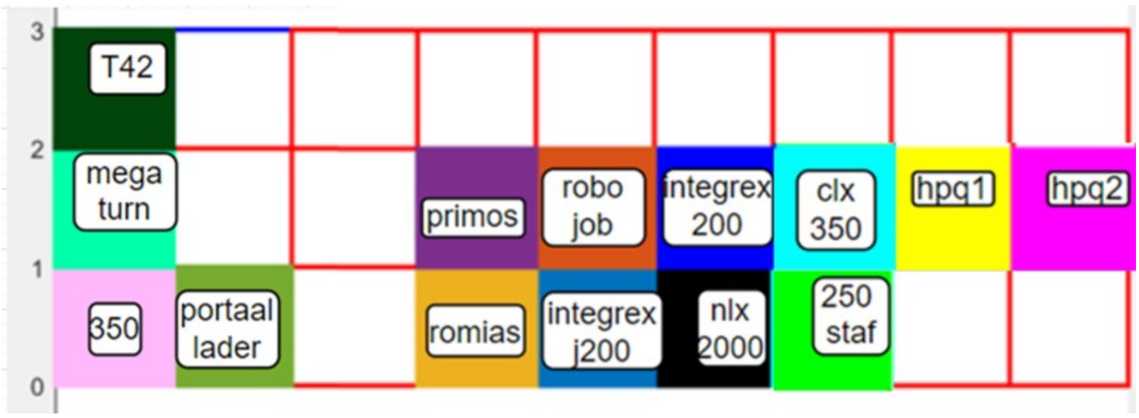

FIGURE 56: Adjusted layout option.

By using Figure 56, the complete first version of the layout could be made visual using the whiteboard and the carton machines. The result is shown in Figure 57.

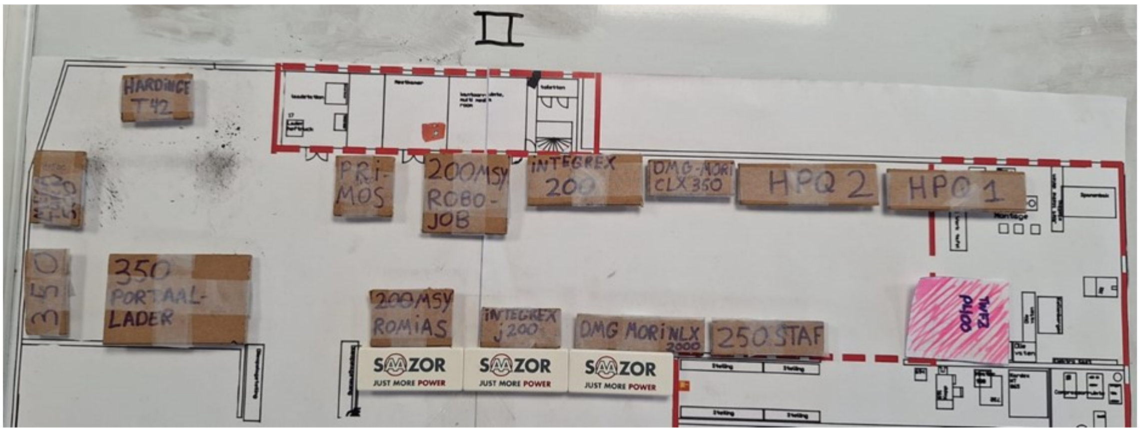

FIGURE 57: First version of layout on whiteboard.

6.3 Practical Layout Adjustments

After a discussion with Hankamp, the presented first version on carton board (Figure 57) was adjusted according to some practical points and insights. Lathe 350 is now put in a corner behind the big lathe 350 PORTAALLADER, see Figure 52 (option 3). This might still minimize the actual sight for the operator and creates a closed work area. Initially, the 350 could not be placed on top (where no gantry crane is present), but after a discussion this is still possibly by placing a light crane (125kg capacity) on the wall. Furthermore, 200 MSY ROMIAS can better be interchanged with HARDINGE T42, such that operators have a better ratio between automatic, barstockfeeder- and lathes operated by hand. Furthermore, the MEGATURN 500 and 350 PORTAALLADER can be changed. Doing so, the MEGATURN is closer to the measurement room, where dimensions are checked for articles. Often, articles from the MEGATURN 500 are big and heavy and need to be carried to the measurement room. Furthermore, by changing the position of the 350 PORTAALLADER, the area becomes more open for operators to work. Taking these comments in consideration, the layout was adjusted. In stead of carton board, now the exact dimensions of the machines and work place are used. The file of the current workshop was used as a basis, where all machines were moved. This lead to the actual chosen layout regarding the lathe department, see Figure 58.

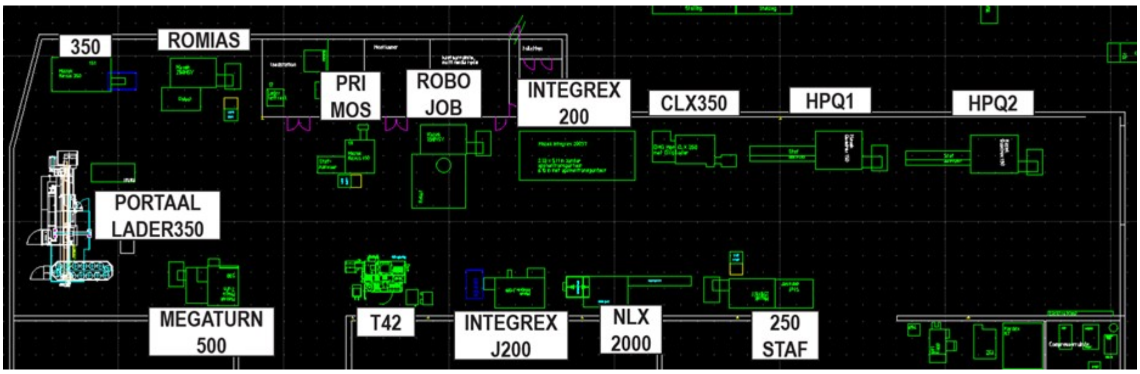

FIGURE 58: Redesigned lathe department layout on scale.

6.4 Adjustment Rest of Workshop

Now that the lathe department is finished, the rest of the workshop needs to be adjusted. This is because on the locations of the new lathe department, other departments and machine were present. These all need to be placed elsewhere in the workshop. The comparison between the old layout (Figure 10) and the redesigned layout is shown in Figure 59. The sawing department (orange) is changed. At this new location, there is more room, the flow of incoming, sawed and finished materials is improved and this was the only other option, since this is the only location with an available 3,2 tonnes gantry crane. The bench working department (yellow) is moved to the old location of the DMG MORI NLX 2000. This is relatively small place where this department can be placed. The assembly department (green) is changed to the new location. Here, the assembly department is separated from all the storage at this department. Furthermore, the chip bin is moved such that is it closer to the trash area. Also for the assembly department this was the only other option since here is a 1,0 tonne gantry crane. The storage (light blue) is moved closer to the other storage of the assembly storage. Doing so, the storage is more centralized. The gear milling machines (dark blue) are moved to the gear milling department. One machine is kept at the area of the lathe department, but it is outside the lathe department, close to the the gear milling department. This gear milling machine had to stay here since it needs a gantry crane. This was the only option to place. The milling machine (purple) and spark-erosion machine (pink) are moved as well. They are still close to each other as before, but now closer to the milling department.

FIGURE 59: Redesigned layout (left) and current layout (right), indicating which other departments and machines have a changed location by color: lathe department (red), sawing department (orange), bench-working department (yellow), assembly department (green), storage racks (light blue), gear milling machines (dark blue), milling machine (purple) and spark-erosion machine (pink).

By applying all these changes, the complete layout is changed. The completely new layout is shown in Figure 60. Here, all lathes are numbered, see Table 12.

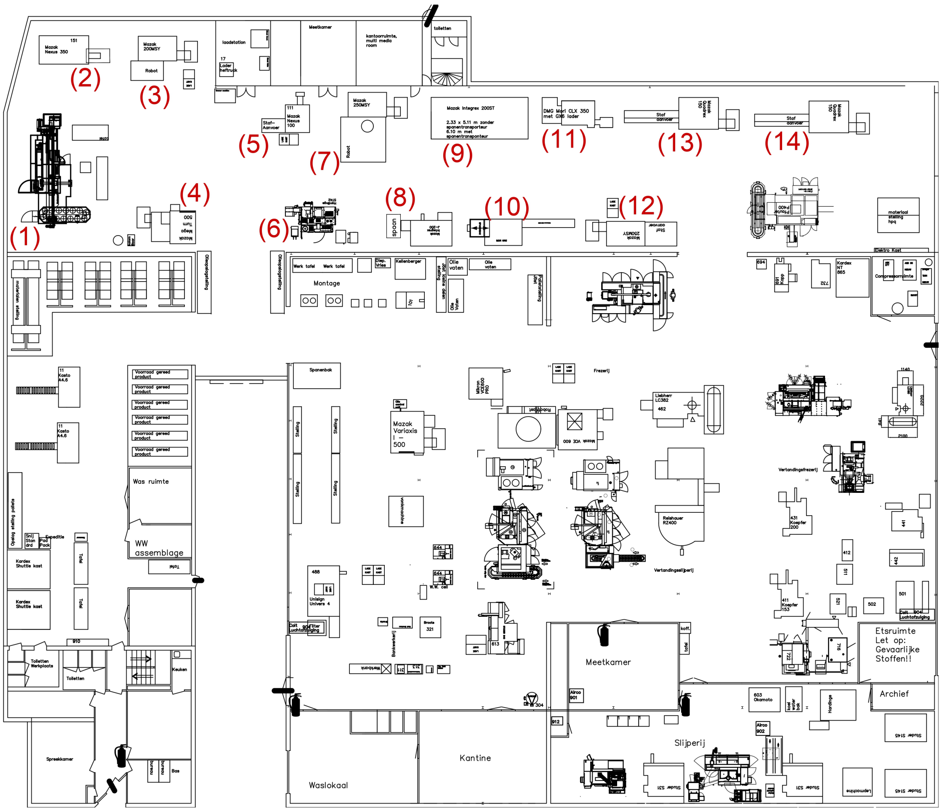

FIGURE 60: Complete redesigned workshop for Hankamp Gears on scale.

TABLE 12: Lathe names with corresponding numbers displayed in Figure 60.

Lathe name	Lathe #	Lathe name	Lathe #
350 PORTAALLADER	(1)	INTEGREX J200	(8)
350	(2)	INTEGREX 200	(9)
200 MSY ROMIAS	(3)	DMG MORI NLX 2000	(10)
MEGATURN 500	(4)	DMG MORI CLX 350	(11)
PRIMOS	(5)	250 STAF	(12)
HARDINGE T42	(6)	HPQ1	(13)
200 MSY ROBOJOB	(7)	HPQ2	(14)

6.5 Costs of Redesign

Redesigning the lathe department and complete workshop comes with additional costs. Based on discussions with Hankamp Gears, it has been estimated that it costs 10.000 euros to move a machine, including installation and time lost for not being able to produce articles. In total, 20 machines need to be moved: 13 lathes (1 lathe, 200 MSY ROBOJOB does not need to be moved since it is already at the correct location for the new layout), 3 gear milling machines, 2 sawing machines, 1 milling machine and 1 spark-erosion machine, totaling 200.000 euros. After a discussion with Hankamp Gears, it was estimated that approximate costs to move all storage racks, the bench-working department and assembly department and installing electrical components costs an additional 50.000 euros. In conclusion, the total costs to redesign the complete workshop (see Figure 59) are approximately 250.000 euros.

6.6 Answering Sub-Question 6

How to ensure that all possible layout options are taken into account?
To ensure that all possible layout options are taken into account, a programming script was made. The space for the new lathe department was approximated into 27 different blocks: at 15 locations machines could be placed and at the other 12 locations machines could not be placed. With 15 possible locations, 14 machines to be placed and no constraints, 1.3 trillion layout options would be possible. All 14 machines were given a color. By setting a total of 8 constraints, the programming script showed different colored cube orientations when the script did run. Each unique orientation of colored cubes represented a unique layout. The script was programmed such that only layouts that met all constraints were shown. Constraints were set based on the impossible locations were machines could not be placed, gantry cranes, available space between present doors, the made machine couples, the specialized cell, only having space for 1 machine on each available cube and out of bounds based on the defined space. By creating the constraints, the number of options and computation time was decreased. By setting-up the model, writing the programming script and running the script with the set constraints, 8 different layouts were the result. Differences between these were analyzed after which 1 first layout was the option. This layout had to undergo practical adjustments, resulting in one finalized lathe department. Because of this, part of the workshop had to be redesigned as well by relocating other machines and departments. The approximate costs to do this are 250.000 euros based on discussion with Hankamp Gears.
Next, in Chapter 7, the new redesigned lathe department will be validated by performed simulations where different scenarios are simulated.

7 Validation by Simulation

To validate the redesigned lathe department, simulations are performed. The goal was to get insights in the effects of the new lathe department compared to the current layout. Siemens Plant Simulation 16.1 was used to perform the simulations [47]. First, the simulation components (Section 7.1) are explained with a simplified simulation model (Section 7.1.1). Second, the multiple variables used in the simulations are explained (Section 7.2). Then, the influence of the moment during which an Operator is present at a machine is elaborated on (Section 7.3). Afterwards, programming scripts in the simulation will be detailed (Section 7.4) with two different situations (Sections 7.4.1 and 7.4.2) regarding set-up and processing times. Lastly, the simulation time results are explained (Section 7.5), which are categorized regarding different situations (Sections 7.5.1 - 7.5.4). To conclude this Chapter, Sub-Question 7 is answered (Section 7.6).

7.1 Simulation Components

Each simulation model consists out of different components, where each component has its own function. All components used in the simulations will be explained. When explaining, different verbs are used: **connected** and **linked**. The difference is made visual using Figure 61.

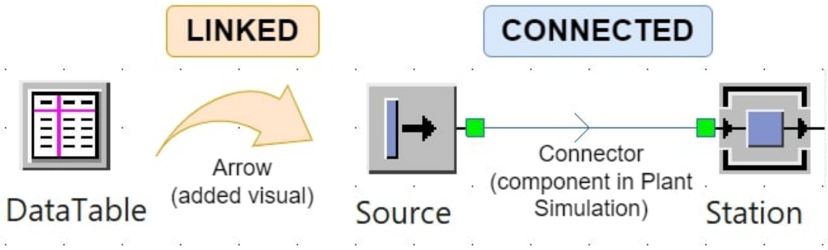

FIGURE 61: In this example, component DataTable is linked to component Source. Furthermore, Source is connected with component Station.

If components are **connected**, it means a Connector (which is an component in Plant Simulator) is placed in between these components. If components are **linked** to each other, it means that there is not a Connector in between the components but they still influence each other or that they used each others input. Now that this difference is made clear, all components used are shown in Figure 62:

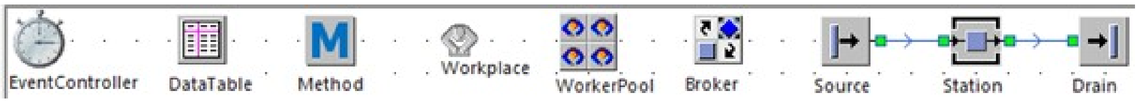

FIGURE 62: Components used in simulation.

In Plant Simulation, there are **Mobile Units (MUs)**. In the simulations, a **Part** is the MU, see Figure 63. Each Part represents an article to be produced. First, all articles from January 2023 produced by Hankamp Gears are defined in the simulation by adding Parts and renaming them.

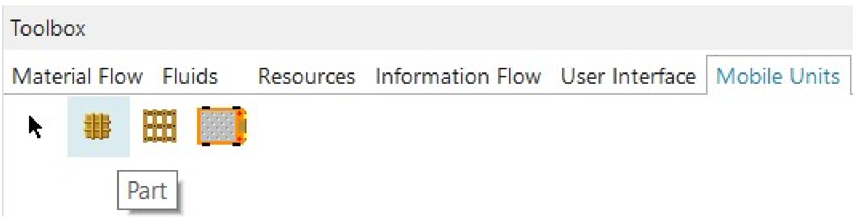

FIGURE 63: Within the Mobile Units category, Parts are used to represent produced articles by Hankamp Gears.

After defining and adding Parts, all Parts are linked to a **DataTable**. Here, the Parts and their corresponding production numbers are filled in. The DataTable is linked to the **Source** block. The Source is the starting point of production, were MUs (Parts) appear. Via the **Connectors**, the Parts stat moving to the connected **Station**. A Station represents a machine that produces the Parts. First, the machine needs to be set-up, after which production can start. Normally, with a Station, only 1 set-up time and only 1 production time can be filled in. Although, there are multiple Parts to be produced, each with its own set-up and production times. By using **Methods**, this problem can be tackled. A Method is linked to the Station. In the Method, a custom programming script is made which defines the set-up and production times for each Part to be produced. Basically, the Method ensures that the set-up and production times in the Station change once the Parts change. Linked to a Station is a **Workplace**. This is the location where

Workers (representing operators that work with machines) go to in order to start working at the Station. The **WorkerPool** is connected to the Workplace. In the WorkerPool, the number of Workers can be adjusted. Also, it can be defined that specific Workers only can go to certain Workplaces and thus only work with certain Stations. The **Broker** enables the link between WorkerPool, Workplace and Station. A Station is connected with a Connector to a **Drain** block. Once a Part at a Station is finished (Setup and Processing times are finished at the machine), the article is transported to the Drain. Here, the production stops and is finished. At the Source, a staring point for the Parts to move is created. The Station processes the Parts and the Drain collects the finished Parts. The **EventController** enables starting, stopping and finishing a simulation. This shows the outcome of the simulation time: this is the actual time it would take before all Parts are produced.

7.1.1 Simplified Simulation Model

Figure 64 displays a simplified simulation model with two stations. Actual representations are omitted due to readability reasons.

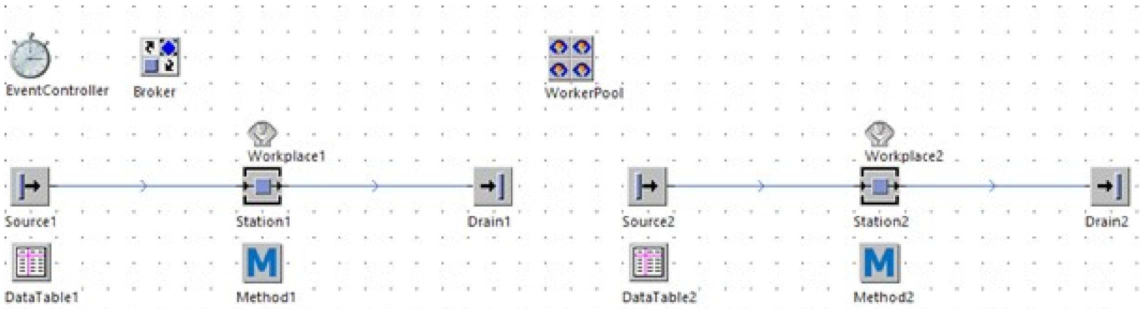

FIGURE 64: Simplified representation of simulation model with 2 stations.

The variable options (Figure 65) are connected to the described simulation components. With the WorkerPool, the number of operators per shift can be adjusted by changing the number of available Workers. Placement of Stations represent the type of layout: for each layout the distances between the Stations are adjusted accordingly. The number of machine groups are made by the WorkerPool and Stations: in the WorkerPool, Workers can be connected to certain Machines (a so called Service is added). This restricts Workers to only work with selected Stations. These Services are according to made machine groups. By adjusting the Workers in the machine groups, the M/O ratios are adjusted. For the flexible option, Services are omitted such that all Workers can go and work with each Station. To simulate different moment during which a Worker needs to be at a Station, Methods are coded to simulate these options by filling in the set-up and processing times according to the Part to be produced. These Methods deserve special attention, since they use the input that determines the simulation time: the set-up and processing times for Parts.

7.2 Variable Options for Scenarios

Multiple simulations, each with a different scenario, were executed. Figure 65 gives an overview of the multiple variables and scenario options to be taken into account in the simulations. Scenarios can differ in number of operators present per shift, the type of layout, the number and type of machine groups, Machine/Operator (M/O) ratios, fixed and flexible man/machine couples and moments during which an Operator is present at a machine.

Number of operators per shift

The number of operators per shift depends on the number of operators retired and the presence off one operator in dayshift. Currently, there are three shifts: a morning shift (8 Operators), a afternoon shift (8 Operators) and a day shift (1 Operator). Since the day shift has mainly overlapping times with the morning shift, for the simulation the Operator from the day shift is put in the morning shift. So, including this operator, per shift their are 9 Operator. Excluding this operator, per shift their are 8 Operators. When Operators retire, the number of Operators will decrease. That is why the range of number of Operator per shift is 6 - 9.

Type of layout

The current layout and the redesigned layout are simulated. The current layout consists out of 4 lathe departments, each with an own machine group. The distance between all machines is thus relatively large compared to the redesigned layout. Here, there is 1 lathe department. In the simulation, based on M/O ratios and made machine couples, 6 machine groups are used. Also two scenarios were their is for both the current and redesigned layout 1 machine group are simulated.

Number of machine groups

The number of machine groups determines the M/O ratios and the man/machine couples. In each machine group, a certain number of operators can work with a certain number of machines. An Operator cannot work on machines in another machine group. So, operators are bounded to their connected machine group. To enable a scenario were this is not the case, 1 machine group (of all machines) and all operators is made. This represents a scenario were everyone is flexible. This means that there are no fixed man/machine couples. Now, everyone can work with each machine.

Moments during which an Operator is present at machine

There are 2 ultimate scenarios simulated when an Operator needs to be present at a machine. During set-up time, an operator always needs to be present at the machine since setting-up the machine is manual work. The production time can be manual, but also automatic. So, the first absolute scenario is that the operator also needs to be at the machine during total production. So, only after all products are produced, the operator can leave the machine and go to the next machine. Another ultimate scenario is that an operator can leave the machine once set-up is done, since the production can be done automatically. In practice, the actual scenario will be in between these two ultimatums depending on the Operator, the machine and the articles. It is unknown who moves at which moment to which machine. Since this is unknown, only the two ultimatums will be simulated.

Articles

For each simulation, period January 2023 was used. In this period. Hankamp Gears produced the most articles and all lathes were operating. All articles, with all corresponding setup times, production times per product and total number of products were put in the simulation software. For each scenario and each simulation, this was the same.

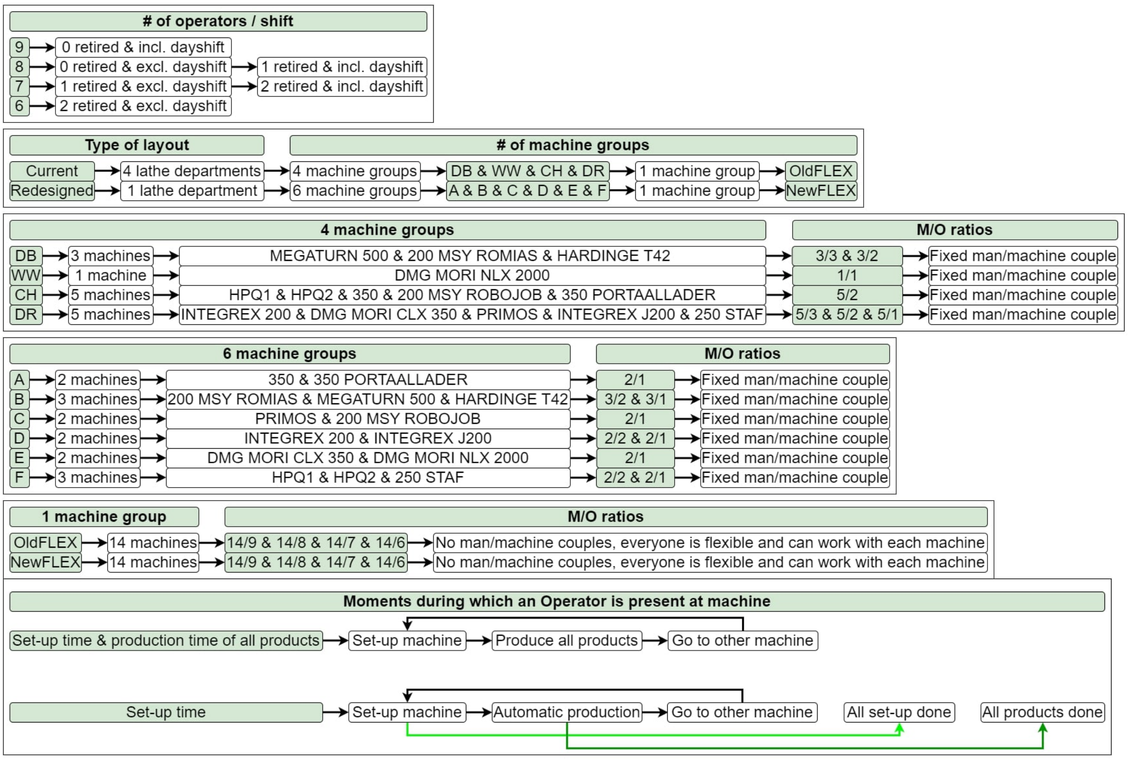

Figure 65: Multiple variable options used in simulations.

7.3 Influence Moment During Which Operator Needs to Be at Machine

For each Part, the set-up (Insteltijd_VoCa) and processing time (Productieuren_VoCa) are known from the analyzed data set (Table 1). The moment when operators need to be present at the machine influences the production time thus simulation time.

First a simplified example is given: there is 1 Operator and there are 2 machines (A and B). Each machine produces a batch of articles. The set-up times of A and B are 30 and 120 minutes, respectively. The total processing time of A and B are 200 and 300 minutes, respectively.

If the Operator needs to be present during set-up and complete production of machine A, then in that time machine B is standing still. Total production time would be 650 minutes (ultimate scenario 1 from Section 7.2). However, if first machine A is set-up and processing would be automatic, after setting-up A, Operator could set-up B and have automatic processing (ultimate scenario 2 from Section 7.2). This would save already 200 minutes. In another case, if Operator start setting-up B, after which processing of B is automatic, then Operator goes to set-up A with automatic processing of A (still ultimate scenario 2, but order of machine set-up is changed) the total time would be 430 minutes and thus saving 220 minutes, see Figure 66:

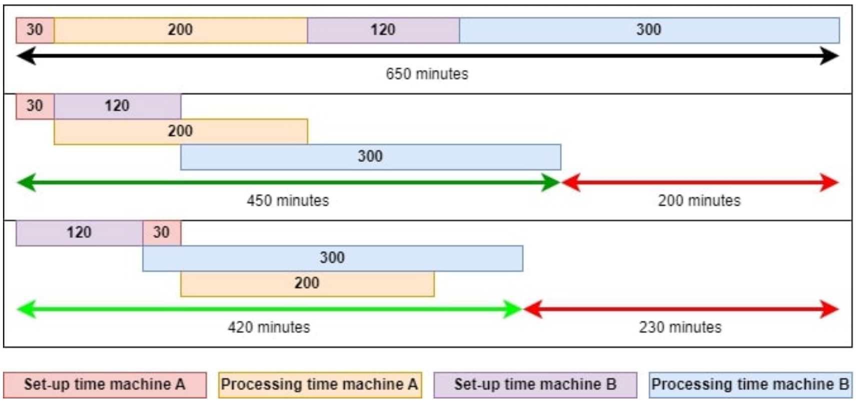

FIGURE 66: Total production time varies from 650 to 420 minutes depending on when the Operator needs to be at a machine.

This relatively simple example shows the influence of the moment at which an operator needs to be at the machine. This example was for only 2 parts, 2 machines and 1 operator. In the simulation, 6 - 9 operators, 14 machines, different machine groups and 107 parts are involved. Now the importance and influence of the moment at which an operator is at a machine are known, the scripts for the methods will be explained.

7.4 Method Programming Script

During set-up of a machine, an Operator always needs to be at the machine since this is manual work at Hankamp Gears. During processing parts at a machine, it could be that an Operator constantly needs to be at the machine (ultimate scenario 1) or not at all (ultimate scenario 2). If the processing time per part is so short that an Operator cannot complete another part or task at another machine, the Operators stays at 1 machine since otherwise time is lost. In that case, the Operator cannot leave the machine until all parts are produced. It could be as well that the processing of parts is mainly automated (for example barstockfeeder) such that after setting-up the Operator can leave the machine and go to another machine.
Each of the above described situations can be modeled with writing Methods. The Methods consists out of written codes that control the set-up and processing times of the machine. In a Method, the set-up time of the machine is called **SetupTime**. The SetupTime is independent of the number of parts to be produced, only the type of Part influences the SetupTime. The SetupTime is the time needed to prepare the machine before it can start producing parts. The processing time per part is called **ProcTime**. Logically, ProcTime increases if more parts are present.
Each of the 2 described ultimatums will be explained with an example. In each example, 3 articles (Part1, Part2, and Part3) need to be produced, see Figure 67. The set-up time from this figure is called **TS**, the processing time per part **TPP** and the total processing time **TP**. The different definitions will be used in Equations 3 - 6 to explain the different situations described with Models.

	Part1 (100 pieces)		Part2 (250 pieces)		Part3 (500 pieces)	
TS	set-up time [sec]	3600	set-up time [sec]	3600	set-up time [sec]	7200
TPP	processing time/part [sec]	200	processing time/part [sec]	150	processing time/part [sec]	180
TP	processing time (total) [sec]	20000	processing time (total) [sec]	37500	processing time (total) [sec]	90000

FIGURE 67: TS, TPP and TP for parts 1, 2, and 3.

7.4.1 Ultimatum 1: Operator at Machine During SetupTime and ProcTime

In the first ultimatum, the Operator only can leave the machine after the machine is set-up and if all parts are produced. A simplified version of the simulation is seen in Figure 68. In DataTableA, articles Part1, Part2, and Part3 are placed. SourceA transfers first all parts of PartA to StationA. Here, due to WorkPlaceA, an Operator is needed at the machine. MethodA controls the SetupTime and ProcTime. After parts are finished, they go to DrainA.

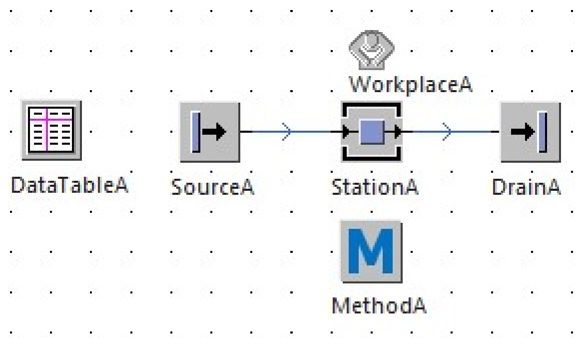

FIGURE 68: Simplified representation of situation 1.

To simulate that the Operator can only leave after the complete production, Equation 3 is used to describe the SetupTime and ProcTime:

$$\mathbf{SetupTime_A} = \mathrm{TS} + \mathrm{TP} \qquad \textit{and} \qquad \mathbf{ProcTime_A} = 0 \tag{3}$$

By taking the sum TS and TP and setting ProcTime to 0, the Operator needs to be present at the Workplace once the complete production time (23600 seconds) is finished. Due to definitions of the Method, this time is still called the SetupTime, but this includes the total time needed to set-up the machine and to produce all 100 parts of A. By defining it like this, the Operator can only leave the machine after the set-up and total production is done. In the Method, the code looks like Figure 69. This means that the Operator can only leave the machine after 23600 seconds, equal to the total set-up and processing time for A. Then, the Operator can for example go to another machine. When coming back to StationA, the operator needs to be present 41100 seconds to set-up and produce parts B. Again, the operator can go to another machine and eventually come back to StationA. Once back at StationA, the Operator needs to be present 97200 seconds at the machine to set-up and process parts C. Since the processing time is already including in SetupTime, ProcTime can be set equal to 0. By writing the Method and defining the SetupTime and ProcTime like equation 3 the Operator is forced to only be at the machine for 1 moment (during SetupTime), but this moment is already the complete time needed to set-up the machine and produce all parts.

```
var currentProduct := @
if currentProduct = .UserObjects.Part1:1
    .Models.Model.StationA.SetupTime := 23600
    .Models.Model.StationA.ProcTime := 0
elseif currentProduct = .UserObjects.Part2:1
    .Models.Model.StationA.SetupTime := 41100
    .Models.Model.StationA.ProcTime := 0
elseif currentProduct = .UserObjects.Part3:1
    .Models.Model.StationA.SetupTime := 97200
    .Models.Model.StationA.ProcTime := 0
end
```

FIGURE 69: Written Method coding for ultimatum 1.

One might wonder why not just use Equation 4 to describe SetupTime and ProcTime:

$$\mathbf{SetupTime_B} = \mathrm{TS} \qquad \textit{and} \qquad \mathbf{ProcTime_B} = \mathrm{TPP} \tag{4}$$

If Equation 4 was used, the written Method would change as well. To best describe this, Figure 68 is transformed into Figure 70, where A is changed to B:

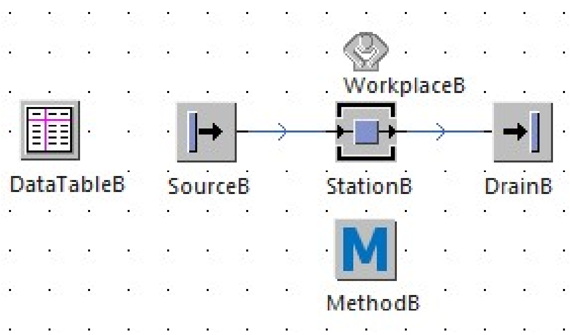

FIGURE 70: All components are now labelled with B instead of A (compared to Figure 68).

The Method would then look like Figure 71:

```
var currentProduct := @
if currentProduct = .UserObjects.Part1:1
    .Models.Model.StationB.SetupTime := 3600
    .Models.Model.StationB.ProcTime := 200
elseif currentProduct = .UserObjects.Part2:1
    .Models.Model.StationB.SetupTime := 3600
    .Models.Model.StationB.ProcTime := 150
elseif currentProduct = .UserObjects.Part3:1
    .Models.Model.StationB.SetupTime := 7200
    .Models.Model.StationB.ProcTime := 180
end
```

FIGURE 71: Alternative written Method code.

Although this might seem more logic to use the SetupTime and ProcTime like this, this is actually something which does not work for the simulations. This has been simulated, but by defining the Methods like this the Operators constantly move in between all machines. Imagine there are 2 machines: M1 and M2. First, the Operator sets-up M1, then goes to M2 to set-up. Then, goes to M1 to process 1 part. Afterwards, goes back to M2 to process 1 part. And go back again to M1 to produce 1 part. This is repeated during the whole simulation. With varying operators (6-9), 14 machines, different machine groups and 107 parts, this does not work. First if all, it is unrealistic that an Operator constantly moves from one machine to the other after only 1 part has been processed. Furthermore, from these test simulations the results were that the simulation time was even longer than simulations where operators needed to be constantly at their machines. This is due to increased time to constantly walk towards the machines and back. For that reason, the results of these simulations are not shown and Equation 4 and Methods from Figure 71 are not thus used.

7.4.2 Ultimatum 2: Operator at Machine During SetupTime

In the second ultimatum, the Operator only needs to be present during the set-up of the machine. Once the set-up is done, the Operator can leave the machine and go to another machine. Processing of parts is now not manual anymore, but automatic. To model this situation, the simplified simulation is shown in Figure 72. At StationC1, an Operator is needed to set-up the machine. That is the reason why there is a workplace, namely WorkPlaceC1. After set-up is done, the Operator can leave, but still the time needed to process all parts needs to be simulated. For that reason, a second station (StationC2) is added. StationC1 and StationC2 represent the same machine: at C1, an operator is needed and the machine is set-up. At C2, no operator is needed and the machine processes all parts. Here, no workplace is available since this is not needed because the process is not manual but automated.

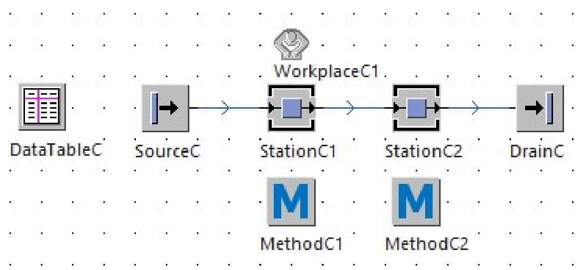

FIGURE 72: Simplified representation of ultimatum 2.

That is why Equations 5 and 6 are used:

$$\textbf{SetupTime}_{\textbf{C1}} = \text{TS} \qquad \textit{and} \qquad \textbf{ProcTime}_{\textbf{C1}} = 0 \tag{5}$$

$$\textbf{SetupTime}_{\textbf{C2}} = 0 \qquad \textit{and} \qquad \textbf{ProcTime}_{\textbf{C2}} = \text{TPP} \tag{6}$$

In MethodC1, only the setup time is accounted for, that is why ProcTime_{C1} is set to 0. In MethodC2, only the processing time per part is accounted for, that is why SetupTime_{C2} is set to 0. The Methods C1 and C2 look like Figure 73:

```
var currentProduct := @
if currentProduct = .UserObjects.Part1:1
    .Models.Model.StationC1.SetupTime := 3600
    .Models.Model.StationC1.ProcTime := 0
elseif currentProduct = .UserObjects.Part2:1
    .Models.Model.StationC1.SetupTime := 3600
    .Models.Model.StationC1.ProcTime := 0
elseif currentProduct = .UserObjects.Part3:1
    .Models.Model.StationC1.SetupTime := 7200
    .Models.Model.StationC1.ProcTime := 0
end
```

```
var currentProduct := @
if currentProduct = .UserObjects.Part1:1
    .Models.Model.StationC2.SetupTime := 0
    .Models.Model.StationC2.ProcTime := 200
elseif currentProduct = .UserObjects.Part2:1
    .Models.Model.StationC2.SetupTime := 0
    .Models.Model.StationC2.ProcTime := 150
elseif currentProduct = .UserObjects.Part3:1
    .Models.Model.StationC2.SetupTime := 0
    .Models.Model.StationC2.ProcTime := 180
end
```

FIGURE 73: Written Method coding for ultimatum 2.

Now that the importance of the moment at which an Operator is present at a machine is explained together with the different situations related to these moments, it is time to go to the results of the simulation.

7.5 Simulation Time Results

The different variables (Figure 65) and situations (Figures 68 and 72) lead to multiple simulations. The results of the most important outcomes will be explained. In Figure 74 the simulation times (in hours) are displayed. In each simulation, all 107 different articles, each with their own production numbers, set-up times and processing times, are made. The simulation time is the time needed to produce all parts. Each simulation is numbered (1-12) and will be explained in the upcoming sections. In Section 7.5.1, the simulations regarding the current situation will be explained. Next, in Section 7.5.2 simulations about the new layout with the operators constantly (during setup and processing) being at the machines will be elaborated on. Information about simulations of the new layout with flexible operators is stated in Section 7.5.3. Finally, Section 7.5.4 will go in depth about the new layout and constantly being at machines and automated machines.

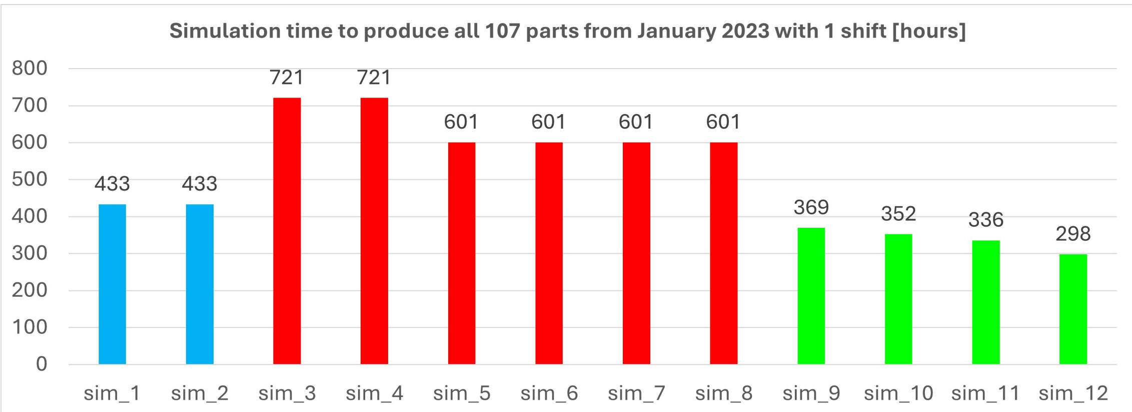

FIGURE 74: Simulation times in hours to produce all 107 parts from January 2023. In total, 12 different simulations are shown. Blue bars represent simulations for the current situation, whilst red bars display simulations that have a longer simulation time compared to blue bars and green bars represent simulations with a shorter simulation time compared to blue bars.

7.5.1 Current Situation

As a baseline measurement, **sim_1** and **sim_2** are performed. The current layout, with the currently used 4 machine groups, is simulated. Depending on the inclusion or exclusion of day shift, the number of Operators varies from 8 to 9. Since the day shift is in the machine group of MEGATURN 500, 200 MSY ROMIAS and HARDINGE T42, only this M/O ratio is changed. From Figure 74, it follows that the simulation time for both simulations is equal to 433 hours. So, it takes 433 hours to finish the production of all parts produced in January 2023. There is no difference between 8 or 9 Operators, since the machine group DB is not the machine group that takes the longest production time. The simulations are dependent on the machine group that takes the longest to produce all its parts.
To see what would happen if nothing would be changed and everyone would be with retirement, **sim_3** and **sim_4** are performed. Operators will retire in machine group DR, that is why this M/O is changing. Again, the M/O ratio in machine group DB changes as well due to including or excluding of Operator in day shift. From Figure 74, it follows that the simulation time increases to 721 hours in both cases, with either 6 or 7 Operators. So, if the layout does not change and Operators do retire, the simulation time increases with 66,5%. Figure 75 summarizes the data from the simulations sim_1 - sim_4:

	Layout	Moment at machine	# of Operators	Machine group	Machines	M/O ratios
sim_1	current	constant	9	DB	MEGATURN 500 | 200 MSY ROMIAS | HARDINGE T42	3/3
				WW	DMG MORI NLX 2000	1/1
				CH	HPQ1 | HPQ2 | 350 | 200 MSY ROBOJOB | 350 PORTAALLADER	5/2
				DR	INTEGREX 200 | DMG MORI CLX 350 | PRIMOS | INTEGREX J200 | 250 STAF	5/3
sim_2	current	constant	8	DB	MEGATURN 500 | 200 MSY ROMIAS | HARDINGE T42	3/2
				WW	DMG MORI NLX 2000	1/1
				CH	HPQ1 | HPQ2 | 350 | 200 MSY ROBOJOB | 350 PORTAALLADER	5/2
				DR	INTEGREX 200 | DMG MORI CLX 350 | PRIMOS | INTEGREX J200 | 250 STAF	5/3
sim_3	current	constant	7	DB	MEGATURN 500 | 200 MSY ROMIAS | HARDINGE T42	3/3
				WW	DMG MORI NLX 2000	1/1
				CH	HPQ1 | HPQ2 | 350 | 200 MSY ROBOJOB | 350 PORTAALLADER	5/2
				DR	INTEGREX 200 | DMG MORI CLX 350 | PRIMOS | INTEGREX J200 | 250 STAF	5/1
sim_4	current	constant	6	DB	MEGATURN 500 | 200 MSY ROMIAS | HARDINGE T42	3/2
				WW	DMG MORI NLX 2000	1/1
				CH	HPQ1 | HPQ2 | 350 | 200 MSY ROBOJOB | 350 PORTAALLADER	5/2
				DR	INTEGREX 200 | DMG MORI CLX 350 | PRIMOS | INTEGREX J200 | 250 STAF	5/1

FIGURE 75: Data of sim_1 - sim_4.

7.5.2 New Layout - Constant at Machines

To see what would happen is there would be a new layout, and when all Operators still would be constantly at the machines (during set-up and processing), **sim_5**, **sim_6**, **sim_7** and **sim_8** were performed. There is a new layout, with new machine groups. The M/O ratios are dependent on the day shift and the Operators going with retirement, see Figure 76. The new layout already acts better than doing nothing, still the simulation time increased. Initially, in the current situation, the simulation time was 433 hours. When doing nothing, the simulation time increased to 721 hours. All 4 simulations (sim_5 - sim_8) have a simulation time of 601 hours (Figure 74). From the simulations, it became clear that the machine group F is the critical one, since this group takes most hours in setting-up and processing parts. Compared to sim_3 and sim_4, simulation times of sim_5 - sim_8 are decreased (16,5%). Although, sim_5 - sim_8 are still higher compared to the initial baseline measurement (38,8%).

<table>
<tr><th></th><th>Layout</th><th>Moment at machine</th><th># of Operators</th><th>Machine group</th><th>Machine groups</th><th>M/O ratios</th></tr>
<tr><td>sim_5</td><td>new</td><td>constant</td><td>8</td><td>A</td><td>350 | 350 PORTAALLADER</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>B</td><td>200 MSY ROMIAS | MEGATURN 500 | HARDINGE T42</td><td>3/2</td></tr>
<tr><td></td><td></td><td></td><td></td><td>C</td><td>PRIMOS | 200 MSY ROBOJOB</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>D</td><td>INTEGREX 200 | INTEGREX J200</td><td>2/2</td></tr>
<tr><td></td><td></td><td></td><td></td><td>E</td><td>DMG MORI CLX 350 | DMG MORI NLX 2000</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>F</td><td>HPQ 1 | HPQ 2 | 250 STAF</td><td>2/1</td></tr>
<tr><td>sim_6</td><td>new</td><td>constant</td><td>7</td><td>A</td><td>350 | 350 PORTAALLADER</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>B</td><td>200 MSY ROMIAS | MEGATURN 500 | HARDINGE T42</td><td>3/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>C</td><td>PRIMOS | 200 MSY ROBOJOB</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>D</td><td>INTEGREX 200 | INTEGREX J200</td><td>2/2</td></tr>
<tr><td></td><td></td><td></td><td></td><td>E</td><td>DMG MORI CLX 350 | DMG MORI NLX 2000</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>F</td><td>HPQ 1 | HPQ 2 | 250 STAF</td><td>2/1</td></tr>
<tr><td>sim_7</td><td>new</td><td>constant</td><td>7</td><td>A</td><td>350 | 350 PORTAALLADER</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>B</td><td>200 MSY ROMIAS | MEGATURN 500 | HARDINGE T42</td><td>3/2</td></tr>
<tr><td></td><td></td><td></td><td></td><td>C</td><td>PRIMOS | 200 MSY ROBOJOB</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>D</td><td>INTEGREX 200 | INTEGREX J200</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>E</td><td>DMG MORI CLX 350 | DMG MORI NLX 2000</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>F</td><td>HPQ 1 | HPQ 2 | 250 STAF</td><td>2/1</td></tr>
<tr><td>sim_8</td><td>new</td><td>constant</td><td>6</td><td>A</td><td>350 | 350 PORTAALLADER</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>B</td><td>200 MSY ROMIAS | MEGATURN 500 | HARDINGE T42</td><td>3/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>C</td><td>PRIMOS | 200 MSY ROBOJOB</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>D</td><td>INTEGREX 200 | INTEGREX J200</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>E</td><td>DMG MORI CLX 350 | DMG MORI NLX 2000</td><td>2/1</td></tr>
<tr><td></td><td></td><td></td><td></td><td>F</td><td>HPQ 1 | HPQ 2 | 250 STAF</td><td>2/1</td></tr>
</table>

FIGURE 76: Data of sim_5 - sim_8.

7.5.3 New Layout - Flexible Operators

Since the new layout with fixed man/machine groups did not result in a lower simulation time compared to the baseline measurement simulations (sim_1 and sim_2), it was tested what would happen if there would be one machine group and thus 1 M/O ratio, see Figure 77. This means that Operators are now not bound by machine groups. They can work with every machine and all Operators can move around to work with all machines. So, if Operators could rotate and learn to work with each machine in the coming 7 years, this could be an ultimate option. Still, they can be constantly at a machine during set-up and processing time. If there are 6 Operators, the simulation time (Figure 74) would decrease with 14,8% compared to sim_1 and sim_2. If there are 7 Operators, the simulation time would decrease with 22,4% compared to sim_1 and sim_2.

	Layout	Moment at machine	# of Operators	Machine group	Machine groups	M/O ratios
sim_9	new	constant	7	flex	ALL MACHINES	14/7
sim_11	new	constant	6	flex	ALL MACHINES	14/6

FIGURE 77: Data of sim_9 and sim_11.

7.5.4 New layout - Constant at Machines and Automated Machines

From the previous simulations it became clear that machine group F is the bottleneck, since in this group the most machine hours are present. It was seen as well that as soon as Operators in group F would retire, the simulation times increased compared to the baseline measurement (with constantly being at machines and with having multiple machine groups). After a discussion with Hankamp, machines HPQ1 and HPQ2 are both barstockfeeder lathes that often operate at night. These are thus examples of lathes that can operate automatically once set-up. To see the effects of this, simulation sim_10 was performed. Still, operators need to be constantly present at each machine other than HPQ1 and HPQ2. For HPQ1 and HPQ2, the operator only needs to be present during set-up. From the simulation, it followed that the simulation time is now 352 hours. This is a simulation time decrease of 18,7% compared to sim_1 and sim_2. To see what would happen if full flexibility was the case in stead of machine groups, simulation sim_12 was performed. Here, the simulation time even decreased more, namely 298 hours compared to 433 hours. This is a time decrease of 31,2%. See Figure 78 for the simulation data.

	Layout	Moment at machine	# of Operators	Machine group	Machine groups	M/O ratios
sim_10	new	During set-up at HPQ1 and HPQ2 & constant at rest of machines	6	A	350 | 350 PORTAALLADER	2/1
				B	200 MSY ROMIAS | MEGATURN 500 | HARDINGE T42	3/1
				C	PRIMOS | 200 MSY ROBOJOB	2/1
				D	INTEGREX 200 | INTEGREX J200	2/1
				E	DMG MORI CLX 350 | DMG MORI NLX 2000	2/1
				F	HPQ 1 | HPQ 2 | 250 STAF	2/1
sim_12	new	During set-up at HPQ1 and HPQ2 & constant at rest of machines	6	flex	ALL MACHINES	14/6

FIGURE 78: Data of sim_10 and sim_12.

The percentages of increase and decrease of simulation times compared to the baseline measurement simulation (sim_1 and sim_2) are shown in Figure 79:

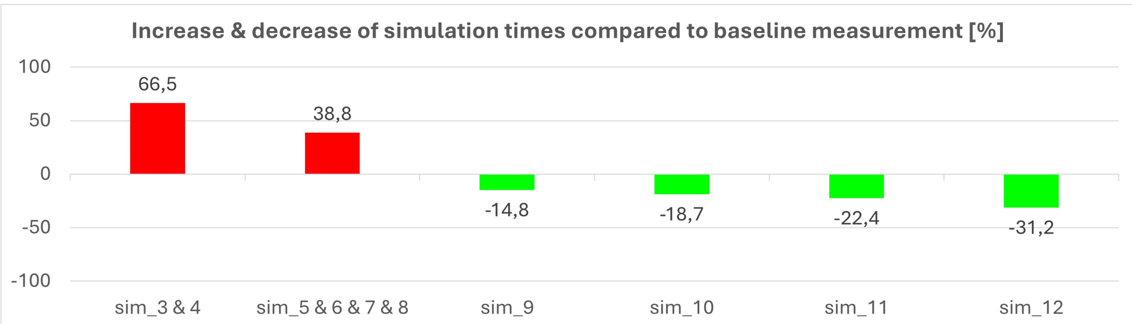

FIGURE 79: Increase (red bars) and decrease (green bars) of simulation times (in percentage) of sim_3 - sim_12, compared to baseline measurement simulations (sim_1 and sim_2).

7.6 Answering Sub-Question 7

How to validate the redesigned lathe department layout?
In conclusion, the newly designed lathe department layout has been validated by multiple simulations using the simulation software Siemens Plant Simulation 16.1. Each simulation consisted out of several components which were either linked or connected to each other. By adding all 107 articles that are produced in January 2023, the busiest production month for Hankamp could be simulated. The simulations had variable options to create several scenarios: number of operators per shift, types of layout, number of machine groups, M/O ratios and the moment during which an Operator is present at machine. Methods were

used and programmed to simulate two ultimatums: an Operator is constantly at a machine (during set-up and processing) or only during the set-up. The baseline measurements resulted in 433 hour simulation time. If nothing will be changed and Operators will retire, the simulation times are increased to 721 hours (+66,5% compared to baseline). For the new layout, with new machine groups and M/Os, the simulation time is still increased to 601 hours (+38,8% compared to baseline). To achieve a lower simulation time with a new layout and less Operators, full flexibility might be an option. This means that there are no machine groups and each Operator is trained to work with all lathes. Depending on the number of Operators, the simulation time would be 369 hours (-14,8% compared to baseline) or 336 hours (-22,4% compared to baseline). All these simulations were performed under the first ultimatum: Operator is constantly at machine. Since HPQ1 and HPQ2 are barstockfeeder that in practice often operate at night, it has been simulated what would happen if these lathes (that are also in the bottleneck machine group F) could be operated with automatic processing times whilst for the rest of all lathes the Operators still had to be constantly present at each machine. Simulation this, with the minimum number of Operators (6), the simulation time was 352 hours (-18,7% compared to baseline). If in this case everyone would be flexible, the simulation time decreased to 298 hours (-31,2% compared to baseline). Summarizing, there are possibilities to produce the same number of articles with less Operators. In fact, this could even be done faster according to the simulations. The most realistic option is sim_10: if the HPQ1 and HPQ2 are operated automatically during processing, and for the rest of the machines the Operators stay at their machines constantly with the new layout, the simulation time is decreased.

8 Conclusion

This last Chapter, this research will be concluded. All the executed steps lead to 19 recommendations, functioning as advice to be taken into account for Hankamp Gears (Section 8.1). After this, future work will be discussed (Section 8.2). Lastly, the main research question is answered (Section 8.3).

8.1 Recommendations & Advice

Based on the executed research, a total of 19 recommendations are summarized. This functions as advice for Hankamp Gears:

1. **All lathes, besides 200 MSY ROBOJOB, need to be relocated to create 1 large department instead of 4 small lathe departments as is done currently.** The 200 MSY ROBOJOB is already at the proper location. Since other departments and machines have been moved, enough space is created to make 1 lathe department with the new design. By placing all machines close to the walls there is enough space to walk, move and work. Furthermore, for the operators it is more clear what is happening in the department, since there is now 1 large and open department which is not separated and blocked by walls. By creating a clear working environment, operators see better what is happening, they can help each other quicker when needed and they can learn quicker from each other since everyone can see what someone else is doing. This can enhance flexibility as well.
2. **Let other operators, so not the lathe operators, use the spark-erosion machine, the grinding machine and the two milling machines.** In the current situation, the lathe operators also use these machines. By relocating these other machines and by creating one lathe department, the machines are separated from

the lathe department. Doing so, the lathe operators can focus on turning operations and have lower M/O ratios. The other machines placed in other departments can be used by operators in those respectable departments.

3. **In the new situation with a redesigned lathe department and with all operators with retirement, keep M/O ratios of 3/2, 2/1 and 3/1.** Based on the simulations performed it became clear that 18,7% reduction in simulation time is possible with these M/O ratios. Furthermore, these ratios are comparable with the ratios used in the current situation (3/1, 5/2, 6/3 and 5/3). Based on conversation with the operators, it was stated that a ratio of 2/1 could be challenging already. For that reason, only ratio 3/1 is used for three bar stock feeder lathes since these can have automatic processing.
4. **Use a balanced hour utilization in the new layout.** In the current layout each of the 4 departments had a varying hour utilization. This varied up to factor 3 per department and up to factor 6 per operator if people will retire. Then, the department where people do retire becomes the bottleneck and thus becomes the slowest group of machine to finish production. With the new layout and a more balanced hour utilization per machine group, the effects of retirement can be compensated for. In practice, if machine are automatically processing the operators with less hours can help operators with more machine hours to spread out the work. In the new situation, three machine groups had equal machine hour utilization. Once was factor 0,5 of this utilization, one factor 1,5 and the bottleneck factor 2,5. In the bottleneck group, by setting HPQ1 and HPQ2 to automatic processing, this factor was brought close to 1.
5. **Prioritize using, setting-up and automatic processing of lathes HPQ1 and HPQ2.** From the simulations is was evident that the machine group with HPQ1 and HPQ2 was the new bottleneck. By automatic processing of HPQ1 and HPQ2, the simulation time reduced with 18,7% compared to the current situation. Automatic processing is realistic, since these lathes are bar stock feeders and often operate (automatically) at night.
6. **Prioritize lathes PRIMOS, 200 MSY ROBOJOB, INTEGREX 200, DMG MORI CLX 350, HPQ1, HPQ2 and 250 STAF regarding production of all articles with diameter up to and including 150 mm.** If these machines are prioritized to be set-up and to process all articles up to 150 mm, then with 7 lathes a total of 37,8% of articles (representing 91,0% of all production numbers) can be produced. This is possible from a technical point of view (possibilities and limitations per machine) and it is possible as well based on the VoCa setup and VoCa processing times. Doing so, already the largest portion of production numbers can be produced with half of the lathes.
7. **Use the other lathes 350 PORTAALLADER, 350, 200 MSY ROMIAS, MEGATURN 500, HARDINGE T42, INTEGREX J200 and DMG MORI NLX 2000 to plan and produce articles with a diameter larger than 150 mm.** Doing so, the largest portion of articles (62,2%) that represents the smallest portion of production numbers (9,0%) is produced with these lathes, whilst the other lathes (as stated above) are prioritized to produce the smallest portion of articles with diameter up to 150 mm (37,8%) that represents the largest production numbers (91.0%). A clear distinction based on diameters and production numbers is made.
8. **Ensure that experienced lathe operators who will retire in the near future transfer their knowledge to the company and the younger generation of lathe operators.** When personnel leaves, not only manpower but also expertise

and experience leaves the company. Knowledge needs to be stored, sorted, saved and transferred from the experiences lathe operators to the company. For example, this can be achieved by correctly ordering and writing setup programs for machines, programming setup and processing codes for machines and archiving information. The younger operators can work together with the older operators to share opinions, expertise and knowledge.

9. **Create and implement standardized working and documentation.** A standard way of working regarding documentation is needed. Currently in the lathe department, it varies how each department and person works and documents. For example, different formats and ways of creating setup plans for machines exist. Or for instance different abbreviations in coding language are used depending on the operator. Unity needs to be created such that everyone works the same way, creates setup instructions the same way and if changes are necessary then this needs to be adjusted also in a standard way. This will both improve data collection and experience transfer from the to be retired operators.
10. **Short Interval Management needs to be implemented in the workshop by having short, daily stand-up meetings at the start of each shift.** During these short conversations at the start of the shift, results and problems need to be communicated. Also, actual performances are compared to planned performances to indicate if all operations go as scheduled. Doing so, possible bottlenecks and challenges can be caught up early on. Missing information and miscommunications thus is reduced by stating the priorities and deadlines. These short meetings can be scheduled per shift by team leaders. Eventually, operators get more responsibilities which they need to handle properly.
11. **Stimulate flexibility within the lathe department by rotating operators.** To become less dependent on certain operators that are the only ones who can work with certain lathes and to create more flexibility within the lathe department, rotation is needed. By rotating the operators, they learn how to work with multiple machines. Furthermore, younger and older operators can work together in shifts and transfer knowledge.
12. **Identify the true reasons why office staff and operators are possibly resistant against change and why they possibly keep holding on to old patterns and habits.** Support of the employees in office and workplace is needed to enhance a change within the company. Although on average all maturity levels and components of People & Organization applicable for a number of areas with possible improvements, spreading clearly shows divided opinions. Hankamp Gears should state clearly why change is needed, what the change of a redesign will bring and how the work to be done will be positively influenced. Operators need to get a chance to think along the process and need to take that opportunity seriously. Active participation between office and workshop is needed to start the change. The company needs to get to know if personnel have any anxiety regarding change, which assumptions they might have and how they look at made changes in the past. This might create a more open culture with less threads regarding change. This can be achieved by discussing the results of the questionnaire or by having 1 to 1 conversations with personnel. This can be done by a confidant of Hankamp Gears. Possibly, personnel feels less pressure when this is performed by an external organization such as Symbol [42].
13. **Create a clear direction and focus regarding the upcoming years (Strategy).** A long-term strategy with achievable and measurable goals needs to be established regarding the redesign of the workplace. The owner of the company and

the office need to agree on what they want to achieve in the coming years. Internal conversations and meetings can be held and the results of the questionnaire can be discussed. To measure the goals and validate them, key performance indicators (KPIs) need to be created. The vision and mission of the company need to be defined, visible and known by all employees. Core values need to be clear and be respected by all employees. A clear strategy is the first step to stimulate quality of management (Leading), which can be used to create an open and action oriented work environment (Openness). The Openness is needed to actively work together with the workshop to change the layout, identify possible other improvement points and to handle made mistakes as a change to learn and grow (Learning). These components together will results in an agile and flexible organization (Agility) than can actively start redesigning and changing the workshop. This all starts with a Strategy.

14. **Relocate sawing department to new location and place sawing machines and storage racks accordingly.** Relocation is needed to create space for the new lathe department and new placement of sawing machines and storage racks improves flow and overview of incoming materials. The new location is the only location since here is a 3,2T gantry crane present. Also, the new location for sawing department has larger area. Security gate around storage is needed to prevent theft of materials and to prevent that operators use materials without permission.
15. **Relocate bench working department to new location and place storage racks accordingly.** Relocation is needed to create space for the new lathe department. Since bench working department is relatively small, it can be placed on old location of DMG MORI NLX 2000.
16. **Relocate assembly department to new location and move storage racks and chip bin accordingly.** Relocation is needed to create space for new lathe department. New location is the only option since here is a 1,0T gantry crane present. The assembly space can be placed to the left such that the gantry crane is above it. The storage racks can be placed to the right, where the gantry crane cannot reach anymore. By placing the chip bin (where also waste articles that do not meet requirements are placed) close to the assembly department, it is close to the waste collection point. Previously the chip bin was placed in a corner in the workshop and by placing it more central, possibly more awareness among the operators regarding quality is achieved. That is because now at a more central point articles that do not meet requirements (waste) are thrown away, which is more clearly visible than previously.
17. **Relocate the gear milling machines closer to the gear milling department.** This is needed to create more space for the new lathe department. The smallest gear milling machine can be placed inside the gear milling department. The other machines has larger dimensions and can be placed in the corner. The biggest machine is next to the lathe department, since this gear milling machine needs a gantry crane.
18. **Relocate the storage racks to make space for the placed gear milling machines.** The storage racks can be placed closer to the storage racks already present at the sawing department and other storage racks of the assembly department. This creates more centralization of storage.
19. **Relocate the milling machine and spark-erosion machine to make space for the newly placed sawing department.** The milling and spark-erosion machine can be placed in the milling department. Doing so, the milling machine is in its own department and the spark-erosion machine can be placed next to the milling machine as is done currently.

8.2 Future Work

Regarding this performed research, there are multiple aspects that deserve attention for upcoming future work. To start with, the CIMM assessment was a first setup and performed by handing out questionnaires and collecting the results. These collected results were mainly used to display spreading of given answers and to indicate how mature Hankamp Gears is regarding the maturity levels and aspects op people & organization. A next step would be to incorporate Symbol to create a more sophisticated and detailed analysis with their experiences. According to Symbol, results can be discussed in a Management Team (MT) session with employees from Symbol, after which a detailed plan of action is made to integrate the right attitude and approach [43]. This might lead to a more thorough step-plan and actions to be undertaken by Hankamp Gears in the upcoming time. Regarding the production data analysis, several simplifications were made. A future step would be to also incorporate the NaCa times and compare the NaCa times with the VoCa times. If relative large differences between the VoCa and NaCa occur, it would be investigated how this happens and how to prevent is. It could be as well that VoCa or NaCa times needs adjustments. Also, maintenance of machines is not taken into account, so those influences are not known yet. A difference in VoCa and NaCa times, together with (un)planned maintenance might influence the machine capacity. If machines have no overcapacity, outsourcing might be an option to look into. For the selected group of lathes to produce 91,0% of production numbers with diameters up to and including 150 mm, a future step would be to investigate how this can be successfully implemented in the planning, since this is not taken into account. Another future work aspect is to investigate how to optimize the equal hour distribution in the workplace as was one of the suggested outcomes. Regarding costs, a future step is to also incorporate profits and turnover to create a realistic cost benefit analysis. It could be investigated as well how another layout can be created with comparable outcomes, but with minimized machine movements to decrease costs since this research had no constraints related to costs. If machines are removed from the workplace, it would be a future research point to identify based on which criteria new machines need to be bought. Lastly regarding the simulations, future research can imply investigating how to simulate more realistically. This can be achieved if it is known more accurately when operators need to be present at a machine and when they can leave.

8.3 Answering Main Research Question

Is it possible to redesign a department such that it becomes future-proof within an SME manufacturing company that is characterized by organic growth and make to order (MTO), high mix low volume (HMLV) manufacturing?
The answer is: yes, this is possible. A case study has been performed for Hankamp Gears, which is an SME company based on the number of employees and annual turnover. Since Hankamp Gears has a workshop and produces parts, it is a manufacturing company. Over the years, Hankamp Gears showed organic growth. When the workshop extended, mainly due to limited resources and no long-term strategy, new machines were placed based on available space instead of logic reasoning. Hankamp Gears produces no standard parts, but parts specifically designed for customers. This makes the manufacturing Make To Order. Since the number of parts is relatively high and the batch size is relatively low, manufacturing is besides Make To Order also High Mix Low Volume. A department, in this case a lathe department, has been redesigned. As a result of the redesign, the lathe department becomes future-proof because with a decrease in operators the same production can be achieved in less production time. If 4 out of 17 operators retire in the near future (23,5%),

in the redesigned layout the simulation time decreased (18,7%) compared to the current situation. This indicates that production time decreased. Furthermore, this means that in the same production time, the production is increased with 23,0%.

This was achieved by first doing literature research. Here, definitions of organic growth and future-proof were stated. It was attempted to find specific literature about lathes regarding redesign, but this was unsuccessful. The literature about HMLV and MTO manufacturing showed the complexity of this type of manufacturing. Often, lean and Kaizen were stated as solutions, although this is more a philosophy and a way of working rather than redesigning a layout. Regarding layout design methods, many do exist. Nevertheless, the layout problem has several challenges and the redesign methods do not solve them regarding this case study. Often, the objective was to minimize costs or distance traveled, whilst the objective for this case study was to redesign a layout to keep equal production rate with a decrease in operators. Lastly, change management was looked into. This was done to better understand why people are against change and how this can be influenced. In short, the research gap was that there is no current method available to make SME, MTO and HMLV manufacturing companies that are organically grown future-proof by redesigning a department in a workshop. The performed research fills this research gap, gives practical insights for Hankamp Gears and other comparable companies can be guided as well by following the proposed theoretical framework and method.
After literature research, the current situation regarding layout, machines, production steps and the department of interest was analyzed to get insights in the starting point for this research. To get an idea of the maturity regarding change and improvement, CIMM questionnaires have been handed out and analyzed, clearly showing divided opinions. This showed that although the averages are around a score of 3 (applicable for number of areas, improvement possible), the spread of scores indicate that most levels, components and people & organization aspects score between 2 (started, limited in presence) and 4 (widely applicable, good).
Once the current situation was analyzed, the product data analysis could be started. Historical data from the past 5 years was analyzed to filter articles of interest and to arrange them based on diameter and production numbers. From all articles produced in the previous 5 years, 68,3% was of interest. This filtering and arrangement allowed to decrease a number of lathes needed to produce a relatively large amount of production numbers with limited articles. The number of lathes to produce 91,0% of production numbers with diameter up to and including 150 mm (equal to 37,8% of all articles) was decreased to 7 lathes (out of 14 lathes). This decreasing number was validated by checking technical capabilities of the lathes and checking machine capacity based on VoCa times. This group of lathes formed a specialistic cell to focus on producing the relative high ratio of production numbers.
Incorporation of employees happened by means of interviews, questionnaires and interactive brainstorm sessions. During the brainstorm sessions, each operator got the opportunity to design his own favorable lathe department layout. This all resulted in 6 machine couples and 4 machine groups: lathes that manufacture articles with relatively large diameters, bar stock feeder lathes, comparable lathes and lathes with similar operating systems. These couples and groups were taken into account to setup constraints for a programming script. The programming script generated layouts that meet all 8 set constraints, decreasing the number of options from 1,3 billion to 8. These 8 theoretical generated layouts were compared to actual practice, rearranged and adjustments were made. This resulted in 1 final layout, meeting all set constraints.

Finally, the chosen layout was simulated with multiple variables to validate the redesign. With a redesigned layout and a decrease in operators, the production rate is even increased (whilst the main goal was to keep the production rate equal). The simulation time was decreased with 18,7% compared to the initial measurement simulations, equal to a production rate increase of 23,0%. To conclude, the redesigned layout becomes future-proof. A recommendation of 19 action points is made for Hankamp Gears is well to take into consideration.

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9 Appendix

In this Appendix, additional information is present. Section 9.1 shows the standard CIMM questionnaire handed out to the office of Hankamp Gears (Figures 80 - 87). Section 9.2 shows the adjusted CIMM questionnaire handed out to the operators of the workshop of Hankamp Gears (Figures 88 - 96). Section 9.3 displays all made layouts by the operators (Figures 97 - 108). Section 9.4 shows the combined scaling factor matrix, were all scaling factors for all machine combinations, and for each operators, is displayed (Figure 109) with a conditional formatted color scale (Figure 110). Section 9.5 shows the Python code regarding the 2D visualization of all machines placed based on average scaling factors (Figure 111). Section 9.6 shows the Matlab code regarding the layout options generation (Figures 112 - 118).

9.1 CIMM Questionnaire Office

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Continuous Improvement Maturity Model Enquête

NAAM: ____
FUNCTIE:____
DATUM: ____

Gelieve deze enquête zelfstandig - dus zonder overleg met collega's - invullen.

De volgende waardes worden tijdens de enquête gebruikt:
1 - Niet aanwezig / geen kennis van
2 - Opgestart, beperkt aanwezig
3 - Toepassing op aantal gebieden, verbetering mogelijk
4 - Uitgebreid toegepast, goed
5 - Volledig geïmplementeerd en geborgd

A.U.B. het toepasbare getal inkleuren.

FIGURE 80: Page 1 of 8 from office questionnaire.

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PROCESVERBETERING SOLIDE FUNDAMENT

Er is een gedegen kwaliteitsmanagementsysteem (KMS) en audits zijn op orde. ① ② ③ ④ ⑤
Er wordt systematisch gezorgd dat alleen datgene wat de klant echt wil, wordt geleverd. ① ② ③ ④ ⑤
Kwaliteitsmanagementsysteem is opgezet volgens de High Level Structure (HLS) ① ② ③ ④ ⑤
Proceseigenaren werken aanpassingen in processen bij in het Kwaliteitsmanagementsysteem. ① ② ③ ④ ⑤
Alle medewerkers begrijpen het belang van kwaliteit en veiligheid. ① ② ③ ④ ⑤
Procedures en protocollen zijn beschikbaar, actueel en duidelijk. ① ② ③ ④ ⑤
Medewerkers zijn op de hoogte en werken volgens procedures en protocollen. ① ② ③ ④ ⑤
Er is een proces om procedures en protocollen continu te verbeteren en te vereenvoudigen. ① ② ③ ④ ⑤
Werk- en inspectie-instructies zijn eenvoudig toegankelijk en bijgewerkt. ① ② ③ ④ ⑤
Er is een programma om medewerkers te trainen in procedures en protocollen. ① ② ③ ④ ⑤
Binnen de organisatie is duidelijk zichtbaar of items wel of niet nodig zijn. ① ② ③ ④ ⑤
Er zijn geen onnodige items op de werkplek aanwezig. ① ② ③ ④ ⑤
Alle benodigde gereedschappen en informatie zijn beschikbaar op de werkplek. ① ② ③ ④ ⑤
Aan het einde van de werkdag liggen alle items op de aangegeven plek. ① ② ③ ④ ⑤
De werkomgeving wordt in stand gehouden, geaudit en continu verbeterd. ① ② ③ ④ ⑤

Figure 81: Page 2 of 8 from office questionnaire.

PROCESVERBETERING CONTINUE VERBETERCULTUUR

Afdeling KPI's zijn gedefinieerd voor o.a. levertijd en kwaliteit. 1 2 3 4 5
Gebieden zijn duidelijk geïdentificeerd en gemarkeerd (bv. vloer, werkplek, labels, borden). 1 2 3 4 5
KPI's zijn duidelijk zichtbaar en gevisualiseerd op communicatieborden. 1 2 3 4 5
Onderhanden werk is duidelijk geïdentificeerd en is op juiste (gemarkeerde) plekken te vinden. 1 2 3 4 5
Dagelijkse planning van activiteiten is duidelijk (minimale betrokkenheid leidinggevenden). 1 2 3 4 5
Dagelijks worden standup meetings gehouden op de werkvloer. 1 2 3 4 5
Operationele prestatie-indicatoren zijn inzichtelijk en up-to-date. 1 2 3 4 5
Elke medewerker in de organisatie ondersteunt het operationele proces. 1 2 3 4 5
Er is een proces gedefinieerd om afwijkingen van de standaard op te lossen. 1 2 3 4 5
Benodigde veranderingen worden snel en goed geïmplementeerd. 1 2 3 4 5
Er is een continu proces voor het uitvoeren van verbeterprojecten (Kaizens) 1 2 3 4 5
Iedereen ziet een fout als een kans voor verbetering, en niet als probleem. 1 2 3 4 5
De PDCA verbetercyclus wordt gehanteerd ingeval van afwijkingen. 1 2 3 4 5
Technieken worden toegepast in het oplossen van problemen (Pareto, 5-Why, Ishikawa, etc.) 1 2 3 4 5
De organisatie is ontvankelijk voor nieuwe ideeën en suggesties voor verbetering. 1 2 3 4 5

Figure 82: Page 3 of 8 from office questionnaire.

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PROCESVERBETERING STABIELE EN VOORSPELBARE PROCESSEN

Relevante Lean prestatie-indicatoren worden bewaakt (bv. takttijd, cyclustijd, OEE, etc.). ① ② ③ ④ ⑤
Continue verbetering is gebaseerd op risico management (Contextanalyse, pFMEA, Control Plan). ① ② ③ ④ ⑤
First Time Right technieken worden toegepast (Poka Yoke, Jidoka, Autonomation) ① ② ③ ④ ⑤
Competenties worden ontwikkeld door middel van een ontwikkelingsprogramma. ① ② ③ ④ ⑤
Systeembeveiliging is op orde en preventief onderhoud wordt uitgevoerd. ① ② ③ ④ ⑤
Belangrijke processen zijn helder beschreven en toegankelijk. ① ② ③ ④ ⑤
Value Stream Mapping wordt jaarlijks toegepast op belangrijke processen. ① ② ③ ④ ⑤
Het verschil tussen de huidige en gewenste prestaties is gedefinieerd. ① ② ③ ④ ⑤
Activiteiten die geen waarde toevoegen worden continu geïdentificeerd en geëlimineerd. ① ② ③ ④ ⑤
Er is een goed functionerende planning & control-cyclus. ① ② ③ ④ ⑤
Opgestelde prestatie-indicatoren zijn in lijn met de strategische doelen. ① ② ③ ④ ⑤
Flow: Doorstroming in de processen is zichtbaar aanwezig. ① ② ③ ④ ⑤
Pull: Uitvoering van werkzaamheden is vraaggestuurd. Systemen als Kanban, CONWIP aanwezig. ① ② ③ ④ ⑤
Knelpunten in het proces zijn geïdentificeerd en worden aangepakt. ① ② ③ ④ ⑤
Agility: De organisatie is flexibel en daadkrachtig. Teams zijn zelfsturend en empowered. ① ② ③ ④ ⑤

Figure 83: Page 4 of 8 from office questionnaire.

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PROCESVERBETERING CAPABLE PROCESSEN

Er is een Lean Six Sigma organisatiestructuur (Champions, YB's, OB's, GB's and BB's). ① ② ③ ④ ⑤
Doorbraakprojecten zijn in lijn met de lange termijn strategie (Hoshin Kanri). ① ② ③ ④ ⑤
De DMAIC aanpak wordt gevolgd. Projectvoortgang wordt bewaakt en er zijn Tollgates. ① ② ③ ④ ⑤
Goede balans tussen operationele activiteiten en tijd voor het werken aan doorbraakprojecten. ① ② ③ ④ ⑤
Champions en (Master) Black Belts hebben een actieve rol in training en coaching. ① ② ③ ④ ⑤
Kritische specificaties van product/dienst zijn weergegeven in een CTQ flowdown. ① ② ③ ④ ⑤
Statistische technieken worden toegepast om de variatie van de CTQ te analyseren. ① ② ③ ④ ⑤
Invloedsfactoren en interacties op de CTQ zijn bekend en geoptimaliseerd (bv. DOE). ① ② ③ ④ ⑤
Kwaliteit wordt gerapporteerd o.b.v. Proces Capability (Cpk) en Proces Performance (Ppk). ① ② ③ ④ ⑤
Maatregelen zijn bepaald voor bijzondere variatie (Out of Control situaties). ① ② ③ ④ ⑤
Er is actief beleid op het verzamelen, verwerken en analyseren van (big) data. ① ② ③ ④ ⑤
Systemen zijn in staat data onderling eenvoudig uit te wisselen. ① ② ③ ④ ⑤
Nauwkeurigheid, repeatability en reproducibility van meetsystemen en data zijn op orde. ① ② ③ ④ ⑤
De organisatie maakt gebruik van complexe analytische software voor analyse van data. ① ② ③ ④ ⑤
Er is een duidelijk besluitvormingsproces o.b.v. data analyse en conclusies. ① ② ③ ④ ⑤

FIGURE 84: Page 5 of 8 from office questionnaire.

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PROCESVERBETERING TOEKOMSTBESTENDIGE PROCESSEN

Alle middelen, processen, bedrijfssystemen en beschikbare data zijn geïntegreerd in PLM. ① ② ③ ④ ⑤
Product Lifecycle Management (PLM) wordt actief toegepast. ① ② ③ ④ ⑤
De organisatie is innovatief en trendsetter in haar marktgebied. ① ② ③ ④ ⑤
Unieke producten / diensten worden in de markt aangeboden (Customer Intimacy). ① ② ③ ④ ⑤
Superieure producten / diensten worden in de markt aangeboden (Product Leadership). ① ② ③ ④ ⑤
Er is een gestandaardiseerde aanpak voor het ontwikkelen van nieuwe producten / diensten. ① ② ③ ④ ⑤
Essentiële/specifieke klanteisen zijn helder (Gebruik van QFD). ① ② ③ ④ ⑤
Design FMEA wordt gebruikt om potentiële risico's in de ontwikkelfase te identificeren. ① ② ③ ④ ⑤
Ontwikkeling o.b.v. Co-creation. Alle disciplines en essentiële leveranciers zijn vroeg betrokken. ① ② ③ ④ ⑤
Design for Six Sigma wordt gebruikt in de ontwikkeling van nieuwe producten. ① ② ③ ④ ⑤
Mass Customization en Modularisatie worden toegepast. Elk product is uniek geïdentificeerd. ① ② ③ ④ ⑤
Gebruik van Cyber Physical Systems, Cobots en/of Robotic Process Automation (RPA). ① ② ③ ④ ⑤
Internet of Things / Digital Factory: Machines en Business Intelligence systemen zijn connected. ① ② ③ ④ ⑤
Er is actief beleid op Cyber Security en Privacy Certificering. ① ② ③ ④ ⑤
Er is actief beleid op ontwikkeling en transformatie van medewerkers naar SMART Industry. ① ② ③ ④ ⑤

Figure 85: Page 6 of 8 from office questionnaire.

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PEOPLE & ORGANIZATION

De visie en missie zijn vastgesteld, zichtbaar en bekend bij alle medewerkers. ① ② ③ ④ ⑤
De kernwaarden zijn vastgesteld en worden doorleefd door alle medewerkers. ① ② ③ ④ ⑤
Er is een heldere langetermijnstrategie. ① ② ③ ④ ⑤
Er is een duidelijke focus en doelstellingen zijn haalbaar. ① ② ③ ④ ⑤
Het management is in staat de focus vast te houden, ook als het tegen zit. ① ② ③ ④ ⑤
Het management is een voorbeeld, is integer, is zichtbaar en geniet vertrouwen. ① ② ③ ④ ⑤
Het management bestaat uit sterke en daadkrachtige leiders. ① ② ③ ④ ⑤
Het management is in staat om het creatieve vermogen van medewerkers te stimuleren. ① ② ③ ④ ⑤
Het management wijst noodzakelijke tijd en middelen toe aan focusprojecten. ① ② ③ ④ ⑤
Het management is daadkrachtig met betrekking tot 'niet-presteerders'. ① ② ③ ④ ⑤
Medewerkers gaan elke dag met veel plezier aan het werk. ① ② ③ ④ ⑤
Medewerkers worden betrokken bij belangrijke beslissingen en projecten. ① ② ③ ④ ⑤
De organisatie vormt een open en veilige werkomgeving voor medewerkers. ① ② ③ ④ ⑤
Medewerkers voelen zich betrokken en verbonden met de organisatie en hun werkzaamheden. ① ② ③ ④ ⑤
De organisatie is resultaatgericht i.p.v. taakgericht. ① ② ③ ④ ⑤

Figure 86: Page 7 of 8 from office questionnaire.

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PEOPLE & ORGANIZATION - VERVOLG

Medewerkers worden geïnspireerd om goede resultaten te behalen. ① ② ③ ④ ⑤
Het maken van fouten is een kans om te leren en te groeien. ① ② ③ ④ ⑤
De organisatie heeft een gevarieerd en complementair medewerkersbestand. ① ② ③ ④ ⑤
De organisatie groeit door samenwerking met leveranciers en/of klanten. ① ② ③ ④ ⑤
De organisatie heeft een actief programma voor het ontwikkelen van competenties. ① ② ③ ④ ⑤
Medewerkers zien verandering als een kans. ① ② ③ ④ ⑤
De organisatie is in staat om snel te acteren op veranderende marktsituaties. ① ② ③ ④ ⑤
Er is sprake van zelfsturing/zelforganisatie en hoge mate van verantwoordelijkheid. ① ② ③ ④ ⑤
Er wordt daadkrachtig geacteerd als resultaten afwijken van de target. ① ② ③ ④ ⑤
Het management is in staat snel besluiten te nemen. ① ② ③ ④ ⑤

Einde enquête

HARTELIJK DANK VOOR HET INVULLEN!

Figure 87: Page 8 of 8 from office questionnaire.

9.2 CIMM Questionnaire Workshop

Enquête Draaierij Hankamp Gears – Afstudeeronderzoek Dominiek

DATUM:____

Gelieve deze enquête zelfstandig – dus zonder overleg met collega's – invullen.

In deze enquête staan stellingen. Iedere stelling kan beantwoord worden aan de hand van scores. De volgende scores worden tijdens de enquête gebruikt:

1 = niet aanwezig / geen kennis van
2 = opgestart, beperkt aanwezig
3 = toepassing op aantal gebieden, verbetering mogelijk
4 = uitgebreid toegepast, goed
5 = volledig geïmplementeerd (toegepast) en geborgd (deel uitgemaakt van dagelijkse werkzaamheden)

A.U.B. gekozen getal aankruisen/inkleuren.

De enquête kan anoniem ingevuld worden.

De enquête begint op de volgende pagina.

FIGURE 88: Page 1 of 9 from workshop questionnaire.

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Georganiseerde werkomgeving (5S) – S1: Scheiden
Alleen noodzakelijke voorwerpen zijn aanwezig op de werkplek. *Voorbeeld: voorwerpen die absoluut nodig zijn op de werkplek, voorwerpen die regelmatig gebruikt worden, voorwerpen die nodig zijn om het werk goed uit te voeren.* ① ② ③ ④ ⑤
Overbodige voorwerpen worden weggegooid of verplaatst naar een andere locatie. *Voorbeeld: voorwerpen die niet regelmatig gebruikt worden, voorwerpen die het echte werk in de weg staan, voorwerpen die de werkvloer potentieel gevaarlijk maken.* ① ② ③ ④ ⑤
Georganiseerde werkomgeving (5S) – S2: Schikken
De werklocatie is zodanig ingericht dat iedereen alles snel en gemakkelijk kan vinden. ① ② ③ ④ ⑤
Voorwerpen die samen horen, zijn gegroepeerd. ① ② ③ ④ ⑤
Het is voor iedereen duidelijk waar een voorwerp gevonden kan worden en waar het na gebruik weer moet worden teruggezet. ① ② ③ ④ ⑤
Ieder voorwerp heeft een vastgestelde plek. ① ② ③ ④ ⑤
De meest gebruikte voorwerpen liggen binnen handbereik. ① ② ③ ④ ⑤
Locaties van voorwerpen worden gevisualiseerd. *Voorbeeld: omlijning, markeringen, borden, pijlen, kleurcodes, labels enz.* ① ② ③ ④ ⑤
Voorwerpen zijn gerangschikt op basis van de frequentie waarmee ze worden gebruikt. *Voorbeeld: voorwerpen die meerdere keren per dag worden gebruikt liggen dichter bij de werkplek dan voorwerpen die slechts een keer per week worden gebruikt en voorwerpen die nog minder vaak worden gebruikt zijn opgeborgen in een kast, aparte afdeling of magazijn.* ① ② ③ ④ ⑤
Georganiseerde werkomgeving (5S) – S3: Schoonmaken
De werkplek wordt schoongemaakt en netjes gehouden. ① ② ③ ④ ⑤
Het schoonmaken van de werkplek is routine: er is vastgesteld wat, hoe, wanneer en door wie er moet worden schoongemaakt. ① ② ③ ④ ⑤
Iedereen neemt de taak van schoonmaken op zich. ① ② ③ ④ ⑤
De omgeving heeft goede verlichting om in te werken. *Voorbeeld: geen kapotte lampen, geen flikkerende lichten, geen slecht verlichte omgevingen, tijdens werkzaamheden is alles duidelijk te zien/lezen.* ① ② ③ ④ ⑤

1 = niet aanwezig/geen kennis van **2 = opgestart, beperkt aanwezig**
3 = toepassing op aantal gebieden, verbetering mogelijk **4 = uitgebreid toegepast, goed**
5 = volledig geïmplementeerd en geborgd

FIGURE 89: Page 2 of 9 from workshop questionnaire.

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Georganiseerde werkomgeving (5S) – S3: Schoonmaken vervolg
Qua geluid is de werkomgeving goed om in te werken met gehoorbescherming. *Voorbeeld: geen lawaaierige omgeving, geen harde geluiden, geen harde knallen, geen hoge piepen, geen overschrijdingen geluidsnormen, geen last van gehoor.* ① ② ③ ④ ⑤
De werkplek is ergonomisch. ① ② ③ ④ ⑤
De werkplek is veilig. *Voorbeeld: machine veiligheid, geen gevaarlijke situaties of gevaren.* ① ② ③ ④ ⑤
Georganiseerde werkomgeving (5S) – S4: Standaardiseren
Er zijn regels voor het plaatsen van materialen in de werkplaats. ① ② ③ ④ ⑤
Er zijn regels voor het aanschaffen van nieuwe materialen. ① ② ③ ④ ⑤
Er zijn regels voor het opstellen van schoonmaakinstructies. ① ② ③ ④ ⑤
Er zijn regels voor het aanbrengen van belijning in de werkplaats. ① ② ③ ④ ⑤
Er zijn regels voor werkkleding. *Voorbeeld: veiligheidsbrillen, handschoenen, oorbeschermers, beschermend schoeisel.* ① ② ③ ④ ⑤
Er is een communicatie bord/scherm aanwezig in de werkplaats. ① ② ③ ④ ⑤
Met betrekking tot veiligheid zijn brandblussers, eerste hulp dozen en uitgangen duidelijk gemarkeerd. ① ② ③ ④ ⑤
Er zijn regels hoe papieren en/of digitale documenten worden opgeslagen. ① ② ③ ④ ⑤
Georganiseerde werkomgeving (5S) – S5: Standhouden
Alle voorgaande stappen en maatregelen (Scheiden, Schikken, Schoonmaken, Standaardiseren) worden in stand gehouden. ① ② ③ ④ ⑤
Op de werkvloer zijn werknemers gedisciplineerd. ① ② ③ ④ ⑤
Op kantoor zijn werknemers gedisciplineerd. ① ② ③ ④ ⑤
Werknemers spreken anderen aan als afspraken en/of regels niet worden nageleefd. ① ② ③ ④ ⑤
Er zijn controles om te checken of afspraken en/of regels worden nageleefd. ① ② ③ ④ ⑤

1 = niet aanwezig/geen kennis van **2 = opgestart, beperkt aanwezig**
3 = toepassing op aantal gebieden, verbetering mogelijk **4 = uitgebreid toegepast, goed**
5 = volledig geïmplementeerd en geborgd

FIGURE 90: Page 3 of 9 from workshop questionnaire.

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Gestandaardiseerd werk en documentatie
Het is vastgesteld wie bevoegd zijn om processen en/of taken uit te voeren en welke trainingen deze personen daarvoor nodig zijn. ① ② ③ ④ ⑤
Er is documentatie aanwezig welke vertelt wat nodig is om het proces te starten. *Voorbeeld: protocollen, richtlijnen, regels, werkorders, instelbladen, tekeningen.* ① ② ③ ④ ⑤
Deze documentatie omschrijft welke voorwerpen en/of gereedschappen nodig zijn om een product te maken. ① ② ③ ④ ⑤
Deze documentatie omschrijft welke procesactiviteiten er moeten worden voltooid. ① ② ③ ④ ⑤
Deze documentatie omschrijft hoe het eindproduct eruit komt te zien. ① ② ③ ④ ⑤
Deze documentatie omschrijft welke kwaliteitscontroles er uitgevoerd moeten worden. ① ② ③ ④ ⑤
Deze documentatie omschrijft hoelang een werknemer over een bepaalde processtap mag doen voordat het product verder gaat naar de volgende processtap. ① ② ③ ④ ⑤
Deze documentatie omschrijft hoe vaak machine gereedschap vervangen moeten worden. ① ② ③ ④ ⑤
Deze documentatie omschrijft hoe vaak machine slijt onderdelen vervangen moeten worden. ① ② ③ ④ ⑤
Deze documentatie omschrijft hoe vaak de producten worden opgehaald en hoe deze producten worden verpakt en/of opgeslagen. ① ② ③ ④ ⑤
Werknemers worden gestimuleerd om een proces continue te verbeteren. ① ② ③ ④ ⑤
Werknemers bespreken manieren om een proces te verbeteren met elkaar. ① ② ③ ④ ⑤
Kwaliteitsmanagement
Er is een Kwaliteit Management Systeem (KMS) geïmplementeerd, oftewel een verzameling van bedrijfsprocessen die gericht zijn op het bereiken van het kwaliteitsbeleid en de kwaliteitsdoelstellingen van de klant en wettelijke eisen. *Voorbeeld: ISO 9001, AS9100.* ① ② ③ ④ ⑤
Er is een kwaliteitsplanning geïmplementeerd, oftewel alles wat een bedrijf zal doen om de kwaliteit aan de klant te waarborgen. *Voorbeeld: het formuleren van kwaliteitsbeleid, identificeren van klanteisen, overzicht van eisen waar een product aan moet voldoen, kwaliteitsdoelen opstellen, kwaliteitsstandaarden, communicatie van al deze voorbeelden naar alle werknemers.* ① ② ③ ④ ⑤
Er is een kwaliteitscontrole geïmplementeerd, oftewel het identificeren en detecteren dan defecten. *Voorbeeld: geplande inspecties/controles, eindinspectie op beschadigingen, goedkeuring management door middel van handtekeningen, detectie van fouten en beschadigingen.* ① ② ③ ④ ⑤

1 = niet aanwezig/geen kennis van **2 = opgestart, beperkt aanwezig**
3 = toepassing op aantal gebieden, verbetering mogelijk **4 = uitgebreid toegepast, goed**
5 = volledig geïmplementeerd en geborgd

Figure 91: Page 4 of 9 from workshop questionnaire.

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Kwaliteitsmanagement – vervolg
Er is een kwaliteitsborging geïmplementeerd, oftewel een manier om fouten/defecten in producten/processen te voorkomen. *Voorbeeld: er wordt gekeken naar het proces om fouten te voorkomen in plaats van op te sporen, risicoschatting maken voordat er een verandering wordt doorgevoerd in product/proces.* ① ② ③ ④ ⑤
Er is sprake van kwaliteitsethiek, oftewel kritisch nadenken over wat goed is om te doen, ten aanzien van kwaliteit die binnen een organisatie leeft. *Voorbeeld: het nemen van gepaste maatregelen wanneer een fout wordt gevonden.* ① ② ③ ④ ⑤
Evaluatie en audits
Er worden interne inspecties en/of audits uitgevoerd. *Voorbeeld: een audit is een periodiek of eenmalig onderzoek naar een bepaald aspect van een organisatie, meestal aan de hand van bepaalde referentienormen zoals NEN of ISO. Intern: uitgevoerd door kwaliteitsmanager of medewerker van kwaliteitsafdeling, andere medewerker binnen organisatie, checken of afgesproken procedures/werkinstructies/protocollen worden gevolgd.* ① ② ③ ④ ⑤
Er worden externe inspecties en/of audits uitgevoerd. *Voorbeeld: uitgevoerd door gecertificeerde instanties of door auditors van klanten, uitgevoerd op specifiek product of proces, uitgevoerd op totale organisatie en onderliggende processen.* ① ② ③ ④ ⑤
De inspecties en/of audits zorgen ervoor dat de organisatie kansen krijgt voor verbetering. ① ② ③ ④ ⑤
Short Interval Management
Eén keer per dag worden er korte bijeenkomsten georganiseerd om resultaten en problemen te communiceren met elkaar. ① ② ③ ④ ⑤
Er is een vaste plek voor deze bijeenkomsten. ① ② ③ ④ ⑤
Er zijn communicatieborden aanwezig bij deze bijeenkomsten met relevante informatie hierop. *Voorbeeld: relevante informatie zoals kwaliteit en kwantiteit afdeling, geproduceerde items, aantal verwerkte documenten, hoeveelheid onderhanden werk, gemiddelde verwerkingstijd, tijdige levering, status spoedorders, veiligheid, aantal afkeuren.* ① ② ③ ④ ⑤
Meerdere keren per dag komt het team op gezette tijden samen om de actuele prestatie naast de geplande prestatie te leggen. *Voorbeeld: 2 tot 4 keer per dag, 5 a 10 minuten per bijeenkomst, bespreken of iedereen op schema ligt, of gestelde dag doelen worden behaald, actie ondernemen als doelen niet gehaald gaan worden* ① ② ③ ④ ⑤
Tijdens werkzaamheden is er geen ontbrekende informatie. ① ② ③ ④ ⑤
Tijdens de werkzaamheden is er geen miscommunicatie. ① ② ③ ④ ⑤

1 = niet aanwezig/geen kennis van **2 = opgestart, beperkt aanwezig**
3 = toepassing op aantal gebieden, verbetering mogelijk **4 = uitgebreid toegepast, goed**
5 = volledig geïmplementeerd en geborgd

Figure 92: Page 5 of 9 from workshop questionnaire.

Short Interval Management – vervolg
Medewerkers begrijpen volledig de prioriteiten, deadlines en de juiste manier om taken uit te voeren. ① ② ③ ④ ⑤
Informatie over voortgang, prioriteiten en standaarden zijn in één oogopslag duidelijk. ① ② ③ ④ ⑤
Er is sprake van open communicatie tussen medewerkers. *Voorbeeld: problemen worden niet genegeerd of weggestopt* ① ② ③ ④ ⑤
Werknemers weten wat ze moeten doen, wanneer en hoe. *Voorbeeld: real time informatie is beschikbaar, duidelijke instructies, verwachtingen en doelen, visuele hulpmiddelen, waarschuwingssignalen, standaard werkwijze.* ① ② ③ ④ ⑤
Werknemers op de werkvloer krijgen eigen verantwoordelijkheid om zaken aan te sturen. ① ② ③ ④ ⑤
Er is sprake van een visuele werkplek. *Voorbeeld: kleurcodering en labelen van gereedschappen, gestandaardiseerde bakjes en kleurcoderingen, afbakening van afdelingen, markeringen op vloer voor machines/onderdelen/looppaden/onderhanden werklocaties, duidelijke orderinstructies bij onderhandenwerk, schaduwborden voor gereedschap, overzichtelijke communicatieborden, lichten bij machines om status te laten zien.* ① ② ③ ④ ⑤
Grond oorzaak (root cause) analyse
Na fouten en/of afkeur wordt er gekeken naar symptomen: kenmerken of klachten die behoren bij een specifiek probleem. *Voorbeeld: Een document is slecht leesbaar (= symptoom).* ① ② ③ ④ ⑤
Na fouten en/of afkeur wordt er gekeken naar problemen: afwijkingen van een verwachting, een speciale oorzaak of een onverwacht effect waarvan de oorzaak onbekend is. *Voorbeeld (gaat verder met vorige voorbeeld): De afdruk van het document is vaag (= probleem).* ① ② ③ ④ ⑤
Na fouten en/of afkeur wordt er gekeken naar foutmodes: de manier waarop een component functioneel in gebreke blijft en op deze manier een probleem veroorzaakt. *Voorbeeld (gaat verder met vorige voorbeeld): Onvoldoende inkt (= foutmode).* ① ② ③ ④ ⑤
Na fouten en/of afkeur wordt er gekeken naar oorzaken: de bijdragende factoren die leidden tot de storing. *Voorbeeld (gaat verder met vorige voorbeeld): De cartridge is leeg (= oorzaak).* ① ② ③ ④ ⑤
Na fouten en/of afkeur wordt er gekeken naar grondoorzaken: de diepste onderliggende redenen voor het ontstaan van de oorzaak *Voorbeeld (gaat verder met vorige voorbeeld): De cartridge was niet op tijd vervangen (= grondoorzaak).* ① ② ③ ④ ⑤

1 = niet aanwezig/geen kennis van **2 = opgestart, beperkt aanwezig**
3 = toepassing op aantal gebieden, verbetering mogelijk **4 = uitgebreid toegepast, goed**
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FIGURE 93: Page 6 of 9 from workshop questionnaire.

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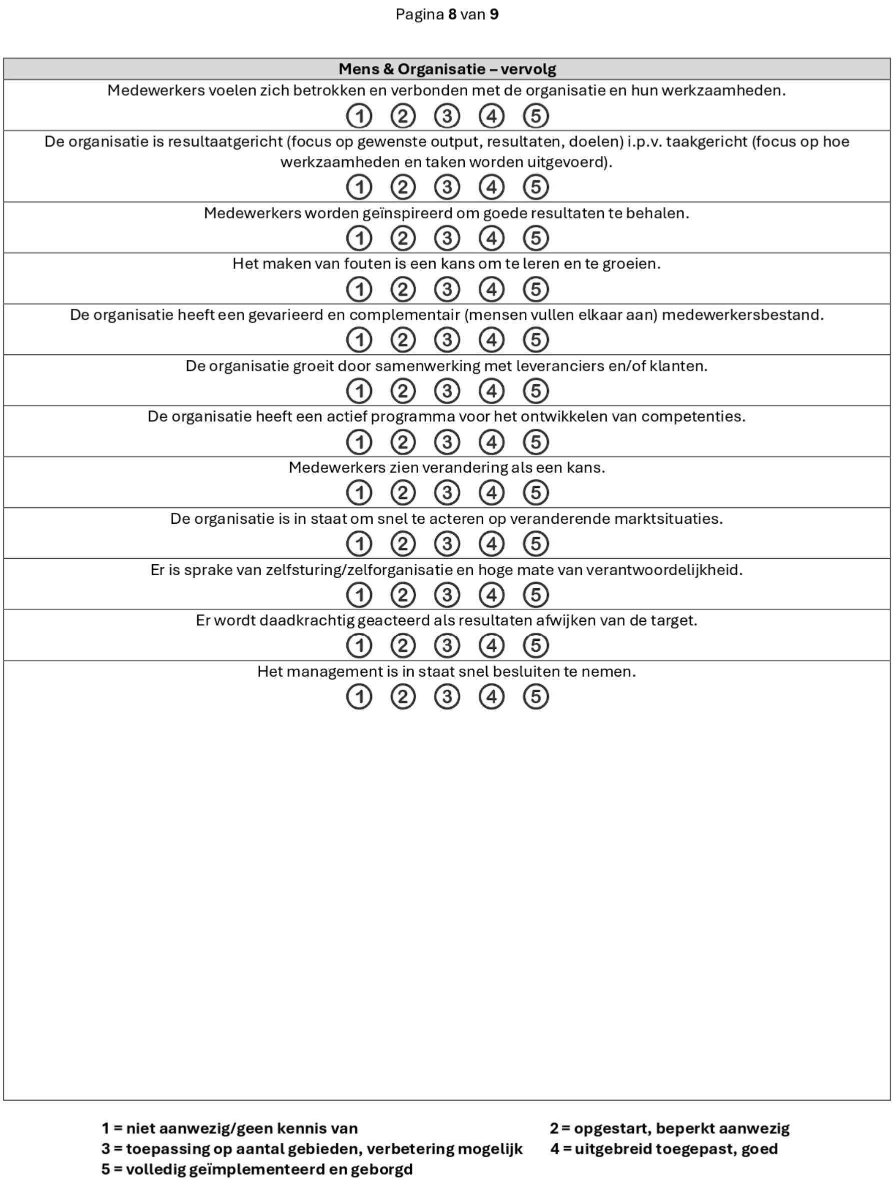
Continue verbetering
Er wordt gefocust op het continue verbeteren van processen door kleine verbeterprojecten. *Voorbeeld: verkorten van omsteltijden in productie, ontwerp van hulpgereedschap om iets makkelijker uit te voeren, verbeteren van werkinstructies en daarmee mogelijke fouten voorkomen, verbetering van de ergonomie en de veiligheid, het reduceren van wachttijden en tussenvoorraden, aanbrengen van markeringen op de werkvloer, invoeren van rekken om tussenvoorraden te beheren, zoeken en elimineren van een probleem.* ① ② ③ ④ ⑤
Als er zich een probleem voordoet, wordt deze opgelost op locatie (de werkvloer) en niet vanachter een bureau of in een vergaderruimte. ① ② ③ ④ ⑤
Medewerkers op de werkvloer worden betrokken bij het bedenken van ideeën. ① ② ③ ④ ⑤
Medewerkers op de werkvloer hebben een bepaalde vrijheid om problemen zelfstandig op te lossen. ① ② ③ ④ ⑤
Mens & Organisatie
De visie en missie van het bedrijf zijn vastgesteld, zichtbaar en bekend bij alle medewerkers. ① ② ③ ④ ⑤
De kernwaarden zijn vastgesteld en worden doorleefd door alle medewerkers. ① ② ③ ④ ⑤
Er is een heldere langetermijnstrategie. ① ② ③ ④ ⑤
Er is een duidelijke focus en doelstellingen zijn haalbaar. ① ② ③ ④ ⑤
Het management is in staat de focus vast te houden, ook als het tegen zit. ① ② ③ ④ ⑤
Het management is een voorbeeld, is integer, is zichtbaar en geniet vertrouwen. ① ② ③ ④ ⑤
Het management bestaat uit sterke en daadkrachtige leiders. ① ② ③ ④ ⑤
Het management is in staat om het creatieve vermogen van medewerkers te stimuleren. ① ② ③ ④ ⑤
Het management wijst noodzakelijke tijd en middelen toe aan focusprojecten. ① ② ③ ④ ⑤
Het management is daadkrachtig met betrekking tot 'niet-presteerders'. ① ② ③ ④ ⑤
Medewerkers gaan elke dag met veel plezier aan het werk. ① ② ③ ④ ⑤
Medewerkers worden betrokken bij belangrijke beslissingen en projecten. ① ② ③ ④ ⑤
De organisatie vormt een open en veilige werkomgeving voor medewerkers. ① ② ③ ④ ⑤

1 = niet aanwezig/geen kennis van **2 = opgestart, beperkt aanwezig**
3 = toepassing op aantal gebieden, verbetering mogelijk **4 = uitgebreid toegepast, goed**
5 = volledig geïmplementeerd en geborgd

Figure 94: Page 7 of 9 from workshop questionnaire.



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Mens & Organisatie – vervolg
Medewerkers voelen zich betrokken en verbonden met de organisatie en hun werkzaamheden. ① ② ③ ④ ⑤
De organisatie is resultaatgericht (focus op gewenste output, resultaten, doelen) i.p.v. taakgericht (focus op hoe werkzaamheden en taken worden uitgevoerd). ① ② ③ ④ ⑤
Medewerkers worden geïnspireerd om goede resultaten te behalen. ① ② ③ ④ ⑤
Het maken van fouten is een kans om te leren en te groeien. ① ② ③ ④ ⑤
De organisatie heeft een gevarieerd en complementair (mensen vullen elkaar aan) medewerkersbestand. ① ② ③ ④ ⑤
De organisatie groeit door samenwerking met leveranciers en/of klanten. ① ② ③ ④ ⑤
De organisatie heeft een actief programma voor het ontwikkelen van competenties. ① ② ③ ④ ⑤
Medewerkers zien verandering als een kans. ① ② ③ ④ ⑤
De organisatie is in staat om snel te acteren op veranderende marktsituaties. ① ② ③ ④ ⑤
Er is sprake van zelfsturing/zelforganisatie en hoge mate van verantwoordelijkheid. ① ② ③ ④ ⑤
Er wordt daadkrachtig geacteerd als resultaten afwijken van de target. ① ② ③ ④ ⑤
Het management is in staat snel besluiten te nemen. ① ② ③ ④ ⑤

1 = niet aanwezig/geen kennis van **2 = opgestart, beperkt aanwezig**
3 = toepassing op aantal gebieden, verbetering mogelijk **4 = uitgebreid toegepast, goed**
5 = volledig geïmplementeerd en geborgd

Figure 95: Page 8 of 9 from workshop questionnaire.

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Ruimte voor extra opmerkingen

EINDE ENQUÊTE – BEDANKT VOOR HET INVULLEN!

Figure 96: Page 9 of 9 from workshop questionnaire.

9.3 Layouts Made by Operators

All layouts made by Operators 1, 3 - 12, and 14 are made using a whiteboard, printed layouts, carton board and magnets. This is shown in Figures 97 - 108:

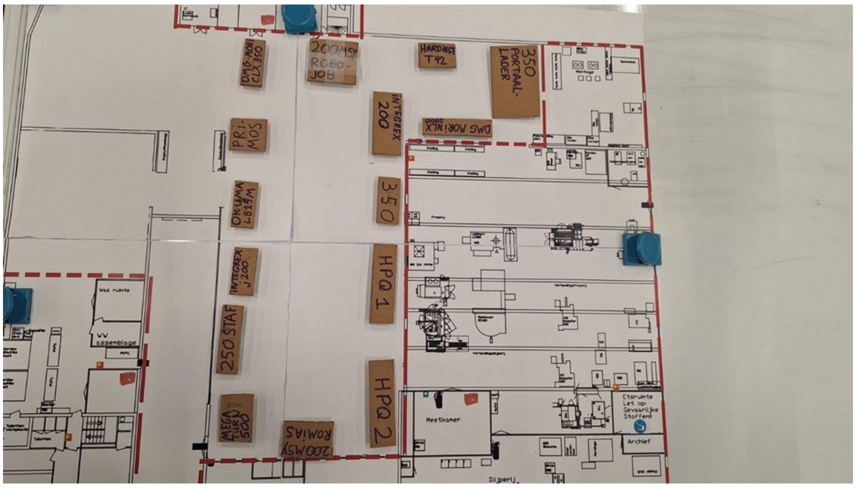

FIGURE 97: Layout of Operator 1.

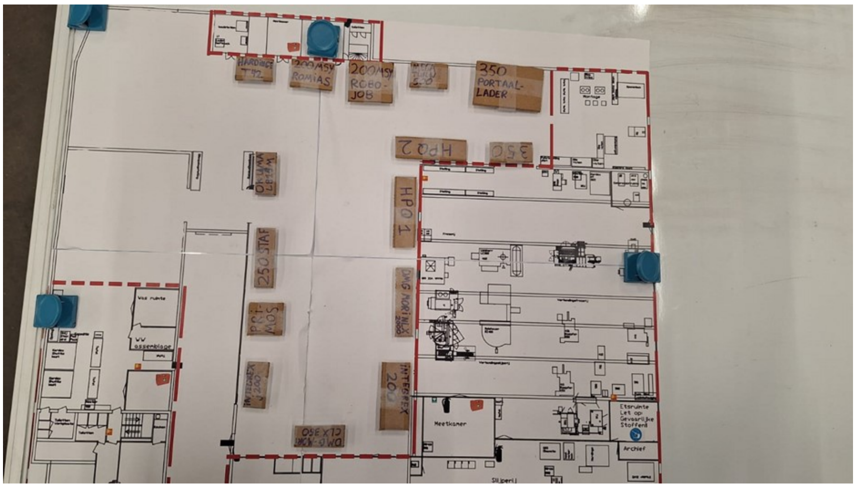

FIGURE 98: Layout of Operator 3.

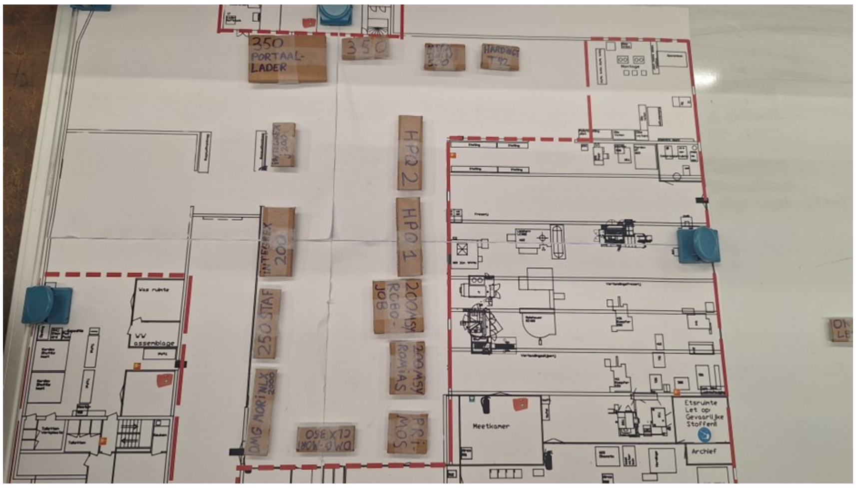

FIGURE 99: Layout of Operator 4.

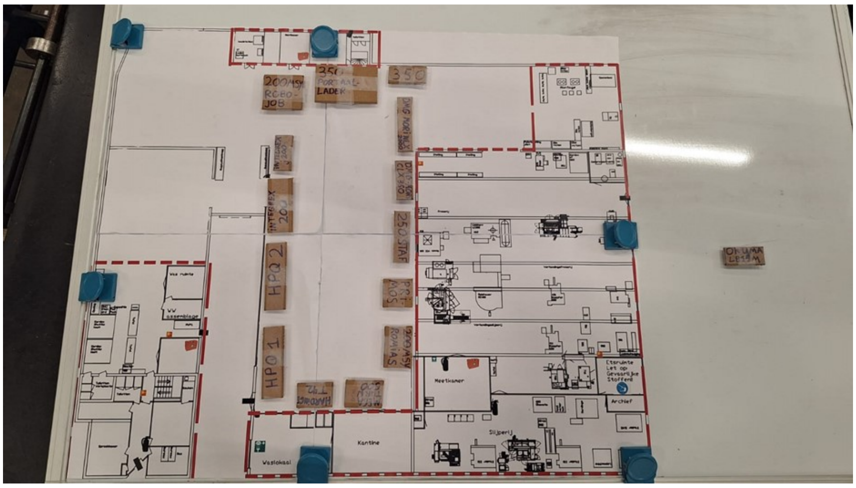

FIGURE 100: Layout of Operator 5.

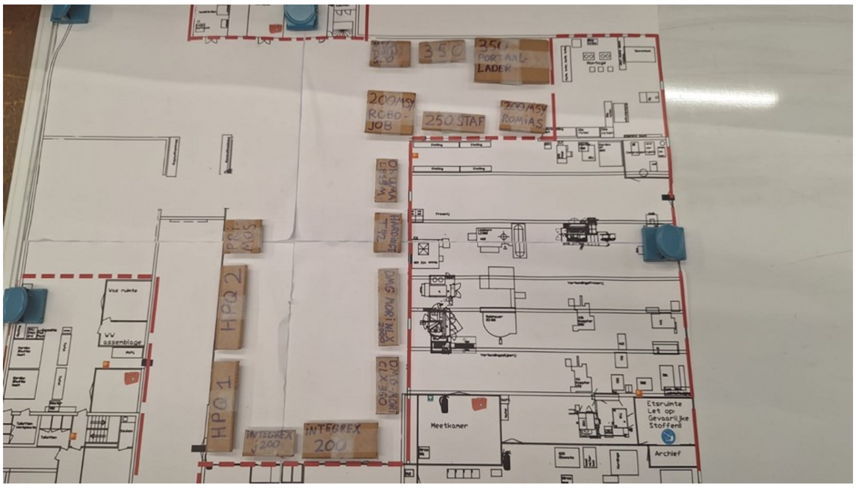

FIGURE 101: Layout of Operator 6.

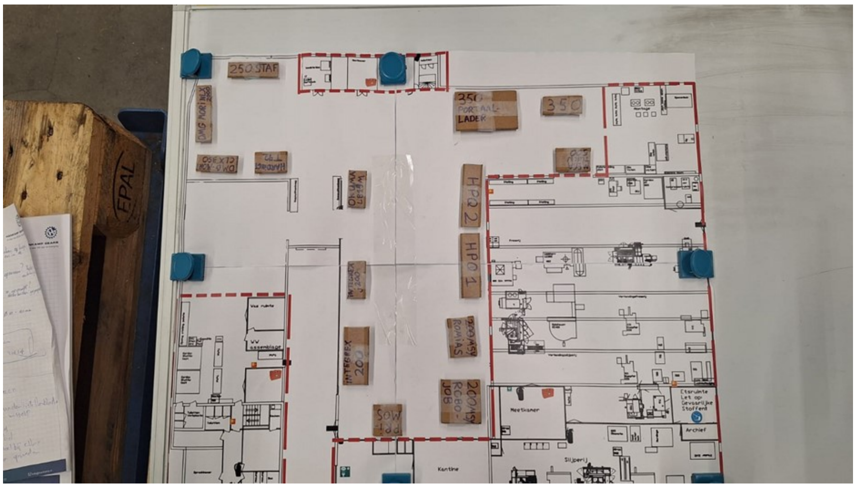

FIGURE 102: Layout of Operator 7.

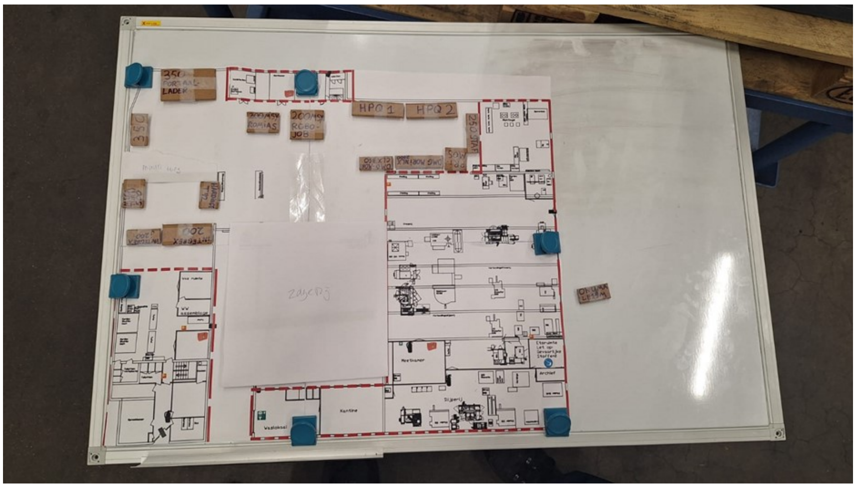

FIGURE 103: Layout of Operator 8.

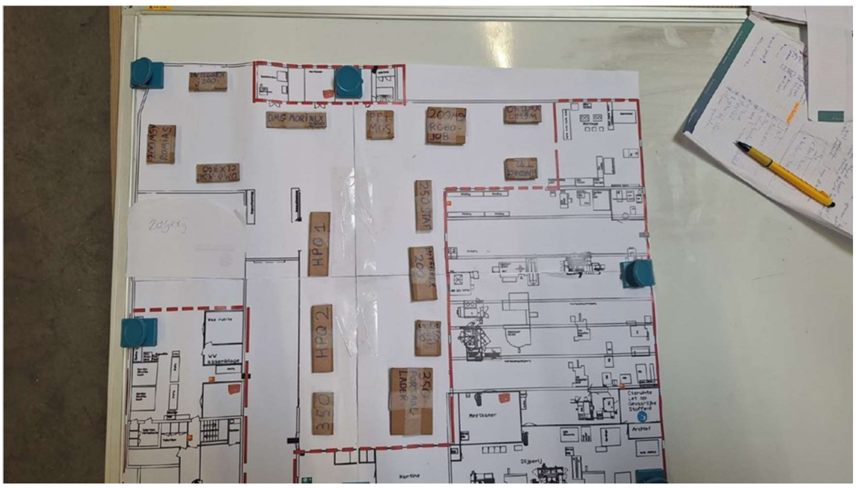

FIGURE 104: Layout of Operator 9.

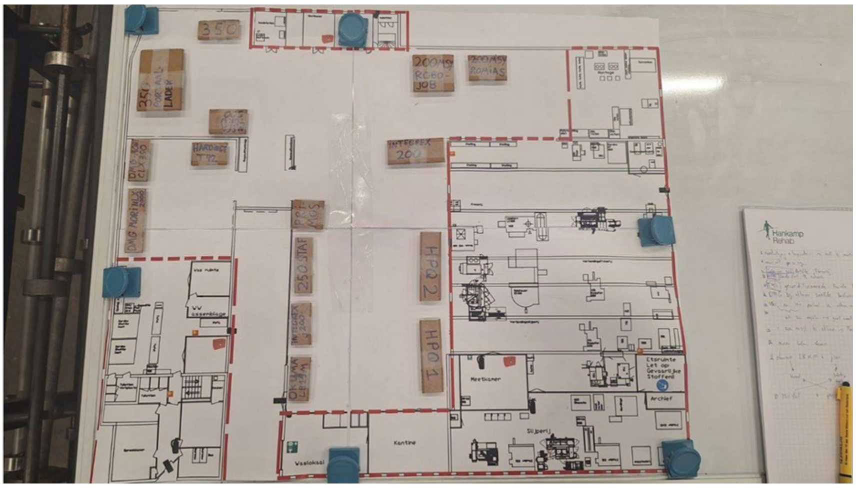

FIGURE 105: Layout of Operator 10.

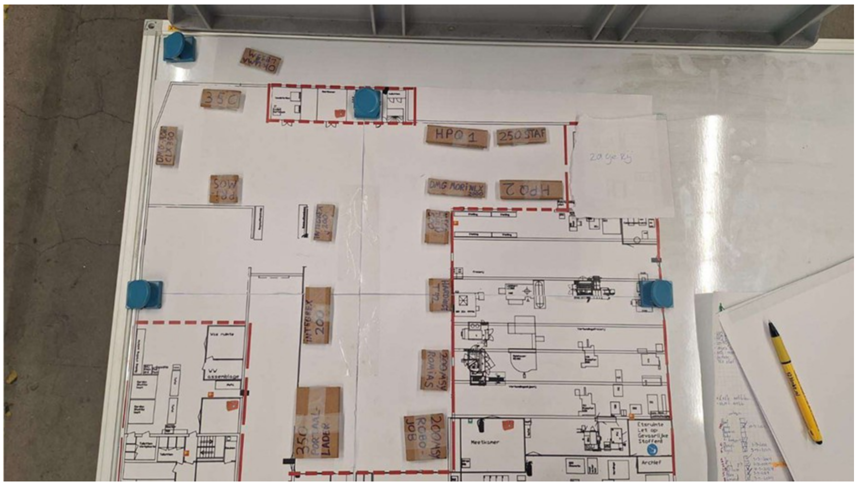

FIGURE 106: Layout of Operator 11.

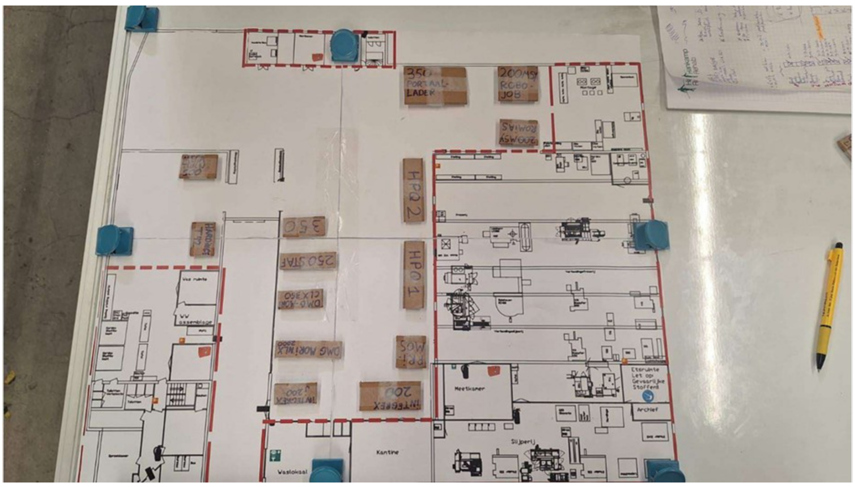

FIGURE 107: Layout of Operator 12.

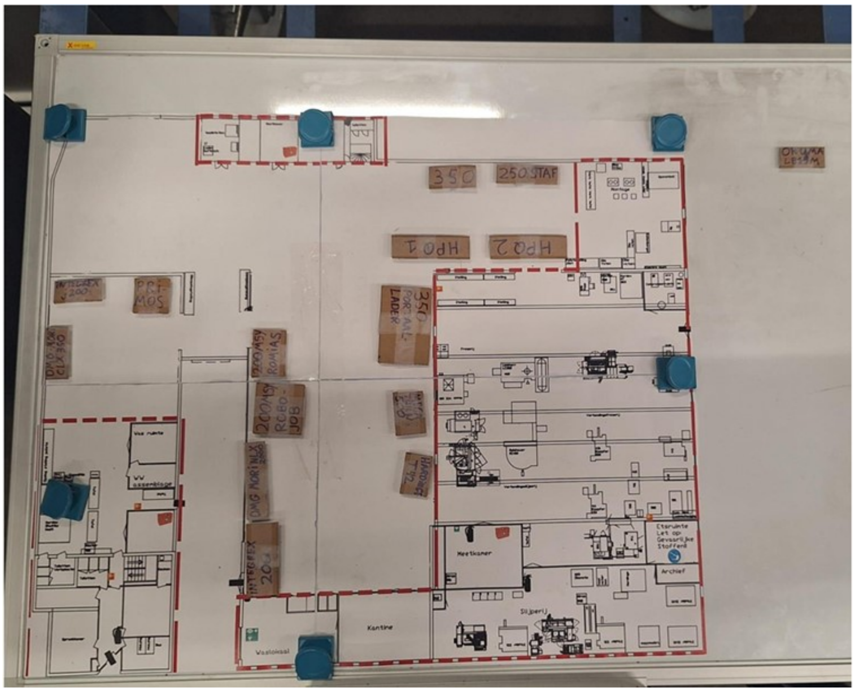

Figure 108: Layout of Operator 14.

9.4 Combined Scaling Factor Matrix

Combined Scaling Factor Matrix were all scaling factors, for each machine combination, for each operator, are shown in Figure 109, together with the used color bar in Figure 110:

	PRIMOS												200 MSY ROBOJOB											
350	25,2	71,0	89,4	60,0	55,7	90,4	90,8	74,6	48,7	15,0	38,3	59,8	23,0	31,2	54,9	27,2	8,7	76,6	43,2	80,3	52,3	100,0	64,4	52,4
PRIMOS													13,7	60,2	20,5	63,6	36,1	8,2	38,6	4,8	44,0	79,0	73,3	27,0
200 MSY ROBOJOB																								

	250 STAF												DMG MORI CLX350											
350	39,5	62,6	63,8	40,3	5,6	76,0	96,0	55,6	61,1	73,8	1,0	5,3	35,1	83,7	90,5	20,7	71,6	86,8	65,7	65,1	34,0	9,2	11,7	84,5
PRIMOS	37,3	2,8	33,8	3,2	47,4	95,2	1,0	13,1	4,5	73,8	29,5	75,9	2,7	20,9	8,2	22,8	40,2	76,0	15,5	35,9	40,5	9,7	25,9	14,0
200 MSY ROBOJOB	61,5	44,5	21,0	49,0	4,1	100,0	42,6	9,9	55,8	78,5	69,2	64,1	4,9	88,5	26,6	35,9	55,7	85,0	16,2	56,2	77,0	98,8	78,1	40,0
250 STAF													56,6	38,4	20,5	3,2	54,6	16,0	22,8	48,6	45,2	88,4	2,2	100,0
DMG MORI CLX350																								

	200 MSY ROMIAS												DMG MORI NLX2000											
350	50,5	46,9	71,6	78,2	13,4	59,2	29,4	80,3	67,6	86,0	57,9	45,6	9,8	37,2	86,7	1,0	52,6	89,2	79,5	74,6	49,9	59,8	26,5	69,1
PRIMOS	65,9	57,7	3,8	2,5	63,4	19,0	53,1	51,8	56,4	66,8	60,9	17,7	39,0	25,8	26,0	42,5	28,3	89,8	2,3	9,3	39,3	54,0	20,6	36,3
200 MSY ROBOJOB	84,1	1,0	2,1	81,1	21,6	5,2	5,0	72,1	5,7	9,2	4,6	1,0	20,8	49,3	32,7	27,9	36,6	97,6	28,1	29,6	84,1	59,8	87,6	6,0
250 STAF	18,1	39,6	24,9	22,1	5,1	83,8	57,8	67,0	67,0	59,2	61,5	58,5	65,4	27,0	11,0	22,8	36,1	5,8	10,2	30,8	39,3	13,2	15,8	79,6
DMG MORI CLX350	84,1	89,7	14,9	41,8	62,4	73,0	29,4	4,2	92,9	87,2	69,2	35,7	40,1	31,8	4,9	3,9	7,7	1,0	4,3	14,3	8,1	70,9	5,1	41,2
200 MSY ROMIAS													74,7	55,9	27,1	60,7	45,3	84,4	41,9	27,7	99,4	40,0	77,5	17,7
DMG MORI NLX2000																								

	INTEGREX 200												MEGATURN 500											
350	4,3	62,0	43,3	48,3	88,1	80,2	27,4	37,2	55,8	56,3	44,9	83,9	53,3	18,5	6,6	96,4	1,5	2,8	11,6	24,5	16,9	59,8	25,3	41,8
PRIMOS	21,4	28,8	48,3	35,2	43,8	7,0	78,9	32,1	25,8	33,6	4,6	53,0	58,8	69,2	87,2	21,4	46,9	79,0	92,7	51,1	25,2	49,9	71,5	51,7
200 MSY ROBOJOB	5,4	75,9	22,7	23,6	70,6	19,0	42,6	30,2	12,8	34,8	87,0	22,7	81,3	1,0	53,3	92,7	2,5	62,8	49,8	49,2	49,3	48,8	85,2	17,7
250 STAF	54,4	40,2	7,1	27,9	71,6	75,4	86,8	5,4	35,2	65,6	35,4	92,6	5,4	54,7	70,5	41,0	11,3	82,6	100,0	25,1	35,8	24,3	33,0	47,4
DMG MORI CLX350	23,0	10,7	39,4	27,9	7,2	55,6	54,5	54,3	68,2	53,4	28,3	53,0	78,0	93,4	92,8	60,0	70,1	89,2	67,7	66,4	18,1	68,6	38,9	67,8
200 MSY ROMIAS	70,3	81,3	33,8	47,6	80,4	17,8	33,3	73,3	21,6	25,5	75,1	34,4	3,8	18,5	68,9	4,6	24,7	47,2	37,3	84,8	65,2	29,5	82,8	22,7
DMG MORI NLX2000	1,6	11,9	31,0	36,7	24,2	69,4	67,7	44,8	71,7	41,8	17,6	6,0	79,7	49,9	92,2	78,9	50,5	94,0	81,5	61,9	28,7	1,0	52,0	26,4
INTEGREX 200													71,4	77,1	52,7	55,6	84,5	71,2	11,6	4,2	43,4	31,3	76,3	35,0
MEGATURN 500																								

	HARDINGE T42												INTEGREX J200											
350	24,1	63,2	21,6	100,0	35,0	71,2	20,8	80,3	25,8	71,5	20,0	55,5	26,9	84,3	19,4	34,5	94,3	64,0	24,1	92,4	77,0	34,8	38,9	74,6
PRIMOS	38,4	57,1	88,9	30,1	24,2	68,2	69,0	29,6	23,4	56,3	58,5	59,8	19,7	3,4	69,4	46,9	39,7	28,0	92,1	38,4	21,0	19,1	25,9	4,7
200 MSY ROBOJOB	10,9	17,9	57,2	89,8	18,0	74,8	28,7	11,2	57,6	29,5	91,7	22,7	43,9	79,5	38,3	5,4	75,3	32,8	53,1	58,1	69,9	55,7	100,0	40,6
250 STAF	76,4	39,0	80,0	46,9	20,1	14,2	76,2	16,2	31,6	39,4	21,7	59,8	2,1	21,5	32,7	35,2	79,4	54,4	100,0	60,7	6,9	49,3	28,9	90,7
DMG MORI CLX350	32,4	92,2	97,8	64,3	25,8	2,2	43,9	77,2	10,4	76,7	24,1	72,8	39,0	7,6	64,4	27,2	21,1	38,8	67,0	13,1	56,4	38,3	18,2	4,1
200 MSY ROMIAS	90,7	1,0	71,6	17,7	31,9	61,0	18,8	94,9	72,9	10,3	86,4	31,3	31,8	76,5	53,3	62,1	90,2	21,4	42,6	9,3	80,0	40,6	89,3	32,6
DMG MORI NLX2000	3,8	64,4	100,0	83,3	6,2	10,6	57,1	54,3	18,1	19,1	34,2	24,5	51,6	34,2	57,2	27,2	33,5	51,4	80,2	15,0	45,8	27,2	4,6	46,8
INTEGREX 200	5,4	87,3	63,3	50,5	40,7	48,4	5,0	28,3	48,1	23,7	60,3	27,6	38,4	25,8	11,6	2,5	5,1	8,8	4,3	72,7	48,7	15,6	17,6	61,0
MEGATURN 500	93,4	34,2	1,0	1,0	32,5	73,6	14,2	43,5	1,0	8,6	11,7	2,9	23,0	86,7	34,9	72,3	89,2	58,6	3,6	87,3	50,5	20,8	62,1	66,6
HARDINGE T42													60,4	76,5	48,3	68,7	47,9	28,6	14,9	84,1	45,2	27,2	42,5	74,0
INTEGREX J200																								

	350 PORTAALLADER												HPQ 1											
350	30,2	4,0	6,6	6,1	5,1	9,4	11,6	11,8	13,4	84,9	46,6	23,3	4,3	19,1	37,2	94,9	91,2	39,4	65,7	35,9	100,0	55,7	25,3	4,7
PRIMOS	56,0	81,9	91,7	59,2	68,0	80,2	78,2	68,9	47,0	60,4	68,0	45,6	36,2	36,6	38,8	33,8	30,4	37,6	20,1	25,8	42,8	55,7	13,4	51,7
200 MSY ROBOJOB	32,4	24,5	58,8	5,4	20,6	70,6	30,0	68,9	68,2	20,2	14,6	22,7	42,8	23,9	4,9	78,2	72,2	25,6	12,9	38,4	69,4	74,4	52,6	38,1
250 STAF	83,0	71,0	56,6	41,8	8,7	53,8	81,5	43,5	56,4	88,9	53,2	31,3	27,4	27,0	30,5	47,6	78,3	71,2	22,1	19,4	34,6	7,4	21,2	14,6
DMG MORI CLX350	53,3	100,0	88,3	24,3	73,7	64,0	54,5	75,3	13,4	78,5	63,8	66,6	50,5	54,7	44,4	62,1	30,4	65,2	7,6	22,6	90,0	70,3	24,7	75,3
200 MSY ROMIAS	93,4	41,4	73,9	77,4	2,5	52,0	16,8	93,7	83,5	26,0	18,8	20,2	30,2	33,0	21,0	28,7	91,2	7,0	27,4	41,6	72,3	55,2	41,3	32,6
DMG MORI NLX2000	3,8	52,9	80,5	9,7	55,7	66,4	67,7	76,5	30,5	66,2	75,7	36,9	28,0	10,7	47,7	78,9	36,6	74,8	12,2	23,8	82,3	4,5	28,9	54,2
INTEGREX 200	19,2	78,9	35,5	32,3	91,8	67,0	38,6	23,2	65,2	20,2	81,0	49,9	25,2	38,4	21,6	38,1	18,5	29,2	62,4	17,5	48,1	52,8	26,5	67,8
MEGATURN 500	100,0	8,2	27,1	92,7	18,0	16,6	30,0	4,2	13,4	54,6	62,7	7,8	36,8	23,3	34,4	17,7	84,5	29,2	72,3	28,3	77,0	15,6	60,3	25,8
HARDINGE T42	5,4	58,3	42,7	92,7	40,2	49,0	26,1	62,6	15,1	39,4	71,0	22,0	44,5	44,5	38,8	2,5	47,4	51,4	49,8	51,1	75,3	34,2	52,6	39,4
INTEGREX J200	71,4	58,3	9,3	16,3	100,0	47,8	40,6	100,0	69,9	46,4	88,7	61,6	21,4	44,5	27,1	57,1	3,6	19,6	74,3	45,4	28,1	33,6	40,1	67,2
350 PORTAALLADER													46,7	30,6	43,3	84,7	99,5	31,6	50,5	39,1	99,4	80,2	46,1	6,6
HPQ 1																								

	HPQ 2											
350	36,8	8,8	17,1	68,0	70,1	23,8	83,5	8,0	80,6	79,0	24,1	12,1
PRIMOS	47,2	52,9	59,4	27,2	5,1	54,4	14,9	51,8	28,1	74,4	36,6	72,8
200 MSY ROBOJOB	74,7	11,3	25,5	47,6	50,5	44,8	30,0	60,0	45,2	64,5	33,0	54,2
250 STAF	27,4	40,8	43,8	30,8	59,3	60,4	5,0	35,3	26,3	5,1	27,1	4,7
DMG MORI CLX350	79,7	73,4	63,8	40,3	31,9	60,4	14,9	44,2	78,2	91,3	36,0	95,7
200 MSY ROMIAS	5,4	25,1	41,6	33,8	73,7	26,2	44,6	61,3	49,3	45,8	25,3	51,1
DMG MORI NLX2000	58,2	28,2	64,4	53,4	27,3	67,6	7,6	51,8	75,3	9,7	46,1	68,4
INTEGREX 200	57,7	55,9	28,3	7,6	30,9	43,0	77,6	21,3	24,0	58,1	49,6	79,6
MEGATURN 500	23,0	5,8	13,8	35,9	61,8	18,4	88,8	16,9	60,5	16,7	53,2	33,8
HARDINGE T42	76,4	40,2	21,6	27,9	30,9	45,4	65,7	64,5	61,1	27,8	53,2	44,9
INTEGREX J200	34,0	40,2	19,9	26,5	23,2	26,8	90,1	70,2	30,5	47,0	58,5	88,2
350 PORTAALLADER	75,8	13,7	28,3	54,9	80,4	13,0	67,7	17,5	83,5	77,9	22,3	20,2
HPQ 1	15,9	2,8	6,0	14,1	12,9	5,2	8,3	12,4	14,6	15,0	14,6	9,7

FIGURE 109: One combined Scaling Factor matrix of all 12 operators who made a layout.

FIGURE 110: Conditional formatting color scale used for combined Scaling Factor matrix, where lowest SF is 1 and highest SF is 100.

9.5 Python Programming Script 2D Layout Based on Average Scaling Factor Matrix

The programming script which was run in Python is shown in Figures 111. To help the writer, ChatGPT 4.0 was used. The writer stated several prompts to generate the code, after which (manual) adjustments were made where necessary. Mainly train and error was used during prompting. For more details about the prompts, please feel free to contact the writer.

```
Python
import numpy as np
import matplotlib.pyplot as plt
from sklearn.manifold import MDS

# Machine names
machines = ['350', 'PRIMOS', '200 MSY ROBOJOB', '250 STAF', 'DMG
MORI CLX350', '200 MSY ROMIAS',
            'DMG MORI NLX2000', 'INTEGREX 200', 'MEGATURN 500',
'HARDINGE T42', 'INTEGREX J200',
            '350 PORTAALLADER', 'HPQ 1', 'HPQ 2']

# Provided distance matrix (average scaling factors)
distance_matrix = np.array([
    [0, 59.9, 51.2, 48.4, 54.9, 57.2, 53.0, 52.6, 29.9, 49.1, 55.4,
21.1, 47.8, 42.7],
    [59.9, 0, 39.1, 34.8, 26.0, 43.2, 34.4, 34.7, 58.7, 50.3, 34.0,
35.3, 44.4, 45.1],
    [51.2, 39.1, 0, 50.0, 55.2, 24.4, 46.7, 37.3, 49.5, 42.5, 54.8,
44.4, 40.2, 30.5],
    [48.4, 34.8, 50.0, 0, 41.4, 47.1, 29.8, 49.8, 44.3, 43.5, 46.8,
55.8, 33.4, 30.5],
    [54.9, 26.0, 55.2, 41.4, 0, 57.0, 19.4, 39.6, 67.6, 51.6, 39.6,
63.0, 49.8, 59.1],
    [57.2, 43.2, 24.4, 47.1, 57.0, 0, 54.4, 49.5, 40.8, 49.1, 52.5,
50.0, 40.1, 40.3],
    [53.0, 34.4, 46.7, 29.8, 19.4, 54.4, 0, 35.3, 58.1, 49.1, 35.3,
51.9, 37.2, 42.1],
    [52.6, 34.7, 37.3, 49.8, 39.6, 49.5, 35.3, 0, 51.2, 40.7, 26.0,
51.9, 46.3, 46.6],
    [29.9, 58.7, 49.5, 44.3, 67.6, 40.8, 58.1, 51.2, 0, 51.6, 51.5,
43.7, 38.5, 46.3],
    [49.1, 50.3, 42.5, 43.5, 51.6, 49.1, 49.1, 40.7, 51.6, 0, 51.5,
59.2, 44.3, 46.6],
    [55.4, 34.0, 54.8, 46.8, 39.6, 52.5, 35.3, 26.0, 51.5, 51.5, 0,
51.9, 38.5, 46.3],
    [21.1, 35.3, 44.4, 55.8, 63.0, 50.0, 51.9, 51.9, 43.7, 59.2,
51.9, 0, 46.3, 30.5],
    [47.8, 44.4, 40.2, 33.4, 49.8, 40.1, 37.2, 46.3, 38.5, 44.3,
38.5, 46.3, 0, 10.9],
    [42.7, 45.1, 30.5, 30.5, 59.1, 40.3, 42.1, 46.6, 46.3, 46.6,
46.3, 30.5, 10.9, 0]
])

# Perform Multidimensional Scaling (MDS) to reduce dimensions to 2D
for visualization
mds = MDS(n_components=2, dissimilarity="precomputed",
random_state=42)
pos = mds.fit_transform(distance_matrix)

# Plot the result
plt.figure(figsize=(10, 7))
plt.scatter(pos[:, 0], pos[:, 1], color='b')

# Annotating points with machine names
for i, machine in enumerate(machines):
```

```
    plt.text(pos[i, 0], pos[i, 1], machine, fontsize=12, ha='right')

plt.title('Machine Arrangement Based on Average Scaling Factors')
plt.xlabel('Dimension 1')
plt.ylabel('Dimension 2')
plt.grid(True)
plt.show()
```

FIGURE 111: Python script.

9.6 Matlab Programming Script Layout Generation

The programming script which was run in Matlab version 2019b is shown in Figures 112 - 118. Each Figure consists out of 4 blocks. Reading in the figures starts at the top left block, then top right, then down left and finally down right. To guide the writer, ChatGPT 4.0 was used. Several prompts were given to structure and create the code, after which adjustments were made. Prompting was mainly trail and error, after which (manual) modifications of the codes were necessary. For more details about the prompts, please feel free to contact the writer.

```matlab
%% xxxx combinaties mogelijk
clc, clear, close all
%% define dimensions, positions and counters DO NOT CHANGE
% large blue rectangle width and height
width_rect = 9;
height_rect = 3;
% restricted red areas positions
x_red_squares = [8, 8, 7, 7, 6, 5, 4, 3, 2, 2, 2, 1];
y_red_squares = [2, 0, 2, 0, 2, 2, 2, 2, 2, 1, 0, 1];
width_red_squares = 1;
height_red_squares = 1;
% colored rectangles (machines) width and height
width_colored_rect = 1;
height_colored_rect = 1;
% movement step sizes (movement of each machine in x and y
step_x = 1;
step_y = 1;
% possible positions for the colored rectangles (machines)
x_positions = 0:step_x:(width_rect - width_colored_rect);
y_positions = 0:step_y:(height_rect - height_colored_rect);
% initialize counter for valid combinations
valid_combination_count = 0;
% initialize storage for valid combinations' positions
valid_positions = [];


%% colors and machines
%{
color      | ith color | machine name
------------------------------------------
green      | 1st       | 250 STAF
yellow     | 2nd       | HPQ 1
pink       | 3rd       | HPQ 2
black      | 4th       | DMG MORI NLX 2000
cyan       | 5th       | DMG MORI CLX 350
blue       | 6th       | INTEGREX 200
navyblue   | 7th       | INTEGREX J200
orange     | 8th       | 200 MSY ROBOJOB
gold       | 9th       | 200 MSY ROMIAS
purple     | 10th      | PRIMOS
grassgreen | 11th      | 350 PORTAALLADER
lightpink  | 12th      | 350
cyangreen  | 13th      | MEGATURN 500
darkgreen  | 14th      | HARDINGE T42
%}



%% loop through all combinations of all colored rectangles



%% GREEN (1st color)
for x_green = x_positions
for y_green = y_positions
%% GREEN and RED AREA overlap
```

```matlab
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_green >= (x_red_squares(i) + width_red_squares) || (x_green +
width_colored_rect) <= x_red_squares(i) || ...
y_green >= (y_red_squares(i) + height_red_squares) || (y_green +
height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip this combination if green overlaps
with a red square
%% GREEN not allowed to be placed
%x and y coordinate are the left lower position, from here the
rectangle
%is drawn
if x_green == 3 && y_green == 1 %tussen linker en midden deur
continue;
end
if x_green == 4 && y_green == 1 %tussen midden en rechter deur
continue;
end
% not to be placed at left 5 locations, since 250 staf is top7
machines
if x_green == 0 && y_green == 0
continue;
end
if x_green == 0 && y_green == 1
continue;
end
if x_green == 0 && y_green == 2
continue;
end
if x_green == 1 && y_green == 0
continue;
end
if x_green == 1 && y_green == 2
continue;
end
% not to be placed at (3,0) (4,0) (5,0) --> force top7 to be placed
in top
% 6 locations and 1 location under it (6,0) to actually seperate the
top7
% from the rest, so the amount of possibilities decreases
if x_green == 3 && y_green == 0
continue;
end
if x_green == 4 && y_green == 0
continue;
end
if x_green == 5 && y_green == 0
continue;
end
%% YELLOW (2nd color)
for x_yellow = x_positions
for y_yellow = y_positions
```

```matlab
%% YELLOW and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_yellow >= (x_red_squares(i) + width_red_squares) || (x_yellow
+ width_colored_rect) <= x_red_squares(i) || ...
y_yellow >= (y_red_squares(i) + height_red_squares) || (y_yellow +
height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% YELLOW not allowed to be placed
if x_yellow == 3 && y_yellow == 1 %tussen linker en midden deur
continue;
end
if x_yellow == 4 && y_yellow == 1 %tussen midden en rechter deur
continue;
end
if x_yellow == 0 && y_yellow == 2 %geen bovenloopkraan links boven
continue;
end
if x_yellow == 1 && y_yellow == 2 %geen bovenloopkraan rechts boven
continue;
end
% not to be placed at left 5 locations, since 250 staf is top7
machines
if x_yellow == 0 && y_yellow == 0
continue;
end
if x_yellow == 0 && y_yellow == 1
continue;
end
if x_yellow == 1 && y_yellow == 0
continue;
end
% not to be placed at (3,0) (4,0) (5,0) --> force top7 to be placed
in top
% 6 locations and 1 location under it (6,0) to actually seperate the
top7
% from the rest, so the amount of possibilities decreases
if x_yellow == 3 && y_yellow == 0
continue;
end
if x_yellow == 4 && y_yellow == 0
continue;
end
if x_yellow == 5 && y_yellow == 0
continue;
end
%% YELLOW and GREEN overlap (2nd , 1st)
if ~(x_yellow >= (x_green + width_colored_rect) || (x_yellow +
width_colored_rect) <= x_green || ...
y_yellow >= (y_green + height_colored_rect) || (y_yellow +
height_colored_rect) <= y_green)
continue; % Skip if they overlap
```

```matlab
end
%% PINK (3rd color)
for x_pink = x_positions
for y_pink = y_positions
%% PINK and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_pink >= (x_red_squares(i) + width_red_squares) || (x_pink +
width_colored_rect) <= x_red_squares(i) || ...
y_pink >= (y_red_squares(i) + height_red_squares) || (y_pink +
height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% PINK not allowed to be placed
if x_pink == 3 && y_pink == 1 %tussen linker en midden deur
continue;
end
if x_pink == 4 && y_pink == 1 %tussen midden en rechter deur
continue;
end
if x_pink == 0 && y_pink == 2 %geen bovenloopkraan links boven
continue;
end
if x_pink == 1 && y_pink == 2 %geen bovenloopkraan rechts boven
continue;
end
% not to be placed at left 5 locations, since 250 staf is top7
machines
if x_pink == 0 && y_pink == 0
continue;
end
if x_pink == 0 && y_pink == 1
continue;
end
if x_pink == 1 && y_pink == 0
continue;
end
% not to be placed at (3,0) (4,0) (5,0) --> force top7 to be placed
in top
% 6 locations and 1 location under it (6,0) to actually seperate the
top7
% from the rest, so the amount of possibilities decreases
if x_pink == 3 && y_pink == 0
continue;
end
if x_pink == 4 && y_pink == 0
continue;
end
if x_pink == 5 && y_pink == 0
continue;
end
%% pink and yellow adjacent
% Check if the pink rectangle is adjacent to the yellow rectangle
```

FIGURE 112: Matlab script part 1.

```
if ~((x_pink == x_yellow + width_colored_rect && y_pink >= y_yellow
&& y_pink < y_yellow + height_colored_rect) || ...  % Pink on the
right
     (x_pink + width_colored_rect == x_yellow && y_pink >= y_yellow
&& y_pink < y_yellow + height_colored_rect) || ...  % Pink on the
left
     (y_pink == y_yellow + height_colored_rect && x_pink >= x_yellow
&& x_pink < x_yellow + width_colored_rect) || ...  % Pink below
     (y_pink + height_colored_rect == y_yellow && x_pink >= x_yellow
&& x_pink < x_yellow + width_colored_rect) || ...  % Pink above
     (x_pink == x_yellow && y_pink + height_colored_rect ==
y_yellow) || ...                                      % Pink
above left corner
     (x_pink + width_colored_rect == x_yellow && y_pink +
height_colored_rect == y_yellow) || ...                       % Pink
above right corner
     (x_pink == x_yellow && y_pink == y_yellow +
height_colored_rect) || ...
% Pink below left corner
     (x_pink + width_colored_rect == x_yellow && y_pink == y_yellow
+ height_colored_rect))                              % Pink below
right corner
    continue; % Skip if pink is not adjacent to yellow
end
%% PINK and GREEN overlap (3rd , 1st)
if ~(x_pink >= (x_green + width_colored_rect) || (x_pink +
width_colored_rect) <= x_green || ...
y_pink >= (y_green + height_colored_rect) || (y_pink +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
%% PINK and YELLOW overlap (3rd , 2nd)
if ~(x_pink >= (x_yellow + width_colored_rect) || (x_pink +
width_colored_rect) <= x_yellow || ...
y_pink >= (y_yellow + height_colored_rect) || (y_pink +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% BLACK (4th color)
for x_black = x_positions
for y_black = y_positions
%% BLACK and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_black >= (x_red_squares(i) + width_red_squares) || (x_black +
width_colored_rect) <= x_red_squares(i) || ...
y_black >= (y_red_squares(i) + height_red_squares) || (y_black +
height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% BLACK not allowed to be placed
if x_black == 3 && y_black == 1 %tussen linker en midden deur
continue;
end
if x_black == 4 && y_black == 1 %tussen midden en rechter deur
continue;
end
%% BLACK and GREEN overlap (4th , 1st)
if ~(x_black >= (x_green + width_colored_rect) || (x_black +
width_colored_rect) <= x_green || ...
y_black >= (y_green + height_colored_rect) || (y_black +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
%% BLACK and YELLOW overlap (4th , 2nd)
if ~(x_black >= (x_yellow + width_colored_rect) || (x_black +
width_colored_rect) <= x_yellow || ...
y_black >= (y_yellow + height_colored_rect) || (y_black +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% BLACK and PINK overlap (4th , 3rd)
if ~(x_black >= (x_pink + width_colored_rect) || (x_black +
width_colored_rect) <= x_pink || ...
y_black >= (y_pink + height_colored_rect) || (y_black +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% CYAN (5th color)
for x_cyan = x_positions
for y_cyan = y_positions
%% CYAN and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_cyan >= (x_red_squares(i) + width_red_squares) || (x_cyan +
width_colored_rect) <= x_red_squares(i) || ...
y_cyan >= (y_red_squares(i) + height_red_squares) || (y_cyan +
height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% CYAN not allowed to be placed
if x_cyan == 3 && y_cyan == 1 %tussen linker en midden deur
continue;
end
% not to be placed at left 5 locations, since 250 staf is top7
machines
if x_cyan == 0 && y_cyan == 0
continue;
end
if x_cyan == 0 && y_cyan == 1
continue;
end
if x_cyan == 0 && y_cyan == 2
continue;
end
if x_cyan == 1 && y_cyan == 0
continue;
end
if x_cyan == 1 && y_cyan == 2
continue;
end
% not to be placed at (3,0) (4,0) (5,0) --> force top7 to be placed
in top
% 6 locations and 1 location under it (6,0) to actually seperate the
top7
% from the rest, so the amount of possibilities decreases
if x_cyan == 3 && y_cyan == 0
continue;
end
if x_cyan == 4 && y_cyan == 0
continue;
end
if x_cyan == 5 && y_cyan == 0
continue;
end
%% cyan and black adjacent
if ~((x_cyan == x_black + width_colored_rect && y_cyan >= y_black &&
y_cyan < y_black + height_colored_rect) || ...  % Cyan on the right
     (x_cyan + width_colored_rect == x_black && y_cyan >= y_black &&
y_cyan < y_black + height_colored_rect) || ...  % Cyan on the left
     (y_cyan == y_black + height_colored_rect && x_cyan >= x_black
&& x_cyan < x_black + width_colored_rect) || ...  % Cyan below
     (y_cyan + height_colored_rect == y_black && x_cyan >= x_black
&& x_cyan < x_black + width_colored_rect) || ...  % Cyan above
     (x_cyan == x_black && y_cyan + height_colored_rect == y_black)
|| ...                                            % Cyan above left
corner
     (x_cyan + width_colored_rect == x_black && y_cyan +
height_colored_rect == y_black) || ...                      % Cyan
above right corner
     (x_cyan == x_black && y_cyan == y_black + height_colored_rect)
|| ...                                            % Cyan below left
corner
     (x_cyan + width_colored_rect == x_black && y_cyan == y_black +
height_colored_rect))                             % Cyan below right
corner
    continue; % Skip if cyan is not adjacent to black
end
%% CYAN and GREEN overlap (5th , 1st)
if ~(x_cyan >= (x_green + width_colored_rect) || (x_cyan +
width_colored_rect) <= x_green || ...
y_cyan >= (y_green + height_colored_rect) || (y_cyan +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
%% CYAN and YELLOW overlap (5th , 2nd)
if ~(x_cyan >= (x_yellow + width_colored_rect) || (x_cyan +
width_colored_rect) <= x_yellow || ...
y_cyan >= (y_yellow + height_colored_rect) || (y_cyan +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% CYAN and PINK overlap (5th , 3rd)
if ~(x_cyan >= (x_pink + width_colored_rect) || (x_cyan +
width_colored_rect) <= x_pink || ...
y_cyan >= (y_pink + height_colored_rect) || (y_cyan +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% CYAN and BLACK overlap (5th , 4th)
if ~(x_cyan >= (x_black + width_colored_rect) || ...
(x_cyan + width_colored_rect) <= x_black || ...
y_cyan >= (y_black + height_colored_rect) || ...
(y_cyan + height_colored_rect) <= y_black)
continue; % Skip if overlaps with black
end
%% BLUE (6th color)
for x_blue = x_positions
for y_blue = y_positions
%% BLUE and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_blue >= (x_red_squares(i) + width_red_squares) || (x_blue +
width_colored_rect) <= x_red_squares(i) || ...
y_blue >= (y_red_squares(i) + height_red_squares) || (y_blue +
height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% BLUE not allowed to be placed
if x_blue == 3 && y_blue == 1 %tussen linker en midden deur
continue;
end
if x_blue == 4 && y_blue == 1 %tussen midden en rechter deur
continue;
end
if x_blue == 0 && y_blue == 2 %geen bovenloopkraan links boven
continue;
end
if x_blue == 1 && y_blue == 2 %geen bovenloopkraan rechts boven
continue;
end
% not to be placed at left 5 locations, since 250 staf is top7
machines
if x_blue == 0 && y_blue == 0
continue;
end
if x_blue == 0 && y_blue == 1
continue;
end
if x_blue == 1 && y_blue == 0
continue;
end
% not to be placed at (3,0) (4,0) (5,0) --> force top7 to be placed
in top
```

Figure 113: Matlab script part 2.

```
% 6 locations and 1 location under it (6,0) to actually seperate the
top7
% from the rest, so the amount of possibilities decreases
if x_blue == 3 && y_blue == 0
continue;
end
if x_blue == 4 && y_blue == 0
continue;
end
if x_blue == 5 && y_blue == 0
continue;
end
%% BLUE and GREEN overlap (6th , 1st)
if ~(x_blue >= (x_green + width_colored_rect) || (x_blue +
width_colored_rect) <= x_green || ...
y_blue >= (y_green + height_colored_rect) || (y_blue +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
%% BLUE and YELLOW overlap (6th , 2nd)
if ~(x_blue >= (x_yellow + width_colored_rect) || (x_blue +
width_colored_rect) <= x_yellow || ...
y_blue >= (y_yellow + height_colored_rect) || (y_blue +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% BLUE and PINK overlap (6th , 3rd)
if ~(x_blue >= (x_pink + width_colored_rect) || (x_blue +
width_colored_rect) <= x_pink || ...
y_blue >= (y_pink + height_colored_rect) || (y_blue +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% BLUE and BLACK overlap (6th , 4th)
if ~(x_blue >= (x_black + width_colored_rect) || (x_blue +
width_colored_rect) <= x_black || ...
y_blue >= (y_black + height_colored_rect) || (y_blue +
height_colored_rect) <= y_black)
continue; % Skip if overlaps with black
end
%% BLUE and CYAN overlap (6th , 5th)
if ~(x_blue >= (x_cyan + width_colored_rect) || (x_blue +
width_colored_rect) <= x_cyan || ...
y_blue >= (y_cyan + height_colored_rect) || (y_blue +
height_colored_rect) <= y_cyan)
continue; % Skip if overlaps with cyan
end
%% NAVYBLUE (7th color)
for x_navyblue = x_positions
for y_navyblue = y_positions
%% NAVYBLUE and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_navyblue >= (x_red_squares(i) + width_red_squares) ||
(x_navyblue + width_colored_rect) <= x_red_squares(i) || ...
```

```
y_navyblue >= (y_red_squares(i) + height_red_squares) || (y_navyblue
+ height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% NAVYBLUE not allowed to be placed
if x_navyblue == 3 && y_navyblue == 1 %tussen linker en midden deur
continue;
end
%% navyblue and blue adjacent
if ~((x_navyblue == x_blue + width_colored_rect && y_navyblue >=
y_blue && y_navyblue < y_blue + height_colored_rect) || ...  %
Navyblue on the right
     (x_navyblue + width_colored_rect == x_blue && y_navyblue >=
y_blue && y_navyblue < y_blue + height_colored_rect) || ...  %
Navyblue on the left
     (y_navyblue == y_blue + height_colored_rect && x_navyblue >=
x_blue && x_navyblue < x_blue + width_colored_rect) || ...  %
Navyblue below
     (y_navyblue + height_colored_rect == y_blue && x_navyblue >=
x_blue && x_navyblue < x_blue + width_colored_rect) || ...  %
Navyblue above
     (x_navyblue == x_blue && y_navyblue + height_colored_rect ==
y_blue) || ...                                              % Navyblue
above left corner
     (x_navyblue + width_colored_rect == x_blue && y_navyblue +
height_colored_rect == y_blue) || ...                         %
Navyblue above right corner
     (x_navyblue == x_blue && y_navyblue == y_blue +
height_colored_rect) || ...
% Navyblue below left corner
     (x_navyblue + width_colored_rect == x_blue && y_navyblue ==
y_blue + height_colored_rect))                               %
Navyblue below right corner
    continue; % Skip if navyblue is not adjacent to blue
end
%% NAVYBLUE and GREEN overlap (7th , 1st)
if ~(x_navyblue >= (x_green + width_colored_rect) || (x_navyblue +
width_colored_rect) <= x_green || ...
y_navyblue >= (y_green + height_colored_rect) || (y_navyblue +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
%% NAVYBLUE and YELLOW overlap (7th , 2nd)
if ~(x_navyblue >= (x_yellow + width_colored_rect) || (x_navyblue +
width_colored_rect) <= x_yellow || ...
y_navyblue >= (y_yellow + height_colored_rect) || (y_navyblue +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% NAVYBLUE and PINK overlap (7th , 3rd)
if ~(x_navyblue >= (x_pink + width_colored_rect) || (x_navyblue +
width_colored_rect) <= x_pink || ...
```

```
y_navyblue >= (y_pink + height_colored_rect) || (y_navyblue +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% NAVYBLUE and BLACK overlap (7th , 4th)
if ~(x_navyblue >= (x_black + width_colored_rect) || (x_navyblue +
width_colored_rect) <= x_black || ...
y_navyblue >= (y_black + height_colored_rect) || (y_navyblue +
height_colored_rect) <= y_black)
continue; % Skip if overlaps with black
end
%% NAVYBLUE and CYAN overlap (7th , 5th)
if ~(x_navyblue >= (x_cyan + width_colored_rect) || (x_navyblue +
width_colored_rect) <= x_cyan || ...
y_navyblue >= (y_cyan + height_colored_rect) || (y_navyblue +
height_colored_rect) <= y_cyan)
continue; % Skip if overlaps with cyan
end
%% NAVYBLUE and BLUE overlap (7th , 6th)
if ~(x_navyblue >= (x_blue + width_colored_rect) || (x_navyblue +
width_colored_rect) <= x_blue || ...
y_navyblue >= (y_blue + height_colored_rect) || (y_navyblue +
height_colored_rect) <= y_blue)
continue; % Skip if overlaps with cyan
end
%% ORANGE (8th color)
for x_orange = x_positions
for y_orange = y_positions
%% ORANGE and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_orange >= (x_red_squares(i) + width_red_squares) || (x_orange
+ width_colored_rect) <= x_red_squares(i) || ...
y_orange >= (y_red_squares(i) + height_red_squares) || (y_orange +
height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% ORANGE not allowed to be placed
if x_orange == 3 && y_orange == 1 %tussen linker en midden deur
continue;
end
% not to be placed at left 5 locations, since 250 staf is top7
machines
if x_orange == 0 && y_orange == 0
continue;
end
if x_orange == 0 && y_orange == 1
continue;
end
if x_orange == 0 && y_orange == 2
continue;
end
if x_orange == 1 && y_orange == 0
```

```
continue;
end
if x_orange == 1 && y_orange == 2
continue;
end
% not to be placed at (3,0) (4,0) (5,0) --> force top7 to be placed
in top
% 6 locations and 1 location under it (6,0) to actually seperate the
top7
% from the rest, so the amount of possibilities decreases
if x_orange == 3 && y_orange == 0
continue;
end
if x_orange == 4 && y_orange == 0
continue;
end
if x_orange == 5 && y_orange == 0
continue;
end
%% ORANGE and GREEN overlap (8th , 1st)
if ~(x_orange >= (x_green + width_colored_rect) || (x_orange +
width_colored_rect) <= x_green || ...
y_orange >= (y_green + height_colored_rect) || (y_orange +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
%% ORANGE and YELLOW overlap (8th , 2nd)
if ~(x_orange >= (x_yellow + width_colored_rect) || (x_orange +
width_colored_rect) <= x_yellow || ...
y_orange >= (y_yellow + height_colored_rect) || (y_orange +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% ORANGE and PINK overlap (8th , 3rd)
if ~(x_orange >= (x_pink + width_colored_rect) || (x_orange +
width_colored_rect) <= x_pink || ...
y_orange >= (y_pink + height_colored_rect) || (y_orange +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% ORANGE and BLACK overlap (8th , 4th)
if ~(x_orange >= (x_black + width_colored_rect) || (x_orange +
width_colored_rect) <= x_black || ...
y_orange >= (y_black + height_colored_rect) || (y_orange +
height_colored_rect) <= y_black)
continue; % Skip if overlaps with black
end
%% ORANGE and CYAN overlap (8th , 5th)
if ~(x_orange >= (x_cyan + width_colored_rect) || (x_orange +
width_colored_rect) <= x_cyan || ...
y_orange >= (y_cyan + height_colored_rect) || (y_orange +
height_colored_rect) <= y_cyan)
continue; % Skip if overlaps with cyan
end
%% ORANGE and BLUE overlap (8th , 6th)
```

Figure 114: Matlab script part 3.

```
if ~(x_orange >= (x_blue + width_colored_rect) || (x_orange +
width_colored_rect) <= x_blue || ...
y_orange >= (y_blue + height_colored_rect) || (y_orange +
height_colored_rect) <= y_blue)
continue; % Skip if overlaps with cyan
end
%% ORANGE and NAVYBLUE overlap (8th , 7th)
if ~(x_orange >= (x_navyblue + width_colored_rect) || (x_orange +
width_colored_rect) <= x_navyblue || ...
y_orange >= (y_navyblue + height_colored_rect) || (y_orange +
height_colored_rect) <= y_navyblue)
continue; % Skip if overlaps with cyan
end
%% GOLD (9th color)
for x_gold = x_positions
for y_gold = y_positions
%% GOLD and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_gold >= (x_red_squares(i) + width_red_squares) || (x_gold +
width_colored_rect) <= x_red_squares(i) || ...
y_gold >= (y_red_squares(i) + height_red_squares) || (y_gold +
height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% GOLD not allowed to be placed
if x_gold == 3 && y_gold == 1 %tussen linker en midden deur
continue;
end
%% gold and orange adjacent
% Check if the gold rectangle is adjacent to the orange rectangle
if ~((x_gold == x_orange + width_colored_rect && y_gold >= y_orange
&& y_gold < y_orange + height_colored_rect) || ...  % Gold on the
right
     (x_gold + width_colored_rect == x_orange && y_gold >= y_orange
&& y_gold < y_orange + height_colored_rect) || ...  % Gold on the
left
     (y_gold == y_orange + height_colored_rect && x_gold >= x_orange
&& x_gold < x_orange + width_colored_rect) || ...  % Gold below
     (y_gold + height_colored_rect == y_orange && x_gold >= x_orange
&& x_gold < x_orange + width_colored_rect) || ...  % Gold above
     (x_gold == x_orange && y_gold + height_colored_rect ==
y_orange) || ...                                          % Gold
above left corner
     (x_gold + width_colored_rect == x_orange && y_gold +
height_colored_rect == y_orange) || ...                       % Gold
above right corner
     (x_gold == x_orange && y_gold == y_orange +
height_colored_rect) || ...
% Gold below left corner
     (x_gold + width_colored_rect == x_orange && y_gold == y_orange
+ height_colored_rect))                               % Gold below
right corner
```

```
    continue; % Skip if gold is not adjacent to orange
end
%% GOLD and GREEN overlap (9th , 1st)
if ~(x_gold >= (x_green + width_colored_rect) || (x_gold +
width_colored_rect) <= x_green || ...
y_gold >= (y_green + height_colored_rect) || (y_gold +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
%% GOLD and YELLOW overlap (9th , 2nd)
if ~(x_gold >= (x_yellow + width_colored_rect) || (x_gold +
width_colored_rect) <= x_yellow || ...
y_gold >= (y_yellow + height_colored_rect) || (y_gold +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% GOLD and PINK overlap (9th , 3rd)
if ~(x_gold >= (x_pink + width_colored_rect) || (x_gold +
width_colored_rect) <= x_pink || ...
y_gold >= (y_pink + height_colored_rect) || (y_gold +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% GOLD and BLACK overlap (9th , 4th)
if ~(x_gold >= (x_black + width_colored_rect) || (x_gold +
width_colored_rect) <= x_black || ...
y_gold >= (y_black + height_colored_rect) || (y_gold +
height_colored_rect) <= y_black)
continue; % Skip if overlaps with black
end
%% GOLD and CYAN overlap (9th , 5th)
if ~(x_gold >= (x_cyan + width_colored_rect) || (x_gold +
width_colored_rect) <= x_cyan || ...
y_gold >= (y_cyan + height_colored_rect) || (y_gold +
height_colored_rect) <= y_cyan)
continue; % Skip if overlaps with cyan
end
%% GOLD and BLUE overlap (9th , 6th)
if ~(x_gold >= (x_blue + width_colored_rect) || (x_gold +
width_colored_rect) <= x_blue || ...
y_gold >= (y_blue + height_colored_rect) || (y_gold +
height_colored_rect) <= y_blue)
continue; % Skip if overlaps with cyan
end
%% GOLD and NAVYBLUE overlap (9th , 7th)
if ~(x_gold >= (x_navyblue + width_colored_rect) || (x_gold +
width_colored_rect) <= x_navyblue || ...
y_gold >= (y_navyblue + height_colored_rect) || (y_gold +
height_colored_rect) <= y_navyblue)
continue; % Skip if overlaps with cyan
end
%% GOLD and ORANGE overlap (9th , 8th)
if ~(x_gold >= (x_orange + width_colored_rect) || (x_gold +
width_colored_rect) <= x_orange || ...
y_gold >= (y_orange + height_colored_rect) || (y_gold +
height_colored_rect) <= y_orange)
```

```
continue; % Skip if overlaps with cyan
end
%% PURPLE (10th color)
for x_purple = x_positions
for y_purple = y_positions
%% PURPLE and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_purple >= (x_red_squares(i) + width_red_squares) || (x_purple
+ width_colored_rect) <= x_red_squares(i) || ...
y_purple >= (y_red_squares(i) + height_red_squares) || (y_purple +
height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% PURPLE not allowed to be placed
% PRIMOS can be placed anywhere: between all doors and gantry crane
is not
% needed, so no restrictions here this time
if x_purple == 0 && y_purple == 0
continue;
end
if x_purple == 0 && y_purple == 1
continue;
end
if x_purple == 0 && y_purple == 2
continue;
end
if x_purple == 1 && y_purple == 0
continue;
end
if x_purple == 1 && y_purple == 2
continue;
end
% not to be placed at (3,0) (4,0) (5,0) --> force top7 to be placed
in top
% 6 locations and 1 location under it (6,0) to actually seperate the
top7
% from the rest, so the amount of possibilities decreases
if x_purple == 3 && y_purple == 0
continue;
end
if x_purple == 4 && y_purple == 0
continue;
end
if x_purple == 5 && y_purple == 0
continue;
end
%% PURPLE and GREEN overlap (10th , 1st)
if ~(x_purple >= (x_green + width_colored_rect) || (x_purple +
width_colored_rect) <= x_green || ...
y_purple >= (y_green + height_colored_rect) || (y_purple +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
```

```
end
%% PURPLE and YELLOW overlap (10th , 2nd)
if ~(x_purple >= (x_yellow + width_colored_rect) || (x_purple +
width_colored_rect) <= x_yellow || ...
y_purple >= (y_yellow + height_colored_rect) || (y_purple +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% PURPLE and PINK overlap (10th , 3rd)
if ~(x_purple >= (x_pink + width_colored_rect) || (x_purple +
width_colored_rect) <= x_pink || ...
y_purple >= (y_pink + height_colored_rect) || (y_purple +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% PURPLE and BLACK overlap (10th , 4th)
if ~(x_purple >= (x_black + width_colored_rect) || (x_purple +
width_colored_rect) <= x_black || ...
y_purple >= (y_black + height_colored_rect) || (y_purple +
height_colored_rect) <= y_black)
continue; % Skip if overlaps with black
end
%% PURPLE and CYAN overlap (10th , 5th)
if ~(x_purple >= (x_cyan + width_colored_rect) || (x_purple +
width_colored_rect) <= x_cyan || ...
y_purple >= (y_cyan + height_colored_rect) || (y_purple +
height_colored_rect) <= y_cyan)
continue; % Skip if overlaps with cyan
end
%% PURPLE and BLUE overlap (10th , 6th)
if ~(x_purple >= (x_blue + width_colored_rect) || (x_purple +
width_colored_rect) <= x_blue || ...
y_purple >= (y_blue + height_colored_rect) || (y_purple +
height_colored_rect) <= y_blue)
continue;
end
%% PURPLE and NAVYBLUE overlap (10th , 7th)
if ~(x_purple >= (x_navyblue + width_colored_rect) || (x_purple +
width_colored_rect) <= x_navyblue || ...
y_purple >= (y_navyblue + height_colored_rect) || (y_purple +
height_colored_rect) <= y_navyblue)
continue;
end
%% PURPLE and ORANGE overlap (10th , 8th)
if ~(x_purple >= (x_orange + width_colored_rect) || (x_purple +
width_colored_rect) <= x_orange || ...
y_purple >= (y_orange + height_colored_rect) || (y_purple +
height_colored_rect) <= y_orange)
continue;
end
%% PURPLE and GOLD overlap (10th , 9th)
if ~(x_purple >= (x_gold + width_colored_rect) || (x_purple +
width_colored_rect) <= x_gold || ...
y_purple >= (y_gold + height_colored_rect) || (y_purple +
height_colored_rect) <= y_gold)
continue;
```

Figure 115: Matlab script part 4.

```
end
%% GRASSGREEN (11th color)
for x_grassgreen = x_positions
for y_grassgreen = y_positions
%% GRASSGREEN and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_grassgreen >= (x_red_squares(i) + width_red_squares) ||
(x_grassgreen + width_colored_rect) <= x_red_squares(i) || ...
y_grassgreen >= (y_red_squares(i) + height_red_squares) ||
(y_grassgreen + height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% GRASSGREEN not allowed to be placed
if x_grassgreen == 3 && y_grassgreen == 1 %tussen linker en midden
deur
continue;
end
if x_grassgreen == 4 && y_grassgreen == 1 %tussen midden en rechter
deur
continue;
end
if x_grassgreen == 0 && y_grassgreen == 2 %geen bovenloopkraan links
boven
continue;
end
if x_grassgreen == 1 && y_grassgreen == 2 %geen bovenloopkraan
rechts boven
continue;
end
%% GRASSGREEN and GREEN overlap (11th , 1st)
if ~(x_grassgreen >= (x_green + width_colored_rect) || (x_grassgreen
+ width_colored_rect) <= x_green || ...
y_grassgreen >= (y_green + height_colored_rect) || (y_grassgreen +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
%% GRASSGREEN and YELLOW overlap (11th , 2nd)
if ~(x_grassgreen >= (x_yellow + width_colored_rect) ||
(x_grassgreen + width_colored_rect) <= x_yellow || ...
y_grassgreen >= (y_yellow + height_colored_rect) || (y_grassgreen +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% GRASSGREEN and PINK overlap (11th , 3rd)
if ~(x_grassgreen >= (x_pink + width_colored_rect) || (x_grassgreen
+ width_colored_rect) <= x_pink || ...
y_grassgreen >= (y_pink + height_colored_rect) || (y_grassgreen +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% GRASSGREEN and BLACK overlap (11th , 4th)
```

```
if ~(x_grassgreen >= (x_black + width_colored_rect) || (x_grassgreen
+ width_colored_rect) <= x_black || ...
y_grassgreen >= (y_black + height_colored_rect) || (y_grassgreen +
height_colored_rect) <= y_black)
continue; % Skip if overlaps with black
end
%% GRASSGREEN and CYAN overlap (11th , 5th)
if ~(x_grassgreen >= (x_cyan + width_colored_rect) || (x_grassgreen
+ width_colored_rect) <= x_cyan || ...
y_grassgreen >= (y_cyan + height_colored_rect) || (y_grassgreen +
height_colored_rect) <= y_cyan)
continue; % Skip if overlaps with cyan
end
%% GRASSGREEN and BLUE overlap (11th , 6th)
if ~(x_grassgreen >= (x_blue + width_colored_rect) || (x_grassgreen
+ width_colored_rect) <= x_blue || ...
y_grassgreen >= (y_blue + height_colored_rect) || (y_grassgreen +
height_colored_rect) <= y_blue)
continue;
end
%% GRASSGREEN and NAVYBLUE overlap (11th , 7th)
if ~(x_grassgreen >= (x_navyblue + width_colored_rect) ||
(x_grassgreen + width_colored_rect) <= x_navyblue || ...
y_grassgreen >= (y_navyblue + height_colored_rect) || (y_grassgreen
+ height_colored_rect) <= y_navyblue)
continue;
end
%% GRASSGREEN and ORANGE overlap (11th , 8th)
if ~(x_grassgreen >= (x_orange + width_colored_rect) ||
(x_grassgreen + width_colored_rect) <= x_orange || ...
y_grassgreen >= (y_orange + height_colored_rect) || (y_grassgreen +
height_colored_rect) <= y_orange)
continue;
end
%% GRASSGREEN and GOLD overlap (11th , 9th)
if ~(x_grassgreen >= (x_gold + width_colored_rect) || (x_grassgreen
+ width_colored_rect) <= x_gold || ...
y_grassgreen >= (y_gold + height_colored_rect) || (y_grassgreen +
height_colored_rect) <= y_gold)
continue;
end
%% GRASSGREEN and GOLD overlap (11th , 10th)
if ~(x_grassgreen >= (x_purple + width_colored_rect) ||
(x_grassgreen + width_colored_rect) <= x_purple || ...
y_grassgreen >= (y_purple + height_colored_rect) || (y_grassgreen +
height_colored_rect) <= y_purple)
continue;
end
%% LIGHTPINK (12th color)
for x_lightpink = x_positions
for y_lightpink = y_positions
%% LIGHTPINK and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_lightpink >= (x_red_squares(i) + width_red_squares) ||
(x_lightpink + width_colored_rect) <= x_red_squares(i) || ...
```

```
y_lightpink >= (y_red_squares(i) + height_red_squares) ||
(y_lightpink + height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% LIGHTPINK not allowed to be placed
if x_lightpink == 3 && y_lightpink == 1 %tussen linker en midden
deur
continue;
end
if x_lightpink == 0 && y_lightpink == 2 %geen bovenloopkraan links
boven
continue;
end
if x_lightpink == 1 && y_lightpink == 2 %geen bovenloopkraan rechts
boven
continue;
end
%% lightpink and grassgreen adjacent
% Check if the lightpink rectangle is adjacent to the grassgreen
rectangle
if ~((x_lightpink == x_grassgreen + width_colored_rect &&
y_lightpink >= y_grassgreen && y_lightpink < y_grassgreen +
height_colored_rect) || ...  % Lightpink on the right
     (x_lightpink + width_colored_rect == x_grassgreen &&
y_lightpink >= y_grassgreen && y_lightpink < y_grassgreen +
height_colored_rect) || ...  % Lightpink on the left
     (y_lightpink == y_grassgreen + height_colored_rect &&
x_lightpink >= x_grassgreen && x_lightpink < x_grassgreen +
width_colored_rect) || ...  % Lightpink below
     (y_lightpink + height_colored_rect == y_grassgreen &&
x_lightpink >= x_grassgreen && x_lightpink < x_grassgreen +
width_colored_rect) || ...  % Lightpink above
     (x_lightpink == x_grassgreen && y_lightpink +
height_colored_rect == y_grassgreen) || ...
% Lightpink above left corner
     (x_lightpink + width_colored_rect == x_grassgreen &&
y_lightpink + height_colored_rect == y_grassgreen) || ...
% Lightpink above right corner
     (x_lightpink == x_grassgreen && y_lightpink == y_grassgreen +
height_colored_rect) || ...
% Lightpink below left corner
     (x_lightpink + width_colored_rect == x_grassgreen &&
y_lightpink == y_grassgreen + height_colored_rect))
% Lightpink below right corner
    continue; % Skip if lightpink is not adjacent to grassgreen
end
%% LIGHTPINK and GREEN overlap (12th , 1st)
if ~(x_lightpink >= (x_green + width_colored_rect) || (x_lightpink +
width_colored_rect) <= x_green || ...
y_lightpink >= (y_green + height_colored_rect) || (y_lightpink +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
```

```
%% LIGHTPINK and YELLOW overlap (12th , 2nd)
if ~(x_lightpink >= (x_yellow + width_colored_rect) || (x_lightpink
+ width_colored_rect) <= x_yellow || ...
y_lightpink >= (y_yellow + height_colored_rect) || (y_lightpink +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% LIGHTPINK and PINK overlap (12th , 3rd)
if ~(x_lightpink >= (x_pink + width_colored_rect) || (x_lightpink +
width_colored_rect) <= x_pink || ...
y_lightpink >= (y_pink + height_colored_rect) || (y_lightpink +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% LIGHTPINK and BLACK overlap (12th , 4th)
if ~(x_lightpink >= (x_black + width_colored_rect) || (x_lightpink +
width_colored_rect) <= x_black || ...
y_lightpink >= (y_black + height_colored_rect) || (y_lightpink +
height_colored_rect) <= y_black)
continue; % Skip if overlaps with black
end
%% LIGHTPINK and CYAN overlap (12th , 5th)
if ~(x_lightpink >= (x_cyan + width_colored_rect) || (x_lightpink +
width_colored_rect) <= x_cyan || ...
y_lightpink >= (y_cyan + height_colored_rect) || (y_lightpink +
height_colored_rect) <= y_cyan)
continue; % Skip if overlaps with cyan
end
%% LIGHTPINK and BLUE overlap (12th , 6th)
if ~(x_lightpink >= (x_blue + width_colored_rect) || (x_lightpink +
width_colored_rect) <= x_blue || ...
y_lightpink >= (y_blue + height_colored_rect) || (y_lightpink +
height_colored_rect) <= y_blue)
continue;
end
%% LIGHTPINK and NAVYBLUE overlap (12th , 7th)
if ~(x_lightpink >= (x_navyblue + width_colored_rect) ||
(x_lightpink + width_colored_rect) <= x_navyblue || ...
y_lightpink >= (y_navyblue + height_colored_rect) || (y_lightpink +
height_colored_rect) <= y_navyblue)
continue;
end
%% LIGHTPINK and ORANGE overlap (12th , 8th)
if ~(x_lightpink >= (x_orange + width_colored_rect) || (x_lightpink
+ width_colored_rect) <= x_orange || ...
y_lightpink >= (y_orange + height_colored_rect) || (y_lightpink +
height_colored_rect) <= y_orange)
continue;
end
%% LIGHTPINK and GOLD overlap (12th , 9th)
if ~(x_lightpink >= (x_gold + width_colored_rect) || (x_lightpink +
width_colored_rect) <= x_gold || ...
y_lightpink >= (y_gold + height_colored_rect) || (y_lightpink +
height_colored_rect) <= y_gold)
continue;
end
```

Figure 116: Matlab script part 5.

```
%% LIGHTPINK and GOLD overlap (12th , 10th)
if ~(x_lightpink >= (x_purple + width_colored_rect) || (x_lightpink
+ width_colored_rect) <= x_purple || ...
y_lightpink >= (y_purple + height_colored_rect) || (y_lightpink +
height_colored_rect) <= y_purple)
continue;
end
%% LIGHTPINK and GRASSGREEN overlap (12th , 11th)
if ~(x_lightpink >= (x_grassgreen + width_colored_rect) ||
(x_lightpink + width_colored_rect) <= x_grassgreen || ...
y_lightpink >= (y_grassgreen + height_colored_rect) || (y_lightpink
+ height_colored_rect) <= y_grassgreen)
continue;
end
%% CYANGREEN (13th color)
for x_cyangreen = x_positions
for y_cyangreen = y_positions
%% CYANGREEN and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_cyangreen >= (x_red_squares(i) + width_red_squares) ||
(x_cyangreen + width_colored_rect) <= x_red_squares(i) || ...
y_cyangreen >= (y_red_squares(i) + height_red_squares) ||
(y_cyangreen + height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% CYANGREEN not allowed to be placed
if x_cyangreen == 0 && y_cyangreen == 2 %geen bovenloopkraan links
boven
continue;
end
if x_cyangreen == 1 && y_cyangreen == 2 %geen bovenloopkraan rechts
boven
continue;
end
%% CYANGREEN and GREEN overlap (13th , 1st)
if ~(x_cyangreen >= (x_green + width_colored_rect) || (x_cyangreen +
width_colored_rect) <= x_green || ...
y_cyangreen >= (y_green + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
%% CYANGREEN and YELLOW overlap (13th , 2nd)
if ~(x_cyangreen >= (x_yellow + width_colored_rect) || (x_cyangreen
+ width_colored_rect) <= x_yellow || ...
y_cyangreen >= (y_yellow + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% CYANGREEN and PINK overlap (13th , 3rd)
if ~(x_cyangreen >= (x_pink + width_colored_rect) || (x_cyangreen +
width_colored_rect) <= x_pink || ...
```

```
y_cyangreen >= (y_pink + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% CYANGREEN and BLACK overlap (13th , 4th)
if ~(x_cyangreen >= (x_black + width_colored_rect) || (x_cyangreen +
width_colored_rect) <= x_black || ...
y_cyangreen >= (y_black + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_black)
continue; % Skip if overlaps with black
end
%% CYANGREEN and CYAN overlap (13th , 5th)
if ~(x_cyangreen >= (x_cyan + width_colored_rect) || (x_cyangreen +
width_colored_rect) <= x_cyan || ...
y_cyangreen >= (y_cyan + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_cyan)
continue; % Skip if overlaps with cyan
end
%% CYANGREEN and BLUE overlap (13th , 6th)
if ~(x_cyangreen >= (x_blue + width_colored_rect) || (x_cyangreen +
width_colored_rect) <= x_blue || ...
y_cyangreen >= (y_blue + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_blue)
continue;
end
%% CYANGREEN and NAVYBLUE overlap (13th , 7th)
if ~(x_cyangreen >= (x_navyblue + width_colored_rect) ||
(x_cyangreen + width_colored_rect) <= x_navyblue || ...
y_cyangreen >= (y_navyblue + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_navyblue)
continue;
end
%% CYANGREEN and ORANGE overlap (13th , 8th)
if ~(x_cyangreen >= (x_orange + width_colored_rect) || (x_cyangreen
+ width_colored_rect) <= x_orange || ...
y_cyangreen >= (y_orange + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_orange)
continue;
end
%% CYANGREEN and GOLD overlap (13th , 9th)
if ~(x_cyangreen >= (x_gold + width_colored_rect) || (x_cyangreen +
width_colored_rect) <= x_gold || ...
y_cyangreen >= (y_gold + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_gold)
continue;
end
%% CYANGREEN and GOLD overlap (13th , 10th)
if ~(x_cyangreen >= (x_purple + width_colored_rect) || (x_cyangreen
+ width_colored_rect) <= x_purple || ...
y_cyangreen >= (y_purple + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_purple)
continue;
end
%% CYANGREEN and GRASSGREEN overlap (13th , 11th)
if ~(x_cyangreen >= (x_grassgreen + width_colored_rect) ||
(x_cyangreen + width_colored_rect) <= x_grassgreen || ...
```

```
y_cyangreen >= (y_grassgreen + height_colored_rect) || (y_cyangreen
+ height_colored_rect) <= y_grassgreen)
continue;
end
%% CYANGREEN and LIGHTPINK overlap (13th , 12th)
if ~(x_cyangreen >= (x_lightpink + width_colored_rect) ||
(x_cyangreen + width_colored_rect) <= x_lightpink || ...
y_cyangreen >= (y_lightpink + height_colored_rect) || (y_cyangreen +
height_colored_rect) <= y_lightpink)
continue;
end
%% DARKGREEN (14th color)
for x_darkgreen = x_positions
for y_darkgreen = y_positions
%% DARKGREEN and RED AREA overlap
overlap = false;
for i = 1:length(x_red_squares)
if ~(x_darkgreen >= (x_red_squares(i) + width_red_squares) ||
(x_darkgreen + width_colored_rect) <= x_red_squares(i) || ...
y_darkgreen >= (y_red_squares(i) + height_red_squares) ||
(y_darkgreen + height_colored_rect) <= y_red_squares(i))
overlap = true;
break;
end
end
if overlap, continue; end % Skip if overlaps with red squares
%% darkgreen and cyangreen adjacent
% Check if the darkgreen rectangle is adjacent to the cyangreen
rectangle
if ~((x_darkgreen == x_cyangreen + width_colored_rect && y_darkgreen
>= y_cyangreen && y_darkgreen < y_cyangreen + height_colored_rect)
|| ...  % Darkgreen on the right
     (x_darkgreen + width_colored_rect == x_cyangreen && y_darkgreen
>= y_cyangreen && y_darkgreen < y_cyangreen + height_colored_rect)
|| ...  % Darkgreen on the left
     (y_darkgreen == y_cyangreen + height_colored_rect &&
x_darkgreen >= x_cyangreen && x_darkgreen < x_cyangreen +
width_colored_rect) || ...  % Darkgreen below
     (y_darkgreen + height_colored_rect == y_cyangreen &&
x_darkgreen >= x_cyangreen && x_darkgreen < x_cyangreen +
width_colored_rect) || ...  % Darkgreen above
     (x_darkgreen == x_cyangreen && y_darkgreen +
height_colored_rect == y_cyangreen) || ...
% Darkgreen above left corner
     (x_darkgreen + width_colored_rect == x_cyangreen && y_darkgreen
+ height_colored_rect == y_cyangreen) || ...                       %
Darkgreen above right corner
     (x_darkgreen == x_cyangreen && y_darkgreen == y_cyangreen +
height_colored_rect) || ...
% Darkgreen below left corner
     (x_darkgreen + width_colored_rect == x_cyangreen && y_darkgreen
== y_cyangreen + height_colored_rect))                             %
Darkgreen below right corner
    continue; % Skip if darkgreen is not adjacent to cyangreen
end
%% DARKGREEN not allowed to be placed
```

```
% Hardinge T42 can be placed anywhere: between all doors and no
gantry
% crane is needed, so no limitations here this time.
%% DARKGREEN and GREEN overlap (14th , 1st)
if ~(x_darkgreen >= (x_green + width_colored_rect) || (x_darkgreen +
width_colored_rect) <= x_green || ...
y_darkgreen >= (y_green + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_green)
continue; % Skip if overlaps with green
end
%% DARKGREEN and YELLOW overlap (14th , 2nd)
if ~(x_darkgreen >= (x_yellow + width_colored_rect) || (x_darkgreen
+ width_colored_rect) <= x_yellow || ...
y_darkgreen >= (y_yellow + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_yellow)
continue; % Skip if overlaps with yellow
end
%% DARKGREEN and PINK overlap (14th , 3rd)
if ~(x_darkgreen >= (x_pink + width_colored_rect) || (x_darkgreen +
width_colored_rect) <= x_pink || ...
y_darkgreen >= (y_pink + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_pink)
continue; % Skip if overlaps with pink
end
%% DARKGREEN and BLACK overlap (14th , 4th)
if ~(x_darkgreen >= (x_black + width_colored_rect) || (x_darkgreen +
width_colored_rect) <= x_black || ...
y_darkgreen >= (y_black + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_black)
continue; % Skip if overlaps with black
end
%% DARKGREEN and CYAN overlap (14th , 5th)
if ~(x_darkgreen >= (x_cyan + width_colored_rect) || (x_darkgreen +
width_colored_rect) <= x_cyan || ...
y_darkgreen >= (y_cyan + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_cyan)
continue; % Skip if overlaps with cyan
end
%% DARKGREEN and BLUE overlap (14th , 6th)
if ~(x_darkgreen >= (x_blue + width_colored_rect) || (x_darkgreen +
width_colored_rect) <= x_blue || ...
y_darkgreen >= (y_blue + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_blue)
continue;
end
%% DARKGREEN and NAVYBLUE overlap (14th , 7th)
if ~(x_darkgreen >= (x_navyblue + width_colored_rect) ||
(x_darkgreen + width_colored_rect) <= x_navyblue || ...
y_darkgreen >= (y_navyblue + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_navyblue)
continue;
end
%% DARKGREEN and ORANGE overlap (14th , 8th)
if ~(x_darkgreen >= (x_orange + width_colored_rect) || (x_darkgreen
+ width_colored_rect) <= x_orange || ...
```

Figure 117: Matlab script part 6.

```
y_darkgreen >= (y_orange + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_orange)
continue;
end
%% DARKGREEN and GOLD overlap (14th , 9th)
if ~(x_darkgreen >= (x_gold + width_colored_rect) || (x_darkgreen +
width_colored_rect) <= x_gold || ...
y_darkgreen >= (y_gold + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_gold)
continue;
end
%% DARKGREEN and GOLD overlap (14th , 10th)
if ~(x_darkgreen >= (x_purple + width_colored_rect) || (x_darkgreen
+ width_colored_rect) <= x_purple || ...
y_darkgreen >= (y_purple + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_purple)
continue;
end
%% DARKGREEN and GRASSGREEN overlap (14th , 11th)
if ~(x_darkgreen >= (x_grassgreen + width_colored_rect) ||
(x_darkgreen + width_colored_rect) <= x_grassgreen || ...
y_darkgreen >= (y_grassgreen + height_colored_rect) || (y_darkgreen
+ height_colored_rect) <= y_grassgreen)
continue;
end
%% DARKGREEN and LIGHTPINK overlap (14th , 12th)
if ~(x_darkgreen >= (x_lightpink + width_colored_rect) ||
(x_darkgreen + width_colored_rect) <= x_lightpink || ...
y_darkgreen >= (y_lightpink + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_lightpink)
continue;
end
%% DARKGREEN and CYANGREEN overlap (14th , 13th)
if ~(x_darkgreen >= (x_cyangreen + width_colored_rect) ||
(x_darkgreen + width_colored_rect) <= x_cyangreen || ...
y_darkgreen >= (y_cyangreen + height_colored_rect) || (y_darkgreen +
height_colored_rect) <= y_cyangreen)
continue;
end

%% Store the positions of valid combinations
valid_combination_count = valid_combination_count + 1;
valid_positions = [valid_positions; x_green, y_green, ...
                   x_yellow, y_yellow, ...
                   x_pink, y_pink, ...
                   x_black, y_black, ...
                   x_cyan, y_cyan, ...
                   x_blue, y_blue, ...
                   x_navyblue, y_navyblue ...
                   x_orange, y_orange ...
                   x_gold, y_gold ...
                   x_purple, y_purple ...
                   x_grassgreen, y_grassgreen ...
                   x_lightpink, y_lightpink ...
                   x_cyangreen, y_cyangreen ...
                   x_darkgreen, y_darkgreen];
```

```
% HIERBOVEN DUS ALLE X AND Y INVULLEN VAN ELKE KLEUR



%% Display the current valid combination graphically
clf; % Clear the figure
% Plot the large blue rectangle (entire area)
rectangle('Position', [0, 0, width_rect, height_rect], 'EdgeColor',
'b', 'LineWidth', 2);
hold on;
% Plot the red squares (restricted areas)
for i = 1:length(x_red_squares)
rectangle('Position', [x_red_squares(i), y_red_squares(i),
width_red_squares, height_red_squares], 'EdgeColor', 'r',
'LineWidth', 2);
end
% Plot the current combination of colored rectangles
rectangle('Position', [x_green, y_green, width_colored_rect,
height_colored_rect], 'FaceColor', 'g', 'EdgeColor', 'g',
'LineWidth', 2);     %rectangle 1
rectangle('Position', [x_yellow, y_yellow, width_colored_rect,
height_colored_rect], 'FaceColor', 'y', 'EdgeColor', 'y',
'LineWidth', 2);   %rectangle 2
rectangle('Position', [x_pink, y_pink, width_colored_rect,
height_colored_rect], 'FaceColor', 'm', 'EdgeColor', 'm',
'LineWidth', 2);       %rectangle 3
rectangle('Position', [x_black, y_black, width_colored_rect,
height_colored_rect], 'FaceColor', 'k', 'EdgeColor', 'k',
'LineWidth', 2);     %rectangle 4
rectangle('Position', [x_cyan, y_cyan, width_colored_rect,
height_colored_rect], 'FaceColor', 'c', 'EdgeColor', 'c',
'LineWidth', 2);       %rectangle 5
rectangle('Position', [x_blue, y_blue, width_colored_rect,
height_colored_rect], 'FaceColor', 'b', 'EdgeColor', 'b',
'LineWidth', 2);       %rectangle 6
rectangle('Position', [x_navyblue, y_navyblue, width_colored_rect,
height_colored_rect], ...
    'FaceColor', '[0 0.4470 0.7410]', 'EdgeColor', '[0 0.4470
0.7410]', 'LineWidth', 2);
%rectangle 7
rectangle('Position', [x_orange, y_orange, width_colored_rect,
height_colored_rect], ...
    'FaceColor', '[0.8500 0.3250 0.0980]', 'EdgeColor', '[0.8500
0.3250 0.0980]', 'LineWidth', 2);
%rectangle 8
rectangle('Position', [x_gold, y_gold, width_colored_rect,
height_colored_rect], ...
    'FaceColor', '[0.9290 0.6940 0.1250]', 'EdgeColor', '[0.9290
0.6940 0.1250]', 'LineWidth', 2);
%rectangle 9
rectangle('Position', [x_purple, y_purple, width_colored_rect,
height_colored_rect], ...
```

```
    'FaceColor', '[0.4940 0.1840 0.5560]', 'EdgeColor', '[0.4940
0.1840 0.5560]', 'LineWidth', 2);
%rectangle 10
rectangle('Position', [x_grassgreen, y_grassgreen,
width_colored_rect, height_colored_rect], ...
    'FaceColor', '[0.4660 0.6740 0.1880]', 'EdgeColor', '[0.4660
0.6740 0.1880]', 'LineWidth', 2);
%rectangle 11
rectangle('Position', [x_lightpink, y_lightpink, width_colored_rect,
height_colored_rect], ...
    'FaceColor', '[1 0.7216 0.9843]', 'EdgeColor', '[1 0.7216
0.9843]', 'LineWidth', 2);
%rectangle 12
rectangle('Position', [x_cyangreen, y_cyangreen, width_colored_rect,
height_colored_rect], ...
    'FaceColor', '[0 1 0.6667]', 'EdgeColor', '[0 1 0.6667]',
'LineWidth', 2);
%rectangle 13
rectangle('Position', [x_darkgreen, y_darkgreen, width_colored_rect,
height_colored_rect], ...
    'FaceColor', '[0.0039 0.2706 0.0510]', 'EdgeColor', '[0.0039
0.2706 0.0510]', 'LineWidth', 2);
%rectangle 14
% HIERBOVEN DUS RECTANGLE VAN NIEUWE KLEUR TOEVOEGEN
% Display combination information above the figure
title(sprintf('Valid count: %d', valid_combination_count));
hold off;
axis equal;
pause(10); % Pause briefly to show the figure



end % y_darkgreen (14th color)
end % x_darkgreen
end % y_cyangreen (13th color)
end % x_cyangreen
end % y_lightpink (12th color)
end % x_lightpink
end % y_grassgreen (11th color)
end % x_grassgreen
end % y_purple (10th color)
end % x_purple
end % y_gold (9th color)
end % x_gold
end % y_orange (8th color)
end % x_orange
end % y_navyblue (7th color)
end % x_navyblue
end % y_blue end (6th color)
end % x_blue
end % y_cyan end (5th color)
end % x_cyan
end % y_black end (4th color)
end % x_black
```

```
end % y_pink end (3rd color)
end % x_pink
end % y_yellow end (2nd color)
end % x_yellow
end % y_green end (1st color)
end % x_green
% HIERBOVEN DUS ends toevoegen voor elke nieuwe kleur
%% Results in Command Window
% Display the total number of valid combinations
disp(['Total valid combinations: ',
num2str(valid_combination_count)]);
% Display the valid positions
disp('Positions of the rectangles');
disp(valid_positions);
```

Figure 118: Matlab script part 7.