IMPROVING THE 4M ANALYSIS PERFORMED AT BENCHMARK

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Preface

In front of you lies my bachelor thesis titled 'Improving the 4M performed at Benchmark', executed at Benchmark Electronics located in Almelo. I would like to thank Engin Topan for the support given towards the completion of my thesis. Being my first supervisor, he provided me with feedback and gave me useful insights on how to further improve my thesis.

I also want to thank Benchmark for providing me with the opportunity to complete my Bachelor thesis within their company. For this, I especially want to thank Herman Wind and Koen Bossink, as they have guided and assisted me towards a successful completion of my thesis.

Lastly, I want to thank all employees that contributed to my thesis and have given me a warm welcome during my time at the company.

I hope you enjoy reading this thesis!

Luc Nijkamp

Management Summary

The aim of this thesis is to improve the responsiveness of Benchmark on move rate increase needs and subsequently improve the on-time delivery performance through the development of a 4M analysis tool.

Problem definition

A low on-time delivery performance causes customer relations to deteriorate, hence Benchmark wants to improve this by developing a 4M analysis tool. The demand from customer A generally increases over time. However, the product mix also changes, making it harder for Benchmark to predict the demand increase per product. As a result, Benchmark currently operates in a reactive manner to the customer demand changes, meaning that they cannot achieve the increased customer demand in the timeframe desired by the customer. *"No insight in the consequences of increasing move rate on the capacity needed"* is the core problem Benchmark has to deal with to increase the responsiveness and on-time delivery performance.

Research

We first identify the current situation at Benchmark. This is done by analysing the current process in place to monitor move rate capabilities and handle the increases of move rate requirements. Secondly, we identify the factors based on which Benchmark defines their move rate capacity, and subsequently establish the actual current capacity and move rate capability per factor.

Next, a literature research is performed to gain insight in possible other factors contributing to limitations of the move rate capabilities. Also, we research whether additional main factors of the 4Ms should be added to further improve the model.

The research focuses on providing Benchmark with a 4M analysis tool, through which they will gain insight in the consequences of move rate changes, and are alerted on the actions that need to be taken. Additionally, the tool will provide an overview of the move rate capability on a detailed level, both in terms of manpower and machines.

Lastly, we have developed a deterministic Dynamic Programming model and incorporated it into the tool, to provide the user of the tool with an overview of the optimal decision taken with regard to working overtime in order to mitigate the 'costs' of not delivering the additionally requested products on time.

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1 Introduction

In this chapter, we will give an introduction to the company Benchmark, where the research is performed. The problem context is explained, after which an action problem is identified. Following this we will find the core problem, look at the different stakeholders involved in this research and discuss the research design including its limitations. Finally, we will determine the scope of this research.

1.1 About Benchmark

Benchmark Electronics, with a location in Almelo where this research is performed, provides localized R&D services such as industrial design, electronics, mechanical and embedded software engineering, and fast prototyping to its customers. Benchmark Electronics was originally founded in Clute, Texas in 1979. After multiple expansions, Benchmark is established in Almelo since 2007.

This site in Almelo hosts the Benchmark European Design Centre of Innovation. Here, the company has an engineering team of over 100 people which focus on solving complex problems and offering customers regional R&D services.

Within Benchmark, different types of products are manufactured, being PCBA's (Printed Circuit Board Assembly), Small Box Builds and Volume cabinets. The PCBA's are produced in high volumes, which means that these are produced with low labour intensity. Small Box Builds are smaller electromechanical boxes. The last type of product that is manufactured at Benchmark are volume cabinets. The volume cabinets are produced in low quantities, using labour intensive manufacturing processes.

1.2 Problem context

Benchmark produces a number of different products for a variety of customers. This research will focus on products that Benchmark produces for customer A. The reason for the selection of this customer, and other decisions about the scope of the thesis will be discussed in section 1.7.

At Benchmark, the demand of customer A increases with approximately 20% per year. According to this increase in demand, Benchmark is forced to increase the Move Rates with which the products are made to be able to deliver the increasing number of ordered products on time. In this context, the Move Rate for a product is defined as "the maximum number of products that are completed per unit time". To make this definition more specific for this research, a product is one complete volume cabinet and the production is measured in cabinets per week. This means that the move rate definition for this research can be stated as "the maximum number of volume cabinets produced per week".

The increasing demand means that Benchmark is required to increase their move rates at a certain point in time. However, it is not clear when exactly this move rate increase should be realised. The consequence of this, is that the move rate increase cannot be realised in time, which is due to the lack of insight in the consequences of demand increase on move rate increases and the corresponding capacity defining factors.

For customer A, Benchmark produces a number of different specifications of volume cabinets. For each separate volume cabinet, customer A might increase demand. To achieve the delivery of products according to this increased demand, Benchmark has to adjust its move rates. At some point in time after the demand increase, Benchmark encounters the problem that they will not be able realise the increased move rate in time, which is necessary based on the increased demand. The move rate capability is insufficient to meet the increased demand for volume cabinets from customer A, resulting in a lower on-time delivery performance. The moment Benchmark realises that an increase in move rate should be realised, is not in time to meet the increased demand during the upcoming time period, which makes Benchmark's action problem the following:

"Move rate increases due to increasing customer demand cannot be realised in time"

1.3 Problem Identification

With the identification of the action problem, the causes that contribute to this problem need to be identified by designing a problem cluster. This problem cluster gives a straightforward overview of the problems related to the action problem, so that it can then be used to identify the core problem. We will explain the problem cluster, and what it is based on.

The action problem, *"Move rate changes due to increasing customer demand cannot be realised in time, due to the lack of a 4M analysis tool",* occurs because there is a difference in the move rate capacity and the increased demand for a certain volume cabinet, or a combination of different volume cabinets. This difference forces Benchmark to increase their move rates. To realise this increase, the move rate capacity has to be increased in terms of either manpower, machines or materials. This is dependent on the move rate capacity per factor, and whether this is sufficient to increase to the overall move rate needed to fulfil demand.

To find out where this problem exactly occurs, we need to find out in which different aspects the capacity can be divided. Within the production process of the cabinets produced for customer A, the capacity is influenced by four main aspects; Manpower, Machine, Materials and Methods, which are the 4Ms in the 4M Approach used to analyse the capacity at Benchmark. Discussions with stakeholders gave the insights that, within Benchmark the capacity can be divided into three main aspects from the 4M model, as these three aspects are potential limiting factors.

The first and most important aspect which determines the capacity is the capacity of machinery in combination with the number of machines in place. In the situation of the assembly process at Benchmark, this mainly means the tools and 'jigs' available, as parts of the volume cabinets need to be produced on these jigs means that no more assemblies can be completed once all jigs are occupied. A more extensive explanation of jigs is done in section 2.4.2.

Secondly, the number of employees in combination with the efficiency and capacity per employee influences the overall capacity. As the production process of the volume cabinets involves a significant amount of manual labour, the number of people performing this labour is related to the number of cabinets produced.

The third part that significantly influences the capacity within the production process of these cabinets are the materials. Without materials, we will not be able to complete the assembly process The fourth component of the 4M approach, Methods, is believed not to be a limiting factor within the scope of this research. The reason we assume this is not a limiting factor, will be further discussed in section 1.7. The 4Ms contributing to a limitation of the move rate capacity can be divided up into more specific factors. The exact factors contributing to a limitation of the capacity are not yet known, we will further research what factors are contributing to limitation of the move rate capacity in chapter 2.4 of this thesis, to get a complete understanding of the reasons why the demand, and more specifically the increases in demand cannot be met.

In certain cases, one of the three main factors influencing capacity is insufficient to meet demand and becomes a bottleneck, which causes the increase in move rate to take longer than expected and means Benchmark is unable to meet the increased demand. The bottleneck is discovered through calculating the needs for the limiting factors. Because the calculation of the capacity needs is not done through a dedicated analysis tool, this causes the capacity to be lower than needed when an increase in demand occurs and the lead times for increase in the capacity is longer than the time period in which the change in demand should be realised. Whenever the move rate is not sufficient to fulfil increased demand, Benchmark starts an internal escalation process to be able to limit the number of products that cannot be delivered on time. The internal escalation process consists of, but is not limited to, working overtime, giving priority to products with increased demand by not producing or producing lower numbers of other products and getting people from other departments within the company to temporarily work in the department where the bottleneck occurs and therefore lowering workforce in their own departments. The internal escalation process therefore has negative effects on other departments within Benchmark, but also causes an increase in costs for the production of volume cabinets. The negative effects on other departments mean that it is not sustainable over the long-term, and it is more cost-efficient to increase move rate capacity than to turn to the internal escalation processes.

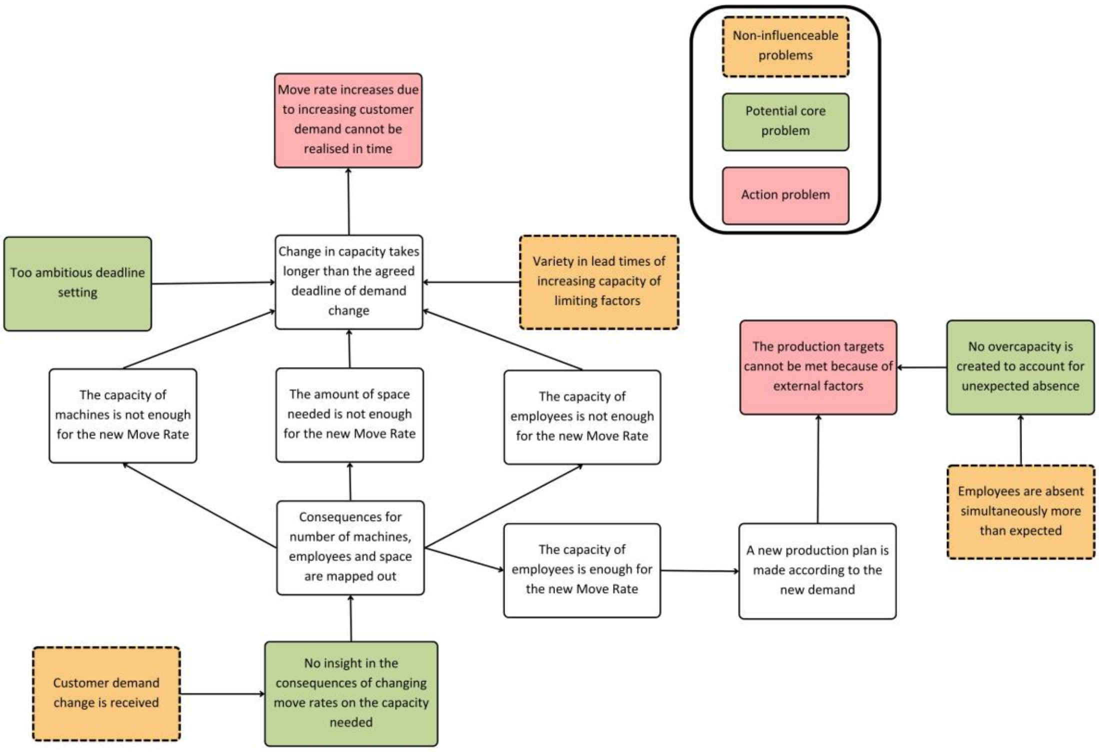


Figure 1: Problem cluster

From the problem cluster, an adequate core problem can be selected. Heerkens & van Winden (2017) state that problems with no direct cause or problems with only non-influenceable problems as cause are possible core problems. Keeping this in mind, there are three possible core problems left after setting up the problem cluster.

The problem of too ambitious deadline setting is a problem that only partly solves one of the causes that the demand increase cannot be met. Next to that, setting less ambitious deadlines for production may negatively impact the time it takes to assemble products. As manual labour is a significant part of the process, the assembly time of products may increase along with the increased time available for the assembly of this product. This effect means that setting production deadlines further into the future will cause longer production times, which means that there will not be an increase in production as a result of solving this problem.

Next to that, we will not select the potential core problem of creating no overcapacity in order to compensate for unexpected circumstances. First of all, contracting more employees brings extra costs, which can be higher than the costs of having to work overtime once because of absence of an employee. Benchmark should make a decision on the overcapacity they want to have, but the problem is not significant enough as it is not the main for the majority of the production targets that have not been met.

Therefore we select, *"No insight in the consequences of increasing move rate on the capacity needed"* as the core problem for this research. As we can see from the problem cluster, this core problem influences most of the problems leading up to the action problem. This means that we will have the most effect on solving the action problem, when we provide a solution for this core problem.

1.4 Stakeholders

Different stakeholders are involved in this research. There are both internal and external stakeholders involved in this research, these will be discussed separately in this section. Internal stakeholders are the stakeholders which are directly affected by the research, while external stakeholders are indirectly affected.

1.4.1 External stakeholders

Customer A: the customer for which the cabinets included in the scope of the research are produced. This customer is a stakeholder in this research as the research aims to improve the on-time delivery performance towards this customer. Therefore, customer A has an interest in a higher on-time delivery performance, as this means more reliability and certainty.

1.4.2 Internal stakeholders

Supply chain analyst: This stakeholder is responsible for improvements of logistical processes at Benchmark Almelo. Therefore, it is also in their interest that this research is performed, as it aims to improve the process of capacity planning and capacity increases.

Manager Logistics: This stakeholder is the owner of planning & logistical processes at Benchmark Almelo. This means that they oversee the process of planning as well as the logistical processes, which are affected by this research.

Program manager customer A: The owner of customer A program at Benchmark Almelo. This stakeholder manages the team responsible for producing the products ordered by customer A. The program manager customer A has the final responsibility in the processes of delivering the products to customer A, which means that they have an interest in this research, as it aims to improve processes within this program to subsequently improve the on-time delivery performance.

Tactical planning: Responsible for maintaining 4M analysis for cabinets & planning of these cabinets. They plan the general machine capacity, which will be improved through a successful completion of this research.

Mechanical Engineers: Owners of building processes for the cabinets. Mechanical Engineers know how much capacity is needed to maintain a certain move rate, and also address what is needed to increase the move rates when needed in terms of product specific tooling, amount of room and standard tooling.

Supervisors Production: Supervisors for the production of cabinets. Also responsible for the number of trained craftsmen in the process, the training of new craftsmen and the capacity during holidays.

1.5 Research design

To solve the core problem described in section 1.3 we have formulated the main research question and sub-questions. We will describe the main research question, followed by the sub-questions below and the goal for each sub-question.

The main research question is:

How can the responsiveness on move rate increases and the on-time delivery performance at Benchmark be improved?

To answer this question, the research has been split up into the following sub-questions. We have formulated these sub-questions with the research goal in mind to provide more transparency to the process of the 4M analysis and to provide a solution for a quick 4M analysis.

1. *"How does Benchmark currently utilise the 4M (Manpower, Machine, Materials, Methods) analysis to handle increased customer demand for volume cabinets?" (chapter 2)*

At the start of the research, a good insight in the current situation has to be gained. This helps getting a deeper understanding the problem and provides a basis to be able to make any improvements to the process. In this chapter, we will describe how Benchmark currently uses the 4M analysis. Also, we will describe the decision-making process of increasing move rates and what steps need to be taken to increase the move rate in the current situation. To answer this question, we will find the answer to the following questions:

a. What does Benchmark currently use as a 4M analysis?
b. How is a move rate increase currently managed at Benchmark?
c. What is the decision to increase move rate based on?

These questions help answering the sub-question by giving an overview of the interaction between customer A and Benchmark with regard to handling change in demand.

2. *"What is the current capacity of Benchmark in terms of manpower, machines, materials and methods?" (chapter 2)*

To be able to propose a tool as a solution to the problem, it is important to gather data about the current capacity in terms of the 4M. Trough discussions with stakeholders within Benchmark, we will gain insight into the important aspects in which the 4M can be divided. These aspects will describe the available move rate of production of the volume cabinets. During these discussions, we aim to get data about the capacity of the aspects discovered. All data which cannot be communicated during the discussions will be gained through Benchmark's database.

3. "*What factors can manpower, machines, materials, methods be broken down into and what are possible relations between these factors?" (chapter 3)*

After discovering the aspects that determine the capacity of production, we will use this information to perform literature research into possible relations between discovered aspects. We will also use literature to research known relations between an increase in 4M and the increase in capacity that follows. Lastly, we want to find out the already known relations between these aspects and the on-time delivery performance.

4. "*How can we minimize the total costs of late deliveries after move rate increase?" (chapter 3)*

To minimize the total costs we use literature about optimization problems to formulate a minimization problem. We study the standard aspects of formulating a minimization problem in chapter 3 and apply these to the situation at Benchmark in chapter 4.

5. *"How do the manpower, machines, materials and methods influence each other at Benchmark?" (chapter 4)*

To answer this question we need to know what the relations are between an increase of the demand and the need for extra capacity per factor of the 4Ms at Benchmark. We will use existing data about past demand changes to assess these relations. To validate whether the found relations can be used in predicting future needs of 4M, we will consult experienced employees about their experiences with changes in demand and the result for the needs of 4M. We also want to know expectations about the future validity of the relations found.

6. *"How can we model manpower, machines, materials and methods as a consequence of demand increase?" (chapter 4)*

In this chapter, we will first describe the wishes of Benchmark in terms of the functionalities of the tool. Afterwards the process of making the tool will be described, accompanied by images of the final product.

7. *"How can the 4M analysis tool be implemented and assessed by Benchmark?" (chapter 4)*

We will provide an implementation plan for the tool, together with a user manual for the tool in this chapter. The optimization problem can also be assessed by studying the differences between the current situation and the improved situation through taking the optimal decisions.

1.6 Theoretical background of 4M

The 4Ms of production is a theoretical framework used in manufacturing and operations management to categorize and analyse key factors involved in the production process. This 4M model is deduced from the 6Ms of production, which include the 4Ms used for this research, as well as Measurement and Milieu (Kaufman Global, 2017). The 4Ms of production are Manpower, Machine, Material and Method, and can be used as a framework to help during problem solving sessions, as a cause and effect diagram. With this framework, various aspects of the manufacturing process can be evaluated and optimized. Organizations aim to enhance productivity, quality and overall performance through this framework by addressing each of these factors. By incorporating the relevant elements associated with the 4Ms into a framework, an organization can analyse and optimize a manufacturing process and its planning processes. Organizations use this framework to assess their performance with regard to these 4Ms and their processes. The 4M principle helps to identify key factors that contribute to the success of certain processes, and will also help to evaluate the strengths and weaknesses of these processes. Apart from this, the framework also helps to identify opportunities for improvement of these manufacturing and planning processes, and can give insight in the areas that should be prioritized for this improvement.

The 4Ms can also be used to describe the current situation of planning and production and its capacity, as it entails the factors on which the production and planning of the company is assessed currently.

We will discuss the 4Ms used in this research and why these are relevant. The specifics of the factors that the 4Ms can be divided into when looking at the situation of Benchmark will be discussed in section 2.4.

The first aspect that is covered by the 4M analysis is manpower, referring to the human resources involved in the assembly of the products. The human resources may involve workers, skills, training and expertise and considers the quantity and quality of the workforce required for effective production and assembly. Manpower covers the analysis of production requirements to determine the optimal number of human resources needed at different stages of the process, while also identifying the quality level necessary to have an efficient assembly process.

Machinery refers to the equipment needed to complete the process. This can range from production machines and equipment used in the production process to the technology used to facilitate the production operations.

The materials can by analysed through looking at the raw materials and other supplies needed to manufacture or assemble a product. Therefore, this has to do with the supplier management as well as inventory management.

Finally, the methods used in production and planning processes have to be described and analysed to be able to identify areas where improvement can be made, without directly changing the capacity in terms of the other Ms, manpower, machinery and materials.

The 4M analysis, using manpower, machinery, materials and methods is selected as a basis for this research, as Benchmark currently assesses their move rate capability on factors mostly similar to factors used in the 4M analysis.

1.7 Scope

The research into the 4M analysis has a lot of factors, of which some are too broad or insignificant to include in the scope of a bachelor assignment. Therefore, we will discuss the factors that will fall outside of the scope, as well as define the aspects that will be inside of the scope of this research.

From the 4Ms; manpower, machines, materials and methods, only three of the variables fall into the scope of the research. The last M, methods, will be kept outside of the scope of the research. The reason for this is that this factor is mainly about the processes of production. As the products have been produced by Benchmark for a significant amount of time, the process maturity is assumed to be good enough and not a limiting factor to increase capacity.

Although manpower, machines and materials are included in the scope of the research, there are some known factors within these variables that we will exclude from the research. Falling under manpower, we will exclude the capacity limiting factor ‘number of executive employees’. This factor does not directly influence the output of the production process, and therefore has less impact on the research.

During the discovery and determination of all factors contributing to the parts of 4M that fall into the research scope, the relevance and impact for the research will be assessed separately. If factors take too much time to be researched within the period of 10 weeks available for this assignment, they will also be considered out of scope.

This research is conducted within the department for the production for customer A. Within the company there are multiple departments, but these are mostly smaller, or include a larger variety of customers. The research is limited to the department of program of customer A, as the other programs and products do not have standalone production locations and are produced in a mixed setting. The products produced for customer A have dedicated assembly locations, and should therefore have a reliable and stable production planning. The total contribution of customer A across all products to the total turnover of Benchmark is currently around 75%. Therefore, other departments are not taken into account, as various products for multiple customers are produced in the same production location. Due to this, Benchmark does not use the same 4M analysis approach for other departments, and these departments are therefore not of interest for this research.

Benchmark produces two types of products for customer A. The first type of products is ‘small boxes’. These products have a relatively low assembly time and are less complex when compared to the second type of products. The small boxes have a building time of 2-3 days, which is performed by a singular craftsman. Because of the relatively low complexity of the planning of these products, and the fact that the small boxes amount to a lower part of the total production, we will leave these out of the scope of the project.

The scope of this thesis will be focused on the volume cabinets, the second type of products, that Benchmark Almelo is producing for customer A. These cabinets are assembled on dedicated production locations, and take between 160-200 working hours per cabinet to complete. To complete a cabinet, multiple specialised workers are involved in the assembly process. For this type of products, Benchmark already performs a simplified version of a 4M analysis, which is why these products are of interest for this research.

Eight different cabinets are produced by Benchmark for customer A. The cabinets that are thus within the scope of the research are:

- Product 1 *Combined Production Location 1*
- Product 2 *Combined Production Location 1*
- Product 3 *Combined Production Location 2*
- Product 4 *Combined Production Location* 2
- Product 5
- Product 6
- Product 7
- Product 8

Apart from the regular cabinets, there is also New Product Introduction (NPI) section within the program. These NPI Cabinets can be kept out of the scope for this project since these are not (fully) industrialized and therefore a 4M analysis is not yet relevant for the program managers. The demand for NPI products is usually a maximum of 1 per week, and often even less than that, so it is not relevant to perform a 4M analysis on these products.

2 Current situation

In this chapter we will answer the question, "*How does Benchmark currently utilise the 4M analysis (Manpower, Machine, Materials, Methods) to handle increased customer demand for volume cabinets?"* By answering this question, we will describe the current situation of how Benchmark handles increased customer demand. To answer this question, we have planned and performed various discussions with relevant stakeholders. As a result from these discussions, we can describe the process of planning and more specifically the decision-making process of when and how to act on an increasing demand, with increasing move rates as a result. We will answer the sub-question mentioned above by first describing what Benchmark currently uses as a 4M analysis in section 2.1. Following this, in section **Error! Reference source not found.** we will describe how Benchmark currently manages increases in move rates and what steps have to be taken before an increase in move rate is realised. Finally, we will describe the decision-making process of when to increase the move rates for volume cabinets in section 2.3.

2.1 Current 4M analysis

In this section we will answer the question *"What does Benchmark currently use as a 4M analysis?"* Benchmark currently analyses the capacity with respect to the 4Ms on which the Program Manager bases his decision of when to act on increased customer demand by increasing the move rate capabilities.

In Figure 2, an overview of the result from a 4M analysis on the Product 1 can be seen as it is currently performed at Benchmark. The Program Manager of the customer A program at Benchmark has collected data about the move rate capability of the Manpower, Machine, Materials and Methods aspects of producing volume cabinets. An overview as presented in Figure 2 is made for every volume cabinet produced for customer A. This result of the current 4M analysis at Benchmark gives an overview of the current move rate capabilities. Benchmark has broken down the 4Ms into the most critical limiting factors for increasing the move rates of volume cabinets. In the overview, the current move rate capabilities per factor can be seen.

Figure 2 gives an overview of the 4M analysis of one volume cabinet, it is not representative for the whole production planning. Once the program manager initiates the process of the current 4M analysis, an analysis is performed for all relevant volume cabinets, so that the move rate capabilities per volume cabinet are clear. As a result, we have multiple files that need to be compared and monitored to get insight in the move rate capability per cabinet and production location. From Figure 2, we can see what actions need to be taken to increase the move rate. However, we cannot see what actions need to be taken to fulfil the combined move rate of combined production locations, and what actions have priority.

Therefore, the Program Manager has to go through all the files with move rate capabilities, to manually determine what move rate increases have priority.

Next to the specification of factors, the owner of the responsibility for this factor is stated. For example, the supervisor is responsible for the number of craftsmen available to meet the required move rate for this product. This means that he is required to monitor how many craftsmen are needed to meet the current required move rate.

On the columns below the header "Bottleneck @ MR", we can see the different realistic move rates for this product. For each factor, the program manager has collected information to determine what move rates are currently manageable without taking further action, what move rates require attention before they can realistically be achieved, and what move rates are currently not attainable. The manageability of various move rates is expressed in three different colours, green for move rates that are under control, yellow for move rates that require attention, and red for move rates that are critical, if Benchmark has to increase their move rates to these levels.

To be able to have an overview of the amount of work that needs to be done before the next move rate can be achieved, these colour codes are associated with ratings that can be found in Table 1 (Benchmark Electronics, 2023). The accumulated value of the ratings for a specific move rate give insight in the amount of factors that need to be increased before the move rate can be met. The program manager now has an overview per product what move rates can be achieved currently per factor. However, this overview does not quantify the additional needs per factor to achieve the increased move rate requirement following from the increased customer demand. Therefore, the program manager still has to acquire additional information to create an overview of the exact actions that need to be taken to increase the move rate capability to the required move rate.

Another disadvantage of the current 4M analysis is the fact that it only focuses on a single product per analysis, and does not take into account the shared capacity of combined production locations. When using the current 4M analysis, the program manager has to take this shared capacity into account when the customer demand for one or more products changes. Currently, this is done manually through acquiring information and manual calculations based on employee experience.

From Table 1 we can conclude that the current move rate capability is 2 products per week, and that this can be increased to 2,5 products per week by taking proactive action to prepare critical suppliers for a move rate increase and thus an increase in demand of critical components. Increasing a move rate to 3 or even higher is currently not possible without making a recovery plan and taking major actions on the factors of product specific tooling, such as jigs, and critical components as well as proactive actions for the number of trained craftsmen, holiday capacity, Test equipment and general machine capacity, the lack of room and the capacity of non-critical first tier suppliers.

However, from Table 1 we cannot conclude what actions need to be taken and by how much the relevant factors need to be increased to meet the required move rate capability.

Supplier: Benchmark Almelo			Actionholder: Bottleneck @ MR								
	Customer average demand per week	**Owner**	**0,5**	**1**	**1,25**	**1,5**	**1,75**	**2**	**2,5**	**3**	**3,5**
Manpower											
	Number of trained craftsman	Supervisor	0	0	0	0	0	0	0	1	1
	Number of executive	Program Manager	0	0	0	0	0	0	0	0	0
	Arrange capacity during holidays	Supervisor	0	0	0	0	0	0	0	1	1
	Other items		0	0	0	0	0	0	0	0	0
Machine											
	Product specific tooling	Manufacturing Engineer	0	0	0	0	0	0	0	3	3
	Test equipment customer specific	Tactical Planner	0	0	0	0	0	0	0	1	1
	General machine capacity	Tactical Planner	0	0	0	0	0	0	0	1	1
	Lack of room	Manufacturing Engineer	0	0	0	0	0	0	0	1	1
	Other items		0	0	0	0	0	0	0	0	0
Materials											
	Critical components	Strategic Buyer	0	0	0	0	0	0	1	3	3
	Capacity first tier suppliers	Strategic Buyer	0	0	0	0	0	0	0	1	1
	Packaging	Strategic Buyer	0	0	0	0	0	0	0	0	0
	Other items		0	0	0	0	0	0	0	0	0
Methods											
	Process maturity	Manufacturing Engineer	0	0	0	0	0	0	0	0	0
	Other items		0	0	0	0	0	0	0	0	0
Total rating			**0**	**0**	**0**	**0**	**0**	**0**	**1**	**12**	**12**

Explanation of the used colours and rating		Rating
0	=under control	0
1	=need attention, proactive action required	1
3	=critical, recoveryplan with milestones required	3

Table 1: Result of current 4M analysis

2.2 Move rate increase

Now that we have identified how Benchmark currently analyses its move rate capabilities through 4M analysis, we will describe how move rate increases are currently managed at Benchmark in this section.

Benchmark produces their volume cabinets according to determined move rates, which is the production output per week. However, Benchmark determines the minimal required move rate by taking the average needed production per week over a quarter. So, firstly the demand of customer A is determined in the number of products that need to be delivered during a quarter. To come to a demand on quarterly basis, various steps and interactions with customer A have to be completed. As the first step for determining this, customer A provides Benchmark with a 2 year forecast of the production of their own products for which they need parts delivered by Benchmark, which is updated on a quarterly basis. This forecast gives the company an overview of the number of products that customer A wants to have produced per quarter for the upcoming time period. Based on this forecast, the company has an indication on the expected demand during the upcoming period. However, the forecast on itself does not give a correct and complete overview of the actual demand per product from customer A that Benchmark has to produce. Because of the potential inaccuracy of the forecast, customer A provides a 'start plan' with the actual demand. This is provided each quarter, so that the company stays up to date on the demand coming from customer A. The 'start plan' given to the company describes the number of production starts customer A plans to do for which they use parts provided by Benchmark. This 'start plan' could be different from the forecast customer A initially provided to the company, which means the company has to deal with an unexpected change in demand from customer A.

Apart from the change in demand when compared to the forecast, there is another form of demand change that occurs in the process, which is the intended increase in demand. Customer A's demand has an increasing trend, which means that we expect an increase in demand over time. The increasing trend is part of the forecast provided by customer A, and therefore gives the company more time to react to this type of demand change. This increase over time will not always be linear, and will also not be spread equally across the various specifications of volume cabinets. There will be periods of time, during which the demand from customer A increases significantly more than the increase during the previous period of time. In addition to this, customer A for example demands an increase of over 25% for product X, when demand for product Y only increases by 5% in this time period. This makes it that this type of demand change also has an impact on the planning process and its complexity.

Following the incoming demand from customer A first through a forecast and later through the 'start plan', the next step is to set up a 'RED table'. The RED table is a table based on the forecasts customer A provides that states the demand the company has to adhere to during the upcoming time period. In this table, the order quantities are reduced to order quantities per volume cabinet on a quarterly basis. The 'RED table' is made because the forecast provided by customer A does not give a complete, accurate and easy to understand overview of the number of products that need to be produced to meet the demand from customer A.

To be able to achieve the delivery of the number of products demanded, Benchmark establishes the move rates that are needed per cabinet. These move rates are determined based on the 'RED table' mentioned above, which contains the demand per product for the upcoming time period. The time period that is covered in this table is divided up into weeks to determine the average move rate the company has to adhere to, to be able to meet the demand of customer A. The move rates that are established in this step of the planning process, are also the minimum move rates the process should have capacity for.

Because the planning of the production, through establishing move rates is done well in advance, the customer should not be able to change these within a shorter notice period, than the company is able to react to. Therefore, together with customer A, the company has agreed on minimum lead times per cabinet. Customer A can only order volume cabinets for which the delivery point is further into the future than the agreed lead time for customer A on that product. This lead time is not the same as the lead time that Benchmark may have when it has to increase its capacity to produce the extra demanded products. This means that, during the planning of these products the company has to account for a change in demand to be able to deal with this.

Benchmark produces three different types of products for customer A, of which the volume cabinets are within the scope of this research. The volume cabinets take between 160-200 hours of assembly time to complete per cabinet. Different parts of the cabinets are assembled on 'Jigs', which are special tables on which the product parts can be attached and assembled. These 'Jigs' are then occupied until the whole cabinet has been completed. This makes the planning of these products more complex, as there is not enough available space to let one employee work through 160-200 hours of assembly time.

2.3 Decision-making process of increasing capacity

As customer A is a company which generally aims to improve their performance, the expectation is that the number of products ordered per quarter will increase over the years. However, the increase in demand is not always linear. In addition to that, the lack of insight in the consequences of changing move rates on the capacity needed means that it is not clear by how much the capacity needs increase when there is an increase in a move rate. An increase of 1 move rate, will not always mean that one additional employee is needed. Additionally, an increase in the forecast does not always mean that an increase in the capacity is needed. It may occur that in the current situation there is enough room within the capacity for increasing a move rate, that no additional preparing actions are needed to meet the new demand.

When the move rates that are needed to be achieved to make sure that the demand can be met are clear, the program manager investigates the needs of extra capacity. This means that the program manager must study data about the current demand and capacity to assess whether a change in capacity is needed. The program manager bases this decision on the move rate data delivered by the planning department. Based on this data, they will decide whether a change in capacity is needed by calculating the needs per product/production location and compare this with the available capacity.

Whenever a change is needed, the program manager informs the other stakeholders involved in the process, who are responsible for the various parts of the process covering the capacity. At this stage in the process, the program manager asks the stakeholders involved for the lead times for a change in the capacity. Depending on the part of the capacity that needs to be adjusted, the lead times for this change varies between 6 weeks and 52 weeks. In the flowchart provided below, an overview of the information flows and the currently known lead times with regard to increasing capacity will be given.

The next step is for the stakeholders within the company to start the process of increasing the capacity by either starting the recruitment process or sent out quote requests for new equipment. After

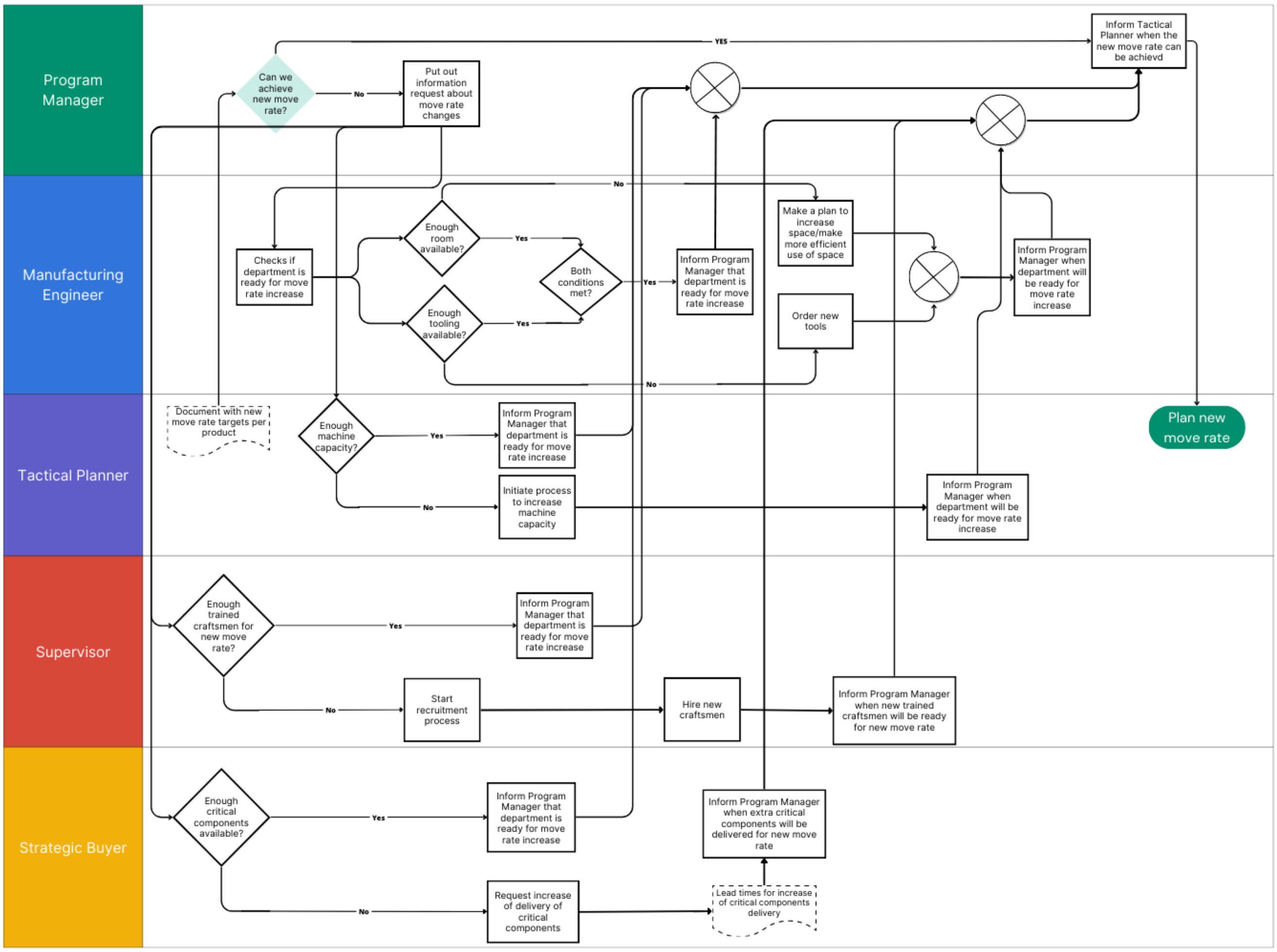


Figure 2: Flowchart current capacity increase analysis
Note: All crossed circles represent a point where all previous actions should be completed before the next action can be taken.

feedback from this step has been received, more specific expected lead times are known. From Figure 2 we can see the current steps taken to analyse the capacity of a volume cabinet. As can be seen in the figure, the program manager initiates and oversees all processes and steps taken to increase the move rate capacity. To improve this process, the program manager should have access to a calculation tool, where the calculations for the additional needs are done after providing the applicable input to calculate the required capacity per factor. This eliminates all steps where the program manager has to acquire information from other departments responsible for various parts of the production process. Then, the program manager can directly inform relevant departments what actions need to be taken and when. This will result in less time lost when compared to the current situation, because the actions can be taken directly when the need for these actions is known.

2.4 Capacity defining factors

In this and the following section, we will analyse the current capacity of all factors with respect to 4M on all production locations used for producing products for customer A. To be able to fully analyse this, we will first establish the capacity defining factors that are present in the process. We will discuss factors that influence the capacity directly as well as indirectly, to create a complete overview of the existing challenges. In the next section, the current capacity will be discussed, if applicable to the factor.

The capacity of the production for customer A at Benchmark can be divided into four main aspects, being manpower, machine, materials and methods. Per aspect, there are multiple factors contributing to a potential limitation of the capacity.

2.4.1 Manpower

- **Number of trained craftsmen**
  As the production of the products within the scope of the research is a labour intensive process, the number of trained craftsmen defines a part of the capacity. This part of the capacity will ultimately be counted in available working hours, where each FTE is counted as 35 working hours. At Benchmark, on contract, each FTE is 40 hours. However, we account for time loss because of several factors. At the start and the end of working days, we expect time loss due to starting up for the day and cleaning up the workspace. In addition to this, we expect time loss due to other factors, such as coffee breaks or small talk with colleagues. In total, this accumulates to 1 hour per working day, making that instead of the original 40 hour FTE, Benchmark counts each FTE as 35 working hours. On top of that, each full-time employee has the right to take vacation days, which amount to approximately 10-15% of the total working hours. The last thing that should be taken into account is the sick days leave that will inevitably be happening, which is more reliable to predict with a bigger group of employees. Adding all these factors up, it means that it is expected that an employee is not present about 18-20% of the time on average.
- **Number of executive**
  The number of executive employees does not have a direct impact on the capacity of the production. However, the absence, or lack of such employees for a longer period of time will ultimately cause a disturbance in the workflow, effecting the capacity. This factor is kept out of the scope, as mentioned in section 1.7.
- **Capacity considering holidays**
  The capacity during holidays is different from normal working periods and should therefore be considered separately. The actual needed number of employees when considering the amount of free days each employee has, as well as the capacity needed during collective holidays.
- **Work-in period**
  When an increasing in the number of trained craftsmen is required to be able to achieve a new move rate, the work-in period of these new craftsmen should also be considered, as they will not immediately be able to work as efficiently as experienced craftsmen.
  For junior (unexperienced) as well as medior (some experience) recruitments, the work-in period is about 6 weeks. As the starting level of expertise is different between new hires, so will be the working level at the end of the 6 week work-in period. However, all new employees will be able to perform tasks independently at full capacity after these 6 weeks, only the complexity of tasks differs. During these 6 weeks new recruitments will be trained through a basic instruction process, after which they will start to work at the working place for a few

weeks to learn. During this time period, the new employee is counted for 70-80% of the normal FTE capacity.

- **Recruitment time**
  As mentioned above, there are two type of recruitments as trained craftsmen, junior and medior hires. Apart from the work-in period, the average recruitment time should also be considered, as this influences the total time in which a move rate increase can be realized. The recruitment period for junior hires is relatively short, as they will be able to start their work-in period within 2 weeks on average. Because this type of recruitment does not require previous working experience, the amount of potential recruitments available is high, meaning a short recruitment period.
  The recruitment time for a medior hire is at least 2 months, depending on the notice period they have on their current job. This will be longer if the notice period at their previous company is longer.

2.4.2 Machine

- **Product specific tooling**
  Every volume cabinet is (partly) constructed on special tables called jigs. These jigs are designed so that the part which will be produced on it can be secured on this jig, and the craftsman can work around it on the height of their preference. The number of jigs directly correlates with the maximum number of cabinets produced. As these tables are built specially for this assembly process, the building time for these jigs should be considered when aiming to improve the move rate for a cabinet.
- **Test equipment**
  All cabinets have to be tested on every aspect of their functioning. Therefore, there needs to be enough test equipment available to deal with the intended move rate. When the capacity of the test equipment is reached, no more cabinets can be tested and shipped, even though it might be possible to produce more cabinets. The capacity of the test equipment is calculated in number of night slots. The reason for the calculation of test equipment capacity in night slots is that the testing of one volume cabinet takes up one full night slot.
- **Room (in m^2)**
  The amount of room available naturally affects the maximum number of products made in a production process where the assembly takes place through manual labour. When there is a lack of room to increase a move rate, either the amount of total space available should be increased, or the room available should be allocated differently between cabinets.
- **Standard tooling**
  Standard tools are needed for every craftsmen. Per working station, a fixed set of tools is needed. Therefore, a trained craftsman cannot continue producing products at the speed with which the move rate capacity is calculated if there are not enough tools available.

2.4.3 Materials

- **Critical components and packaging materials**
  The lead times for an increase of delivery of critical components determines the earliest possible moment for an increase in move rate capability. The volume cabinets produced by Benchmark need specific packaging materials, which have to meet certain standards to ensure safe transport from Benchmark to the shipping locations.
- **Capacity first tier suppliers and packaging materials**
  The capacity of the first tier suppliers determines the moment when additional suppliers need to be approached. As calculation of lead times for newly identified suppliers needs additional

research from the company, we keep the calculation of these lead times out of the scope of this bachelor thesis.

2.4.4 Methods

- **Process maturity**
  The process maturity refers to the level of effectiveness, efficiency and reliability in the internal processes of the organisation. In addition to this, it is a measure of how well defined and controlled a company's processes are. When process maturity is sufficient, it is not necessary to change the processes, as the processes are sufficiently effective, efficient and reliable. However, we want to change the processes if we identify that process maturity is not optimal or sufficient.

2.5 Current capacity

Now that we have established the capacity defining factors currently used within Benchmark, we want to identify the current capacity for these factors and the overall move rate capabilities for volume cabinets.

In general, Benchmark defines its capacity in terms of the maximum attainable move rate per product. In the current situation, the capacity in terms of move rates is the following per volume cabinet:

Volume cabinet	**Move Rate (volume cabinet per week)**
Product 1	3
Product 2	5
Product 3 + 4	3
Product 5	2
Product 6	5
Product 7	2
Product 8	2

Table 2: Current move rates of volume cabinets produced for customer A

Table 2 shows the result of the combination of the capacity of all capacity defining sub-factors mentioned in section 2.4. We will further discuss relevant individual capacities of sub-factors, to gain a deeper understanding of how the above mentioned move rates can be achieved.

In Table 3, an overview of the move rate capability for all production locations is presented. Additionally, in the last column we show what the number of available trained craftsmen is that can achieve the corresponding move rate capability.

Volume cabinet	**Manpower move rate capability**	**Number of trained craftsmen available**
Production location 1	10	20
Production location 2	4,5	9
Product 5	2	1
Product 6	6	3
Product 7	2	1
Product 8	2	1

Table 3: Move rate capacity for Manpower

As mentioned before, at Benchmark Products 1 and 2 are produced at combined production location 1. This means that the amount of space, tooling and number of trained craftsmen partly or fully share a combined capacity. In addition to this, there is production location 2, where both Product 3 and 4 are produced. Here, these two types of products share the capacity of amount of space, tooling and number of trained craftsmen available. Lastly, the other products are produced in the SBB production location.

More specifically, this means that there is currently a maximum of 19x13 meters (247 m^2) available for the production of the combination of these products at production location 1. At this production location, there are jigs needed for both the production of back plates and connector plates. These jigs are specialised for making specific parts of the volume cabinets, and cannot be used to produce other parts of these cabinets. In addition to this, jigs may also be specifically made for a type of volume cabinet, and can therefore not always be used to produce parts for other types of volume cabinets. Currently, for making the connector plates of Product 2, there are 7 jigs available. For making the connector plates for Product 1 there are currently 5 jigs available. Next to that, there are also a total of 10 jigs available to produce back plates for all volume cabinets made in production location 1.

Per jig, there is sufficient tooling available. Benchmark has a selection of tooling that has to be available per jig, so that craftsmen can continuously work, without having to wait for equipment. The tooling is therefore calculated in sets of tools, which can be different depending on the type of jig the tooling is meant for. Currently, there is one set of tools available per jig.

To operate these jigs, 20 craftsmen are currently working in this department. The capacity of this factor, number of craftsmen, is currently higher than the overall move rate capacity at the Production location 1. For the current combined move rate of 8 at the Production location 1, the minimum number of craftsmen needed is 16. The additional craftsmen available at this production location are new employees currently going through their work-in period, while a safety in number of employees is created to be able to still meet the required move rate in case of unexpected absence of employees.

As mentioned above, the combined move rate for the Product 1 is 3 per week and the move rate for the product 2 is 5 per week. This makes the current maximum combined move rate for the Production location 1, 8 per week. With some of the capacity defining factors, such as the number of craftsmen working in this department, Benchmark is ready for a higher move rate while for other factors the current move rate is the maximum attainable move rate without increasing capacity. The current number of available jigs and tooling is limiting the potential to increase the move rate for the Production location 1, so Benchmark has to take action on this before they can increase the move rate.

Apart from the Production location 1, the Product 3 and 4 are also produced in a combined production location at Benchmark. Currently, the amount of space available for the production of the production location 2 is 180 m^2. There are 14 jigs available for these volume cabinets. Not all of these jigs will be available to produce new product parts continuously. This is because of the fact that a part of these jigs will be occupied because of waiting times for final assembly, and testing. Therefore, the number of working places available for these volume cabinets is currently 10 maximum. However, because of new employees and part-time workers, 9 of these working places are used on average.

The other volume cabinets are not produced in separate production locations, but in a combined production location, where a mix of these products is produced and capacity allocation is shared between these products. For these products, Benchmark does not use the same type of jigs used for production locations 1 and 2, which is why we define this capacity factor for these volume cabinets as the number of working locations available. The number of working places needed for these cabinets is 1 working place per 2 additional move rates. That means that Benchmark can produce 2 additional products per week if 1 additional working place is created. Currently, there is enough capacity to handle the current move rates. As the combined move rate of these products is currently 11, there are 6 available working places in the current situation.

The capacity of the testing equipment is defined in the number of hours testing time per week. There are currently 6 different testers available for testing the volume cabinets produced at Benchmark. Each volume cabinet is tested on one or more of these six testers, taking up capacity. However, the testers are also used for testing other products produced at Benchmark. In table 2, an overview of the number of hours that each volume cabinet takes up per tester. As can be seen from table 2, volume cabinets are not tested on all available testers, as each specific tester is capable of assessing the quality of different aspects of the volume cabinets.

Cabinet	Testers 1 through 6					
Names are confidential, these are products 1 through 8	10,9		0,3	0,4		
	12,0		0,9		1,0	
	20,2		1,0	0,2	1,0	
			2,0	26,7		
			0,3	0,2		
			1,0	0,1		1,0
		0,5	0,5	0,3		

Table 4: Testing hours per cabinet

In addition to the required testing hours for the volume cabinets, Benchmark uses these testers to test their other products. The average testing demand of these products on the various testers will be determined through taking the average number of hours used by non-cabinet products over the upcoming 26 weeks. For this timeframe, we assume that the demand for these product is sufficiently clear and complete to determine the average testing hours that are used up by non-cabinet products. In table 3, the averages per tester are presented.

Base hours used per tester	45,2	24,3	30,0	61,0	2,7	1,2

Table 3: Base hours used per tester

These averages are then used to determine the available number of testing hours for the volume cabinets by subtracting the average base hours used from the test capacity. The number of testers per type, and the available testing hours per tester are presented in table 4, which we combine to the capacity per type of tester. The MHCT tester is used 7 days a week, and 16 hours per day because of a day- and night-shift making the total available testing hours per MHCT tester 112 hours per week.

Capacity per tester (hours)	224,0	112,0	56,0	168,0	56,0	56,0
Number of testers	2,0	2,0	1,0	3,0	1,0	1,0
Available testing hours per tester	112,0	56,0	56,0	56,0	56,0	56,0

Table 4: Capacity of testers

The other testers only work during day-shifts and therefore have 56 total testing hours available per week.

In figure 4, we add a graph with the planning of non-cabinet products on the MHCT tester. We used an input file with all orders currently planned on these testers, in combination with the planned hours per tester for each order to determine the planned hours per week, and subsequently the average planned hours per week, which is used for the base line presented in table 3. The graphs for all other testers can be found in Figures 5-9. (Benchmark Electronics, 2023)

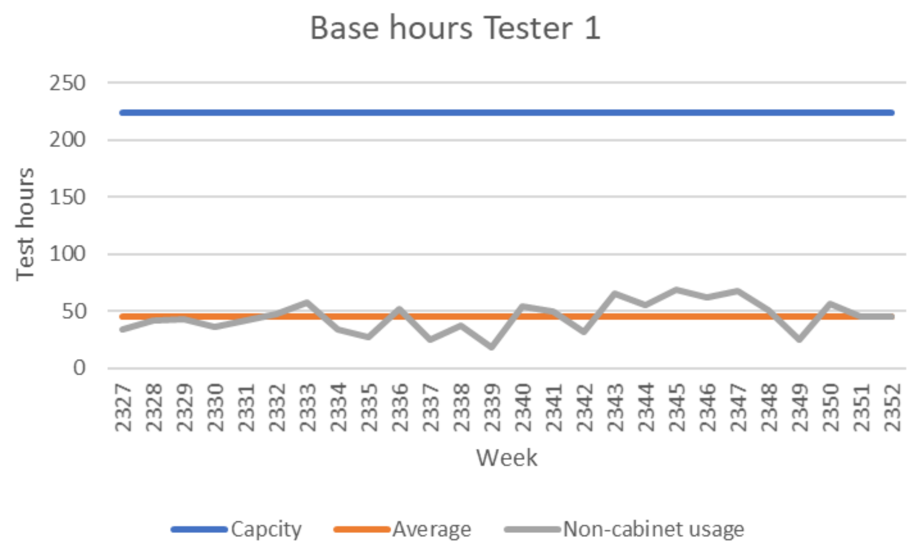


Figure 3: Tester 1 Planned hours non-cabinet products

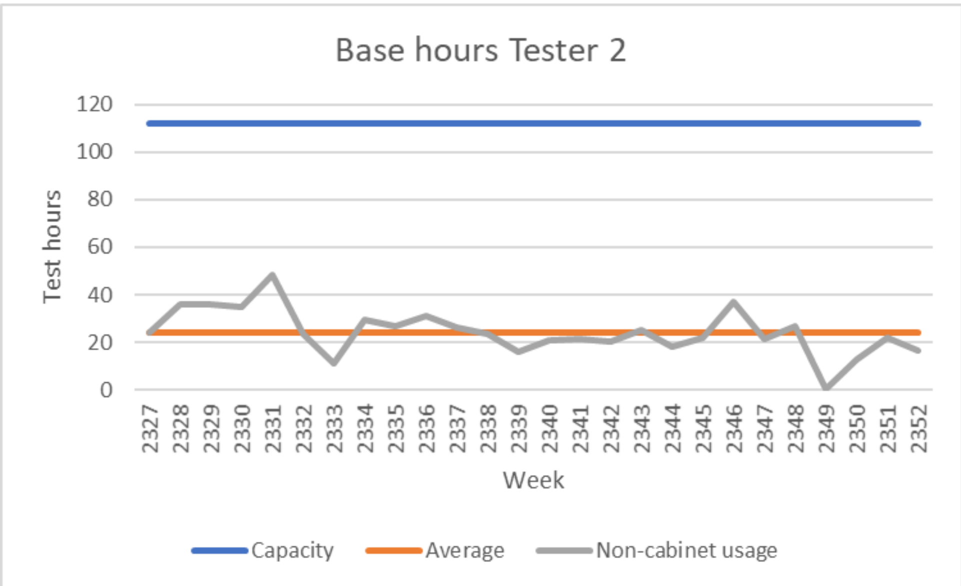


Figure 4: Tester 2 Planned hours non-cabinet products

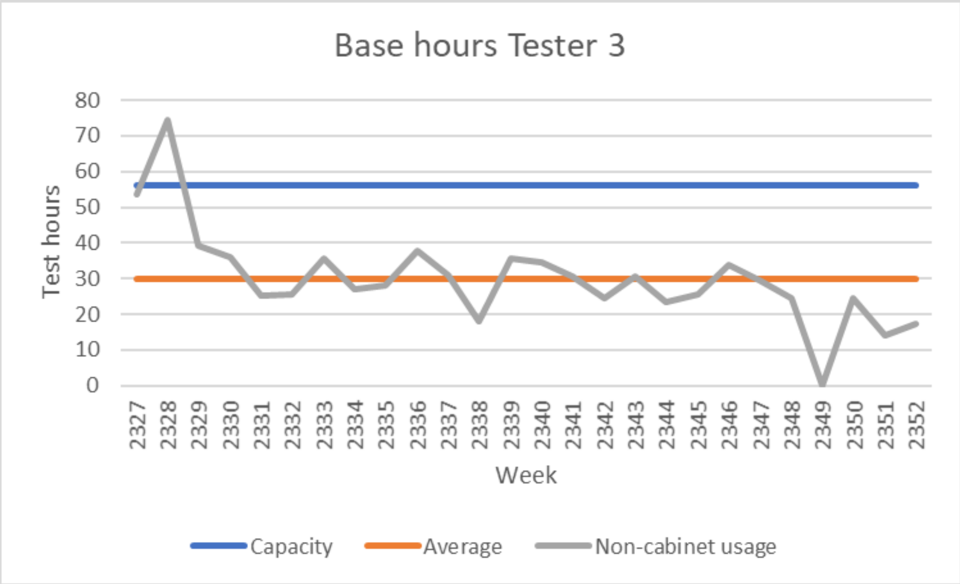


Figure 5: Tester 3 test planned hours non-cabinet products

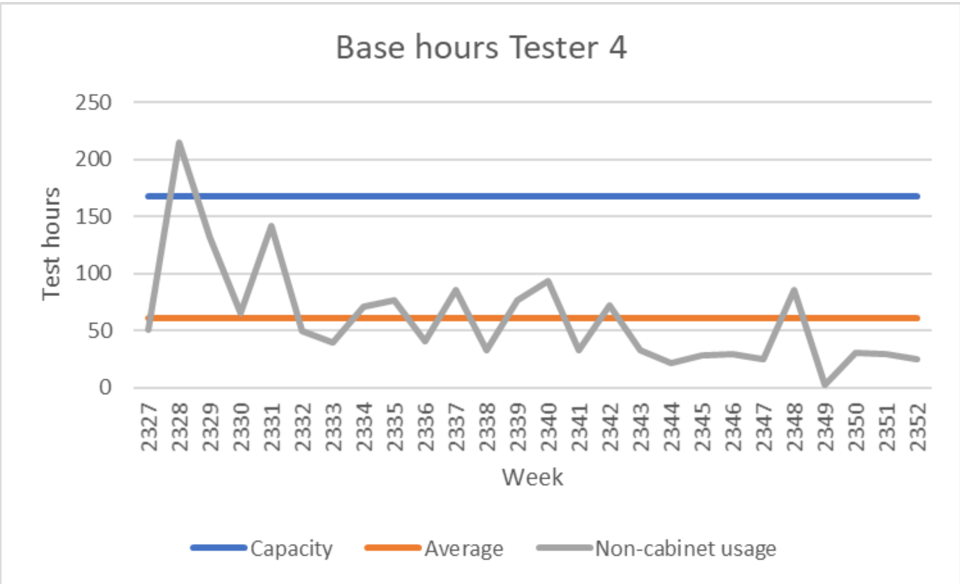


Figure 6: Tester 4 Planned hours non-cabinet products

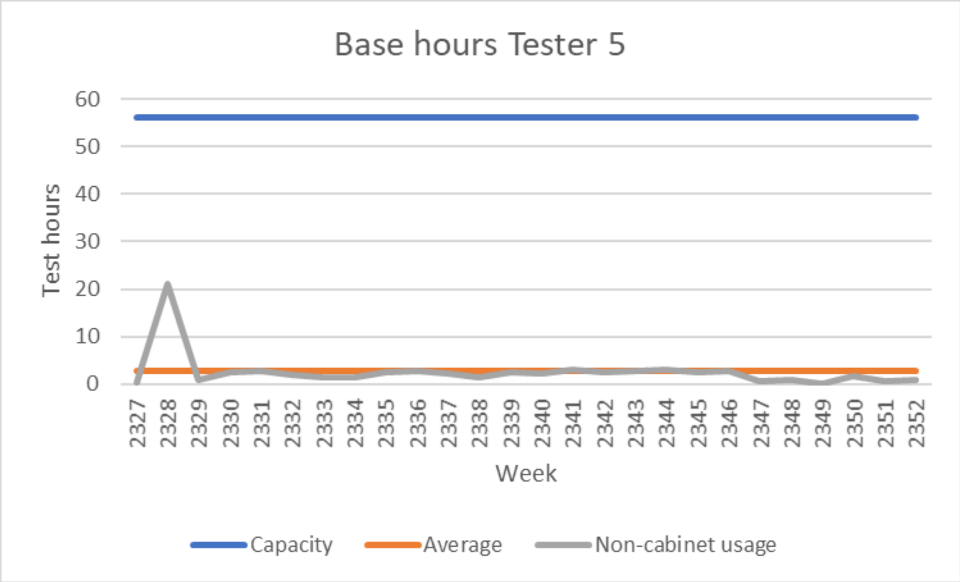


Figure 7: Tester 5 Planned hours non-cabinet products

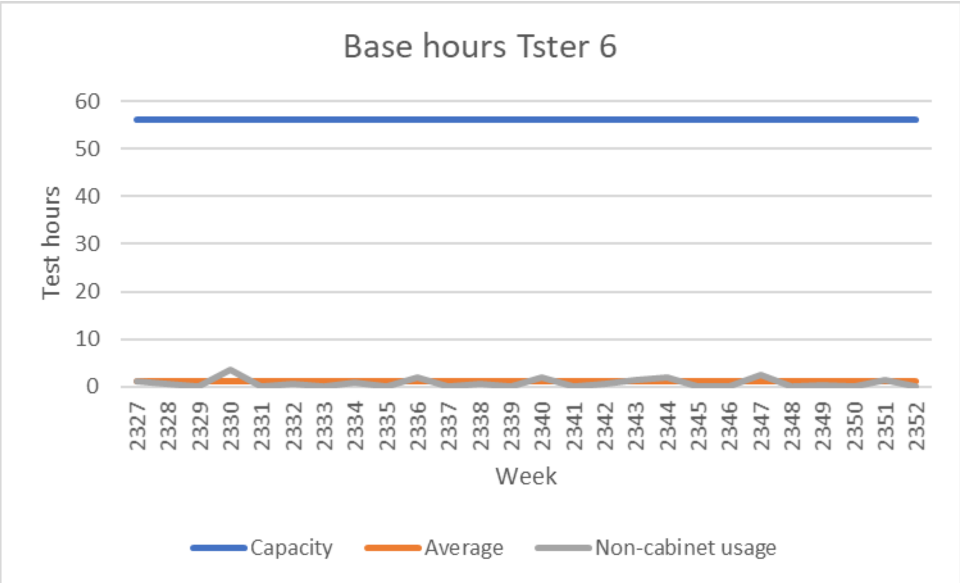


Figure 8: Tester 6 Planned hours non-cabinet products

Materials

Lastly, for all volume cabinets, the current agreements in place with suppliers account for the current move rate capabilities. Therefore, whenever Benchmark decides to increase the move rate of one or more volume cabinets, the strategic buyers need to contact these suppliers to make new agreements based on the newly agreed move rates. Currently, lead times for some critical components are less than one week, while the longest lead times for critical components is around 52 weeks.

3 Literature Research

In this chapter we will answer the question "*What factors can manpower, machines, materials, methods be broken down into and what are possible relations between these factors?"* based on a systematic literature review about 4M analysis theory. We will describe the factors related to manpower, machines, materials and methods and also how these factors are related to each other. In this chapter we will give an overview of additional factors found per factor of the 4Ms, but also other factors that can be added to the 4Ms according to theory.

The 4M analysis method is a root cause analysis used to discover the causes of a problem or as potential factors contributing to a solution for the problem, with respect to the 4Ms of Manpower, Machines, Materials and Methods. The analysis is performed in the form of a diagram, which is also referred to as the fishbone diagram. (Singh et al., 2021) As the 'head' of the diagram, the identified issue is stated to be able to give an overview of the causes leading up to the problem. Within Benchmark, the 4Ms are used as the factors that define the capacity of the production. Here, the decision when to increase the capacity is the issue as the 'head' of the diagram. In chapter 2.4 we have identified the factors that Benchmark currently uses to decide when to increase their capacity. However, there might be more factors that give important insights for Benchmark. We will therefore perform literature review to identify additional possible factors that contribute to the problem. In addition to identifying potential factors, we will also identify possible relations between these factors. Based on potential relations we will discuss in chapter 5 which of these potential factors are of interest for Benchmark.

3.1 Factors defining 4Ms

3.1.1 Manpower

For the aspect of manpower, we expect that there are more factors that influence the capacity in terms of manpower, than the factors mentioned in subsection 2.4.1. While these factors directly influence the move rate at a certain moment in time, we expect there to be more factors influencing the move rate, either directly or indirectly. After literature research we found the following factors that have an influence on capacity in other situations.

- **Skill and knowledge**
  The skill and knowledge of both existing and new employees are of influence on the move rate capability. Highly skilled existing employees are less likely to make mistakes and will in general be capable of working faster. In addition to the skill level, we found the level of knowledge likely to be of influence on the performance of craftsmen. The knowledge about the products can be improved through training the craftsmen, with the aim of gaining understanding of why certain assembly steps are done.
- **Number of shifts**
  The number of shifts potentially influences the production capacity, even for assembly processes that involve significant amounts of manual labour. Producing during one shift requires a certain number of employees, machinery to create the required number of products. Increasing the number of shifts will create the opportunity to increase the production levels, as the number of total working hours are also increased through creating an extra shift. (Kumar Pati, Chandrawanshi, & Reinberg, 2001)
- **Age of craftsmen**
  The age of the craftsmen hired may be of influence on the move rate capacity. As the physical condition of craftsmen generally declines while growing older, the manual labour done within the production process of volume cabinets will be asking more of the craftsmen. As the

manual labour done is not directly comparable between various production processes, the impact of age on the productivity of the trained craftsmen should be tested by Benchmark, before deciding on whether or not the age is of significant influence in the production process of volume cabinets at Benchmark.

- **Change of craftsmen**
  While Benchmark accounts for the number of trained craftsmen and a work-in period for new employees, they do not currently take into account a change in craftsmen while maintaining the same move rate capability. In this situation, we consider a change of craftsmen when a more experienced craftsman leaves the company and is replaced by a less experienced craftsman. New inexperienced craftsmen are likely less productive than more experienced craftsmen. However, Benchmark has to measure the exact difference in productivity and decide whether this difference has a significant influence on the overall move rate capability as literature suggests that this may impact productivity and therefore the move rate capability.
- **Psychological factors**
  Psychological external factors can be of influence on the craftsmen. External factors such as home environment and family circumstances are likely to influence the productivity of human resources either positively or negatively. Whenever psychological factors positively affect employees, they tend to be more productive, but also more resilient towards errors of other employees. This effect also occurs when external factors negatively impact the psychological welfare of employees. They will be likely to be less productive and make more errors.

3.1.2 Machine

The number of machines in production and assembly processes need to be sufficient to not be a limiting factor for the capacity of these processes. In addition to this, we have identified additional factors that can be of influence on the capacity of the machines part of the assembly process.

- **Quality of tooling**
  The quality of the tools needed for the process will impact the workflow of the assembly process. Higher quality tooling can make some assembly steps easier, as the tool will be easier to handle when compared to lower quality tools. On the other hand, tools may get too complicated to handle easily for employees, counteracting the previously mentioned benefits. The tools should however always be of sufficient quality, so that the craftsmen will not have to deal with faulty tools that are subject to breakdowns on a regular basis. Within the assembly process at Benchmark, this is of minor importance compared to the number of tools available, however a quality check of these tools or an evaluation of the type of tools used is important to ensure a smooth assembly process.
- **Design of tools used in production processes**
  When using tools in processes at a company, we should aim to keep the tool design simple, so that employees can easily learn how to operate these tools. This is more important for tools that are used often, than for tools that are rarely used, as it will save the most time when employees will not have to think about how to handle tools that are used regularly.
- **Machine breakdowns and yield**
  Number of machine breakdowns should be considered when calculating the capacity of machines. The number of breakdowns of machines determines the uptime of these machines. Another factor we should consider about machine capacity is the yield of these machines. The percentage of products that are successfully produced or tested by the machinery partly determine the actual capacity of machinery.

3.1.3 Materials

Without materials, production processes cannot continue. However, there are more components associated with materials that are of influence on the capacity within production processes.

- **Quality of materials**
  The quality of materials affects the quality and quantity of the products produced, as lower quality materials will result in lower quality products. Naturally, higher quality materials will result in higher quality of finished products.
- **Lead times of materials**
  Lead times of raw materials defines the reaction time of a company. Additional raw materials should be ordered at least the amount of weeks in advance of the start date that covers the lead times of these materials.
- **Availability components** (Chopra, 2019)
  Material shortages at any stage of the manufacturing process cause the production process to slow down or stop entirely. The component availability leads to higher uptime of the production process, however it can also lead to higher inventory costs.

3.1.4 Methods

Businesses have developed methods which the production, but also other parts of these businesses, have to adhere to, because it is believed that the used methods are sufficient or optimal for the current situation. In this subsection, we suggest factors to consider when assessing whether these methods used are still sufficient for the current production rates.

- **Decision support systems** (Power & Sharda, 2007)
  Decision support systems are used to help managers make better decisions. Model-driven decision support systems use a combination of algebraic, decision analytic, financial and optimisation models to provide decision support.
- **Key Performance Indicators (KPIs)**
  The Key Performance Indicators (KPIs) are an important measure of assessing the performance of a business. Businesses should consider and reconsider new and current KPIs to continuously be able to assess the business performance. Through the right KPIs we can asses the question of whether the current methods used are still the best for the current production rates, but also for future higher production rates.
- **Internal communication methods**
  Internal communication is essential for effectively completing production processes. In addition to this, effective internal communication can help to prevent or resolve problems that are related to the production output.

3.1.5 Additional Ms

In addition to the 4Ms and their sub-factors identified in chapter 3 and chapter 4, we have identified factors that do not entirely fit in one of the 4Ms, manpower, machines, materials and methods. According to Kaufman Global (Kaufman Global, 2017), the model of 4M can be extended by adding another M, making a 5M model. Kaufman Global presents 6M factors, of which the 4Ms used in this research are most directly applicable to the situation at Benchmark.

As Kaufman Global suggest, we have found other factors that may be applicable to the situation at Benchmark. We found the Measurement factor the most applicable to the situation of producing volume cabinets at Benchmark. Measurement covers all aspects of how to measure the output and difficulties of the process that are not covered by the original 4Ms used by Benchmark.

Another aspect that we find interesting to look at is Money (BIBS, 2022), as it is often considered as an additional factor in a 5M model, which is an expansion on the 4M model we use in this research. (Dudgikar, Kumthekar, & Khot, 2012) Money is part of the foundation of business management processes. Any business needs capital to be able to function properly, as money is necessary to purchase materials, hire employees, and acquire machinery. Apart from the cost aspect of businesses, money is an important way of measuring the performance of businesses. Looking at production in terms of money and the corresponding profit margins is interesting for a business, as making money is the ultimate goal of a business.

For Benchmark, literature suggests it can be interesting to look at a combination of those two additional factors as it gives Benchmark the opportunity to quantify the effects of the improved 4M-analysis tool.

3.2 Relations between factors

In this section, we will describe relations between factors suggested by the literature reviewed. It is interesting to know how the different factors potentially influence each other. In this section, we both consider the factors identified through literature research as well as the factors that have already been identified by the company.

Firstly, literature suggests working in shifts can increase the production capacity, by only hiring additional employees. However, working in shifts can increase absence of employees, especially because of an increase in sickness. (Kumar Pati, Chandrawanshi, & Reinberg, 2001)

Following this, the skill level of current employees may influence the potential skill level of new employees. As the new employees will be guided by current employees throughout their work-in period, they will adopt their working habits. The skill level of employees also affect the productivity and number of mistakes made. This means that the quality of products may be influenced by the skill level of employees.

The quality of raw materials affects the yield of products when they are tested on quality by the testing machines. When faulty materials are delivered, this naturally results in a lower percentage of products pass the quality testing machines at the first test.

3.3 Deterministic Dynamic Programming

The 4M analysis is a method to identify the causes of a problem. Benchmark uses the 4M analysis to determine the causes that prevent a move rate increase. We have established the factors that can prevent a move rate increase, and in the 4M analysis calculation tool we provide a quantified overview of the actions required to increase the move rate. However, as the lead times for increasing move rate capabilities are long, we want to know the optimal decision to minimize penalty costs for not delivering enough products whenever the move rate increase cannot be met in time to fully meet the increased customer demand. So, to complete the 4M-analysis tool, we need to provide an optimal solution to minimize the costs of not delivering all requested products due to the increased demand. This has to be as short-term solution, between 0 and 13 weeks, to minimize the cost between the moment customer A has increased their demand and the lead time on the move rate increase to cover this demand. For this, we develop a deterministic Dynamic Programming (DP) model. The principle of Dynamic Programming is that a complex problem is divided into smaller, less complicated, sub problems, where every sub problem has the same structure. These sub problems are then related by a recursion formula (Boucherie, Braaksma, & Tijms, 2022).

We are thus looking at a short term solution for minimizing the costs of missing deliveries requested by customer A, making Dynamic Programming a suitable optimization model. For long term, we cannot consistently influence the long lead times for increasing move rate capabilities. Therefore, we are not developing a Mixed-Integer Linear Programming model.

Every DP problem consists of a standard set of key components (Boucherie, Braaksma, & Tijms, 2022). A DP problem can be divided into stages, where each *stage n* represents a point in time on which a decision has to be made. Next, in each *state i*, the problem has a state *space* S_n, which contains all the possible *states i* that can occur at the current *stage n*. The state space provides information that is required to make an optimal decision. This decision is then made from the decision space $D_n(i)$, being the set of feasible decisions given that the problem is currently in stage n and *state i*.

The consequence of the decision taken is twofold. Firstly, the problem will transition into another *state j* and into the next *stage n+1*. Restrictions on the transition into the next stage are described in the transition function. Secondly, we define the immediate cost or immediate reward as $C_n(i,d)$ *or* $r_n(i,d)$ respectively. This is the consequence of the decision d made in state i during stage n. When solving for the optimal decision, we want to look at either minimizing the costs or maximizing the rewards.

After defining the stage space, state space, decision space and the transition function we define the objective function to minimize the total costs over all stages. Formula (1) is the general formula for minimizing the total costs of a deterministic dynamic programming problem.

$$\min\left\{\sum_{n=0}^{N} C_n(i,d)\right\} \qquad (1)$$

The calculation of the minimum total costs is done recursively. For this the *optimal value function* $f_n(i)$ is used, being the total minimum costs from *stages n* through *N* if the system is currently in *state i* and at *stage n*. The general formula (2) for the recursion relation is:

$$f_n(i) = \min_{d \in Dn(i)} \{r_n(i,d) + f_{n+1}(d)\} \qquad (2)$$

At the final stage N, the problem cannot transition into another state and therefore only the immediate cost is of influence on the decision made in the final stage. As a result, $f_N(i)$ can be found easily for all possible *states i,* meaning that this is an easy starting point for recursive relations.

Lastly, the principle of optimality states that given the current state, the optimal decision for all of the remaining stages cannot depend or be influenced by previously reached states or previous decisions made. A simpler representation of the principle of optimality is that every optimal policy consists of only optimal sub policies (Cooper, 1981).

4 4M-analysis Tool

In this section, we will answer the question "*How do the manpower, machines, materials and methods influence each other at Benchmark?*" and "*How can we model the needs of manpower, machines, materials and methods as a consequence of demand increase?*". To answer these questions, we will first describe the identified influences of capacity deciding factors on other capacity defining factors and the mathematical relations between them in section 4.1. Subsequently, we will describe how we will model these relations in the tool in section 4.2. Then, in section 4.3 we will describe the tool design and how it works. Finally, in section 0 we provide a user manual to answer the last research question: *"How can the 4M analysis be implemented and assessed by Benchmark?"*

4.1 Relations between variables

Through developing a 4M analysis tool, making use of standardized calculations to determine the required capacity increase to meet the move rate increase, we aim to reduce variance in the decision making process around increasing move rates. Firstly, we have discovered all parameters and variables that are of influence on other variables, from which we have developed mathematical equations that will be modelled in the 4M analysis tool.

The relations between factors provide a basis for the calculations that need to be done to get a complete and accurate overview of the challenges and actions that need to be taken in order to meet the newly desired move rate based on the increased demand. Therefore, we will go through the relations between factors that we have found by analyzing company data and performing interviews. As mentioned before, we leave the effect of the methods on the analysis out of the scope of this research. This means that the relations between factors may be subject to change if methods are changed in the future.

We will first give an overview of the calculations performed and the mathematical relations between factors. Following this, we will describe the calculations done more detailed and potential assumptions made.

Move rate capabilities consist of the following main factors, which subsequently consist of the following parameters:

- Manpower
    - Number of craftsmen
- Machines
    - Number of jigs available
    - Number of workplaces available
    - Available tooling
    - Amount of room
    - Testing machines capacity
- Materials
    - Critical components

Figure 9 presents an overview of the general relations between factors. For every X, the exact numerical relation differs between various products. We show the

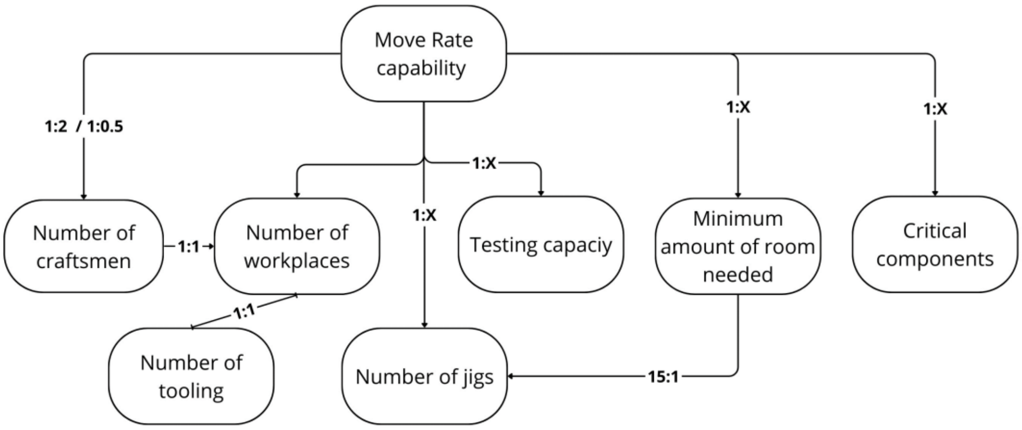


Figure 9: Relations between factors

We perform the following calculations to determine the required increases for increasing the move rate capability:

Number of craftsmen for products 1-4

$$Number\ of\ craftsmen\ needed = 2 * Required\ Move\ Rate$$

Number of craftsmen for products 5-8

$$Number\ of\ craftsmen\ needed = 0{,}5 * Required\ Move\ Rate$$

Number of jigs

The number of jigs is calculated by looking at the throughput time per jig, and the number of hours that a jig is used throughout a working week.

$$Number\ of\ jigs\ needed = \frac{(Move\ Rate * Throughput\ time)}{Available\ hours\ per\ week}$$

Workplaces

The number of workplaces needed is only influenced by the number of craftsmen needed. For each craftsmen needed, there is also one workplace required.

Amount of room

$$Amount\ of\ room = m^2\ used\ per\ Move\ Rate * Move\ Rate$$

Here, the space used per move rate is calculated based on detailed drawings where a floor planning is made for the maximum attainable capacity considering the amount of room currently available.

Testing machines capacity

For each testing machine, the same general calculation can be used, although not every volume cabinet will be tested on all testing machines. The base hours are the base hours as calculated in figures 4-9. The hours used for product is the testing hours needed to test a single product. The hours used per product * Move rate is repeated for every volume cabinet, resulting in an available capacity. This is the total increase this tester can manage across all products. Additionally, Benchmark plans with only 70% of its capacity for these testers to take into account failures, and sudden move rate increases. Once the 70% has been reached, we advise Benchmark to purchase a new testing machine.

$$Available\ capacity = 70\% * Total\ capacity - Base\ hours - (Hours\ used\ for\ product * Move\ rate)$$

Explanation

First, starting of with the variables and relations used to calculate the required number of craftsmen. The number of craftsmen is connected with the move rate through the number of craftsmen that are needed per move rate. During interviews with supervisors, we have identified that the relation between the number of craftsmen and the move rate capability is linear, meaning that the same number of additional employees are needed to increase the move rate by 1 regardless of the starting move rate.

Newly hired employees are not as productive as experienced employees already working at Benchmark. Therefore, through observations done by supervisors we have established that they have a relative productivity of 70% when compared to experienced employees throughout their 6 week work-in period. In addition to the work-in period there is a recruitment time of 2 weeks for junior recruitments and 8 weeks for medior recruitments. During this time, employees do not yet work at the company and therefore do not contribute to production.

Next, for the factor machine we look at 'jigs'. To calculate the number of jigs needed per move rate, we need to know how long one jig is in use before its part of the volume cabinet is completed and the jig is available for the next assembly. We call this variable the throughput time of a jig. To convert this to the number of jigs needed to produce one volume cabinet in one week we divide the throughput time of a jig by the total available working hours per jig per week. Additionally, whenever new jigs are needed, the lead time for a jig is relevant to establish when the new move rate can be realized.

The tooling and workplaces are related, for each workplace one complete set of tooling needs to be available, as craftsmen will often work on cabinet parts simultaneously and can therefore not share the tooling. For each craftsmen, one workplace and set of tooling need to be available. Related to the amount of workplaces, is the amount of room needed. Through calculations done by the supervisors, this is brought back to the amount of room needed per move rate in m^2.

At Benchmark, there are 6 testers used for the volume cabinets. The combined testing hours of the volume cabinets must be lower than the capacity of the tester available for the volume cabinets. To determine the available testing hours for volume cabinets, the hours used to test other products needs to be subtracted from the total capacity by defining the average planned test hours for the upcoming 26 weeks.

Lastly, the required increase in critical components cannot be defined through a standardized formula, and additional important information is required for the output to be useful. However, the quantity of components used is defined in the Bill-Of-Materials, so the additional quantity of critical components can be calculated through multiplying the move rate increase by the quantity used for a component per volume cabinet. The outcomes of the calculations, and therefore the values used in the tool, can be found in section 4.2.2.

4.2 Modelling the tool

4.2.1 Functional requirements

To provide a working tool for Benchmark that fulfils the requirements set throughout various discussions with company representatives, we have defined the following functional requirements for the 4M-analysis tool. These are the minimum requirements for the tool, we will discuss what these requirements mean for the situation at Benchmark subsequently.

- Desired move rates
- Current situation per capacity defining factor, for each volume cabinet
- Input for variables that impact the process in other ways
- Output per cabinet
- Overview of the output
- List of components that are delivered by 'critical suppliers'

Desired move rates

As a main input, relevant employees should be able to fill in the current and desired move rates, to get an overview of the required increase of the production rates. In addition to this, a third input column should be added, to provide the possibility to calculate the desired move rates based on the forecasted yearly demand.

Current situation per factor

Besides the main input, we want separate input sheets per cabinet to fill in the current situation for the parameters identified in previous chapters. This gives input for the calculations that the tool performs, in terms of manpower and machines.

Input for variables

In addition to the input per cabinet, there are variables of influence on the capacity which are not directly related to a specific volume cabinet, but have impact on the move rate capability of the volume cabinets. In addition to this, the general input sheet contains variables attained through interviews and calculations during data analysis. The available test hours per cabinet and the hours needed to test each cabinet as well as the lead times of machines are variables that can be found in this sheet.

Output per cabinet

Using the input sheets in combination with the general input sheet for variables, the tool has to calculate the needs to achieve the desired move rate per capacity limiting factor. This sheet gives an overview per cabinet or production location with regard to the actions that need to be taken per factor to increase the move rate capability from the current move rate to the desired move rate. This includes the required increase, lead times and the move rate capability per week by for the upcoming 1.5 years.

Concise overview of the output

The complete output per cabinet may give a complete but cluttered overview of the actions that need to be taken, and the factors that do not require action to meet the required move rate increase. Therefore, it is of interest for Benchmark to provide a concise overview of the actions that need to be taken, in combination with the ultimate date at which this action needs to be taken. Using this concise overview, employees and other stakeholders can be quickly informed about the required actions.

List of critical components

Lastly, a requirement for the tool is to see what components are critical and therefore needs to be prioritized to be able to realize the increase to the required move rate. A list of critical components per volume cabinet that is sorted from the largest lead time to the shortest lead time. Lead times vary significantly, the lowest lead time for critical components is less than one week, while the longest lead time for critical components is up to 52 weeks.

4.2.2 Design

Start page

We start by looking at the design of the starting page, and what functionalities can be found on there. In Figure 10 , we see a screenshot of the start page and how several requirements come back in the design of the start page.

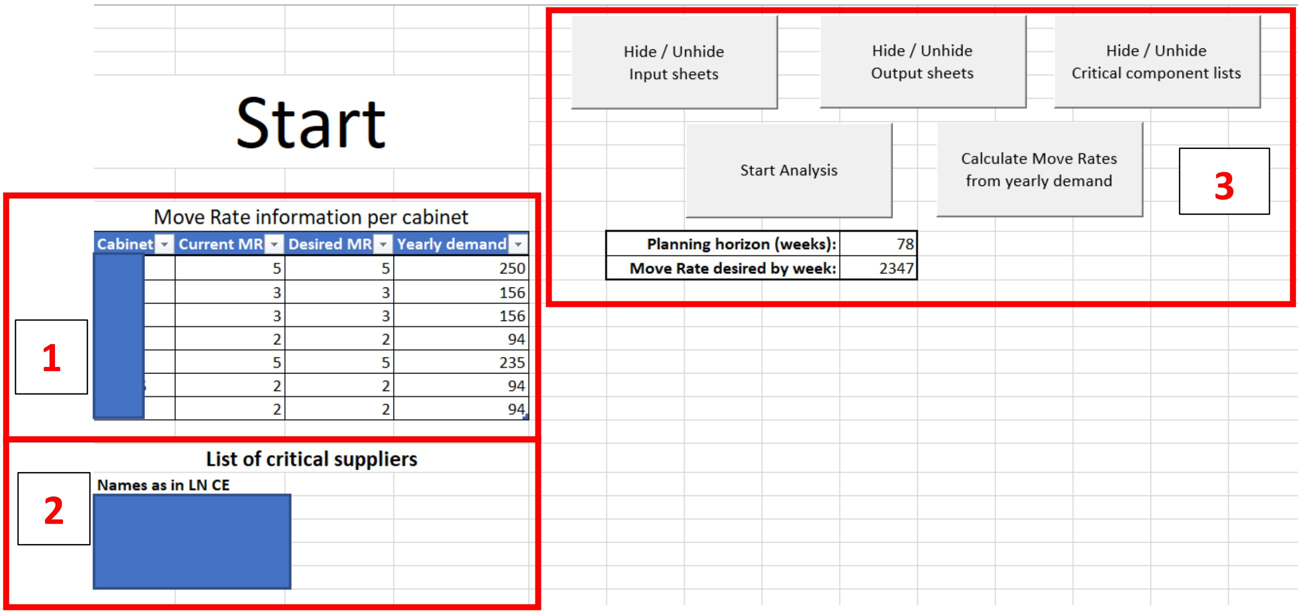


Figure 10: Startpage 4M-analysis tool

Firstly, we should be able to compare the current Move Rate capability per volume cabinet to the desired Move Rate capabilities determined according to customer demand increases. Therefore, we design a 'Start page' where the user can create an overview of the differences in required production levels based on demand increases by putting in the desired move rate capabilities, which can be found in the red outlined section 1 in Figure 5. In addition to this, there are cases where Benchmark wants to look ahead to see what the impact of planned demand increase will be on the required or desired move rate. Therefore, the last column in section 1 gives the possibility to provide the expected yearly demand as input to calculate the desired move rate per cabinet.

Next, in section 2 is an input list of the defined critical suppliers. Benchmark determines which suppliers are marked as critical and will therefore be in this list of input variables. This list of suppliers determines for which suppliers the critical components per cabinet will be returned as output. We use this outcome to alert buyers that they should inform these suppliers of the expected increase in demand and update the agreements in place with these suppliers if necessary.

Lastly, section 3 consists of two input variables and five buttons. The first input variable is the 'Planning horizon (weeks)' which determines how far into the future you want to determine and assess the move rate capabilities. The second input variable is 'Move Rate desired by week', where the year and week number of the date where the user wants to know whether or not the desired move rates can be achieved. Next, the three buttons 'Hide / Unhide Input sheets', 'Hide / Unhide Output sheets' and 'Hide / Unhide critical components lists' are designed to give a clear overview of the sheets that are available in the 4M-analysis tool. By clicking these buttons, the user can show only the sheets which they are using.

Variables

Within the sheet 'Variables', there are three main categories of variables being, 'Global variables', 'Cabinet variables' and 'Tester variables'.

Global variables	GoTo
Cabinet variables	GoTo
Tester variables	GoTo

Global variables

Manpower	Value	Unit
1 FTE	35	hours/week
Efficiency inexperienced recruitment	70%	
rectuitment time junior	2	weeks
recruitment time medior	8	weeks
work-in period	6	weeks
#holiday weeks	5	weeks
Holiday capacity	20%	

Machine	Value	Unit
Lead time jigs	16	weeks
#hours jig is available per week	36	hours
Lead time additional room	12	weeks
max capacity utilization testers	70%	
Lead time new	52	weeks
Lead time new	40	weeks
Lead time new	40	weeks
Lead time new	12	weeks
Lead time new	40	weeks
Lead time new	40	weeks

Testers

Figure 11: Global variables

In Figure 11, we see the global variables that the tool uses to calculate the required output. The global variables are divided up into the 4M factors Manpower and Machine. Relevant variables such as lead times and work-in periods can be found in this section of the 'Variables' sheet. These variables have to be regularly checked by Benchmark to ensure that they are still relevant and up-to-date. Therefore, these are input parameters that have to be checked regularly, but not every time the tool is used.

In addition to the 'Global Variables', we created hyperlinks to swiftly navigate through the sheet to find the relevant variables the user wants to check or update.

Cabinet variables							
Manpower							
#craftsmen per MR	2	2	2	0,5	0,5	0,5	0,5
Machines							
#Backplate throughput time per jig	19	24					
#Connector plate throughput time per jig	32	44					
#Throughput regular jig			96				
#working places and tools per move rate	2	2	2	0,5	0,5	0,5	0,5
additional m^2 per MR	16	16	30				
available m^2	123,5	123,5	247				
m^2 used			180				

Figure 12: Cabinet variables

In figure 12, we gathered the variables that are different for each volume cabinet under the section 'Cabinet variables'. For Manpower, this shows the number of craftsmen that are needed per move rate for each cabinet. For every additional volume cabinet that needs to be produced according to the desired move rate, this variable gives the input of how many additional craftsmen are needed.

Secondly, the Machines variables per cabinet cover the throughput time for jigs, if they are used at all for a specific cabinet, the number of working places and tools needed per move rate and the variables relevant for the available room. Within this table, whenever a variable is not relevant for the specific volume cabinet, the cell is left blank.

Tester variables						
Cabinet	Testers					
Products 1-7	10,9		0,3	0,4		
	12,0		0,9		1,0	
	20,2		1,0	0,2	1,0	
			2,0	26,7		
			0,3	0,2		
			1,0	0,1		1,0
		0,5	0,5	0,3		
Base hours used per tester	45,2	24,3	30,0	61,0	2,7	1,2
Capacity per tester (hours)	224,0	112,0	56,0	168,0	56,0	56,0
Number of testers	2,0	2,0	1,0	3,0	1,0	1,0
Available testing hours per tester	112,0	56,0	56,0	56,0	56,0	56,0
New tester delivered in week	2401					

Figure 13: Tester variables

Figure 13 shows the variables that are applicable to the testers used for testing the volume cabinets. First it shows the hours used up for testing per volume cabinet, and the base hours used per tester. The calculation for the base hours used per tester is performed in section 2.5.

In addition, the capacity of these testers are provided below together with the opportunity to add the expected delivery date of already ordered testers.

Input sheets

In addition to the general input sheets and the starting page, we designed an input sheet that covers the 4M input per volume cabinet. In Figure 14 we will show this input sheet for the combined

Production location 1, consisting of the product 1 and 2 volume cabinets. The input sheets for the other volume cabinets are designed similarly and can be found in appendix A

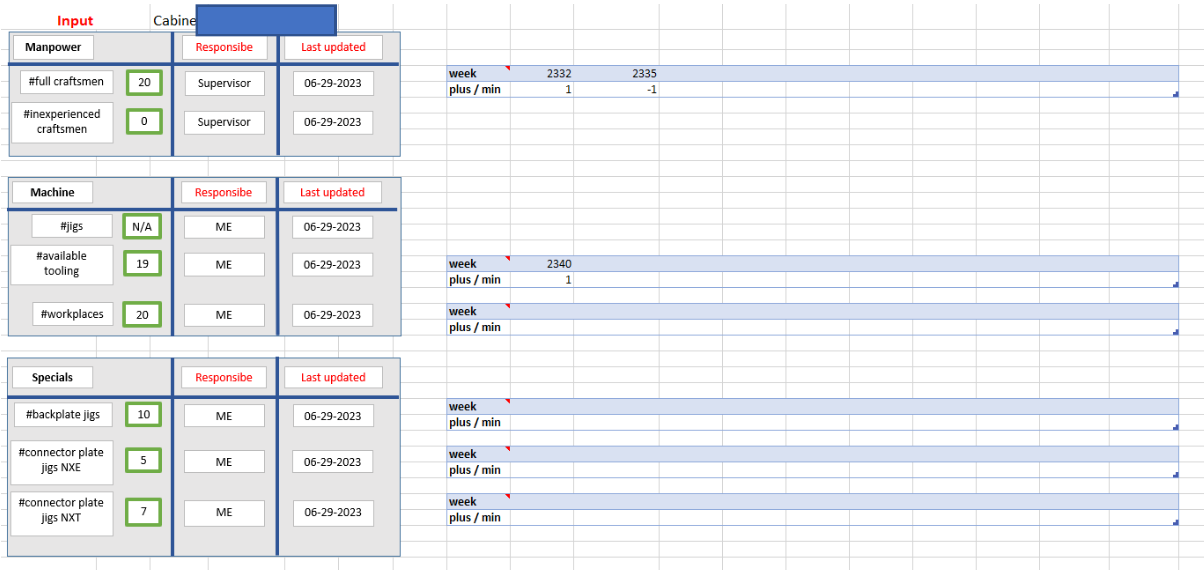


Figure 14: Input Product 1 + 2

On the left, there are three blocks of input covering, manpower, machines and specials. Within each block is a box for the input variable, responsible employee and the date when the input variable has been last updated. Because not every volume cabinet is produced through the same standardized methods and using the exact same type of equipment, we added the third block labelled 'Specials', in which the user can provide input for non-standardized methods or equipment. In addition to this, the user is required to fill in 'N/A' at the places of the irrelevant input to initiate the calculation of the 'Specials' input.

Next to these three blocks, we provide tables where already known changes to the input in the upcoming weeks can be inserted. In the top row, the user will add the year and week numbers of the expected change. In the row below, the quantity of the expected change is added, and can be either positive or negative.

Output sheets

The output sheets have been designed in two separate sections, where the upper section gives an overview of the main input from the 'Startpage' and a legend explaining what is shown in the lower section. The lower section gives an overview of the move rate capability plan by firstly presenting the current situation and the desired situation per analysis factor. Secondly, it presents the move rate capability per factor for the each week within the time frame chosen through the input on the 'Startpage'. Similarly as for the input sheets, the output sheets have the same design for all volume cabinets, and therefore we will add the remaining output sheets to appendix A.

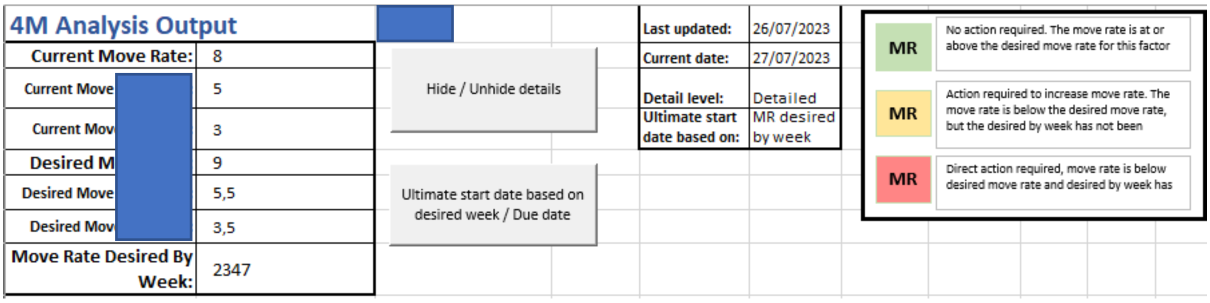
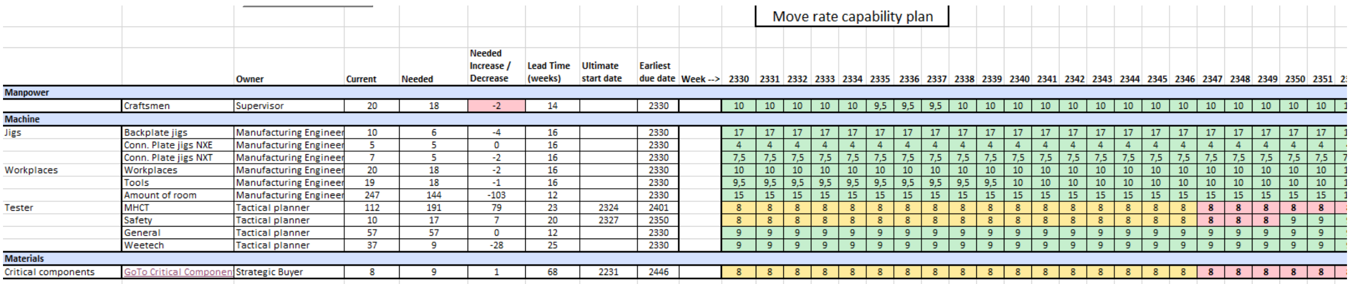


Figure 15: Upper section output production location 1

On the left side, we present an overview of the input from the 'startpage', summarizing the difference between the current and desired situation. Next, the buttons give the opportunity to hide and unhide the details from the lower section, which is added to fulfil the requirement of a concise overview of the output and the actions that need to be taken. When using this button, only the rows of the factors will be shown that currently do not meet the desired move rate capability and therefore require actions to be taken to increase the move rate capability. The button 'Ultimate start date based on desired week / Due date' acts as a switch for what the shown ultimate start date is based on.

On the right side, an overview of information about what information is currently shown, when this was last updated and how to interpret the information shown in the lower section.



		Owner	Current	Needed	Needed Increase / Decrease	Lead Time (weeks)	Ultimate start date	Earliest due date	Week -->	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351
Manpower																															
	Craftsmen	Supervisor	20	18	-2	14		2330		10	10	10	10	10	9,5	9,5	9,5	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Machine																															
Jigs	Backplate jigs	Manufacturing Engineer	10	6	-4	16		2330		17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
	Conn. Plate jigs NXE	Manufacturing Engineer	5	5	0	16		2330		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	Conn. Plate jigs NXT	Manufacturing Engineer	7	5	-2	16		2330		7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5
Workplaces	Workplaces	Manufacturing Engineer	20	18	-2	16		2330		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	Tools	Manufacturing Engineer	19	18	-1	16		2330		9,5	9,5	9,5	9,5	9,5	9,5	9,5	9,5	9,5	9,5	10	10	10	10	10	10	10	10	10	10	10	10
	Amount of room	Manufacturing Engineer	247	144	-103	12		2330		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Tester	MHCT	Tactical planner	112	191	79	23	2324	2401		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
	Safety	Tactical planner	10	17	7	20	2327	2350		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	9	9
	General	Tactical planner	57	57	0	12		2330		9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	Weetech	Tactical planner	37	9	-28	25		2330		9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Materials																															
Critical components	GoTo Critical Componen	Strategic Buyer	8	9	1	68	2231	2446		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

Figure 16: Lower section output production location 1

In Figure 16 we see the detailed version of the move rate capability plan. Here, the current and desired situation per factor is shown, as well as the earliest possible due date and the ultimate start date. The ultimate start date is only shown for factors that require action to be taken, as it is not relevant to show starting dates for factors that do not require any action. This ultimate start date is calculated in two ways, managed through the button on the upper section. The first way is by deriving the ultimate start date by looking at the 'Move rate desired by week:' which means that the lead time is subtracted from the desired by week. The result from this subtraction is the ultimate start date. The second way of calculating the ultimate start date is by basing it on the latest due date. This means that every factor will be capable of realizing the desired move rate by the latest due date, if they are ultimately started on the ultimate start date.

In addition, the move rate capability per factor per week is shown and colour coded according to the legend in the upper section.

Critical components

The critical components lists gives an overview of the parts and its most important attributes ranked by longest lead time. In Figure 17, we only show the critical components for the cabinets product 1 and product 2 based on the critical suppliers list as shown in Figure 5. The lists of critical components for other volume cabinets are comparable and are added to appendix A.

Supplier	Lead time	Component	Description	Buyer	Cabinet	Current Quantity per week	Desired Quantity per week	Last updated:	26/07/2023
[redacted]	337	ASM4022_438_33850-LF	[redacted]	[redacted]	[redacted]	12	14		
[redacted]	272	ASM4022_438_35111-LF	[redacted]	[redacted]	[redacted]	23	27		
[redacted]	267	ASM4022_476_11011-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	267	ASM4022_476_11011-LF	[redacted]	[redacted]	[redacted]	9	10		
[redacted]	217	ASM4022_646_19022-LF	[redacted]	[redacted]	[redacted]	3	4		
[redacted]	212	ASM4022_636_38114-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	212	ASM4022_636_33663-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	167	ASM4022_636_33282-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	167	ASM4022_636_19333-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	167	ASM4022_636_19422-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	167	ASM4022_636_38052-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	167	ASM4022_636_72482-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	167	ASM4022_636_38093-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	167	ASM4022_636_33654-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	167	ASM4022_646_88294-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	167	ASM4022_654_08582-LF	[redacted]	[redacted]	[redacted]	5	6		
[redacted]	157	ASM4022_439_97211-LF	[redacted]	[redacted]	[redacted]	20	22		
[redacted]	157	ASM4022_439_90742-LF	[redacted]	[redacted]	[redacted]	25	28		

Figure 17: Critical components Products 1 and 2

Here, the supplier, lead time, component name and description, buyer code, cabinet and current and desired quantity per week are shown. In Figure 12, only the top 18 critical components are shown, whereas this list consists of 804 critical components given the current selection of critical suppliers. Strategic buyers, who are responsible for this part of the 4M-analysis, use this list as input for the actions they need to take to realize the desired move rate.

4.3 Optimization deterministic DP

To conclude the 4M-analysis, we developed a deterministic Dynamic Programming (DP) model to minimize the costs of realizing the move rate increase. In this model, we exclude the investment costs of manpower, machines and materials. The investment costs have to be made by Benchmark once the decision has been made that a move rate increase is necessary to meet increased demand, regardless of whether the demand increase can be met by the 'desired by week' and the consequences if this cannot be met in time, and are therefore excluded from this DP model.

Additionally, we only look at the factor 'Manpower' within the DP model, as this is the only factor that can be influenced by Benchmark in a short term. For the factor 'Machines', the lead times for testing machines and 'jigs' are fixed and can generally not be influenced by Benchmark. Additionally, these lead times are long, and the move rate capability increase should be realised in time through making use of the 4M analysis calculation model. Lastly, the materials lead times are fixed, and will not change if the required quantities marginally increase. This makes that also the lead times will not be considered in constructing the DP problem. As mentioned before, the 'Methods' are completely left out of the scope for constructing this model.

4.3.1 Formulation of the DP problem

To formulate the deterministic DP model we define stages, state variables, decision variables, transition function, the immediate cost function and the constraints that the model is subject to

Stages

We can make decisions at the start of each week from the desired by week (DB), until the week of the longest lead time (LT). Therefore, we define stage n as the start of week n, where ∈ {DB,DB+1,DB+2,…,LT-2,LT-1,LT}

States

For this DP model, we define three state variables i, j and k where:

- i: Number of volume cabinets not delivered {0,1,2,3,…,Add.Req.}
  The additional requested cabinets until lead time (Add.Req.) is calculated through the following formula:

$$(Desired\ Move\ Rate - Current\ Move\ Rate) * (Lead\ Time\ week - MR\ desired\ by\ week)$$

- j: Consecutive weeks in which employees worked overtime {0,1,2,3,4}
- k: Number of building hours needed to complete next volume cabinet {0,1,2,…,Build.hours.}
  The number of building hours needed to complete a volume cabinet (Build.hours.) is calculated through the following formula, which is then rounded up to the next integer.

$$\frac{35\ (total\ effective\ hours\ per\ week)}{current\ move\ rate} * \frac{1}{efficiency\ of\ work\ during\ overtime}$$

- l: Is the current week before or after the move rate desired by week.
  Where $\in \{0,1\}$ and l is 0 if the current week is before the desired by week and 1 if the current week is at or past the desired by week.

Decision variable

The decision D(i,j,k,l) that has to be made every week is the number of hours overtime work this week. where $\in \{0,1,2,\ldots,7,8\}$ as the maximum number of overtime hours per week is 8.

An exception to the set of decisions is when state j =4. Then the number of hours overtime work for this week is $\in \{0\}$

Transition function

As a result from decision D(i,j,k,l) in stage n, in stage n+1 will move into state (i',j',k',l'). The feasible set of states i', j', k' and l' is dependant on the decision D made in stage n in combination with the state of stage n. In table 5, we will show the possible states i', j', k' and l' in stage n+1.

State i,j,k,l in stage n	**Possible states i',j',k',l' in stage n+1**
i = any i (as i has no influence on the possible future states j = {0,1,2,3} k > D D > 0 l = {0}	i' = i j' = j+1 k' = k – D if n+1 is before desired by week -> l' = 0 else l' = 1
i = any i (as i has no influence on the possible future states j = {0,1,2,3} k > D D > 0 l = {1}	i' = i+ (Desired MR – Current MR) j' = j+1 k' = k – D l' = 1
i = any i (as i has no influence on the possible future states j = {0,1,2,3} k =< D D > 0 l = {0}	i' = i-1 j' = j+1 k' = Build.Hours – (D-k) if n+1 is before desired by week -> l' = 0 else l' = 1

i = any i (as i has no influence on the possible future states j = {0,1,2,3} k =< D D > 0 l = {1}	i' = i-1+(Desired MR – Current MR) j' = 0 k' = Build.Hours – (D-k) l' = 1
i = any i (as i has no influence on the possible future states j = {0,1,2,3,4} k = any k D = 0 l = {0}	i' = i j' = 0 k' = k if n+1 is before desired by week -> l' = 0 else l' = 1
i = any i (as i has no influence on the possible future states j = {0,1,2,3, 4} k = any k D = 0 l = {1}	i' = i+(Desired MR – Current MR) j' = 0 k' = k – D l' = 1

Value function

Value function $f_n(i,j,k,l)$: The minimum total cost associated with demand increase given that at stage n there are i volume cabinets not delivered, j consecutive weeks of overtime have been worked, k overtime hours are needed to finish the next volume cabinet and l, the desired by week has or has not been passed.

Recurrence relation

$$F_{LT}(i,j,k,l) = \min_{d \in D} \left[D(i,j,k,l) * C_{cab} * C_{hour} + Y(i-x) * C_{missed} + Y * 5000 * C_{Escalation}^{(i-1)}\right]$$

$$F_n(i,j,k,l) = \min_{d \in D} \left[F_{n+1} + D(i,j,k,l) * C_{cab} * C_{hour} + Y(i-x) * C_{missed} + Y * 5000 * C_{Escalation}^{(i-1)}\right]$$

Constraints and constants

The constraints have been formulated through interviews with stakeholders. This means that the constraints and constants given have been acquired through a combination of data analysis and stakeholder experience or minor assumptions in combination with incomplete data.

- C_{cab} = the number of craftsmen available on this cabinet
- C_{Hour}= the cost of 1 hour of working overtime, which is more than working regular time.
- C_{missed} = the cost of missing the delivery of a volume cabinet
- $C_{Escalation}$ = the factor by which the escalation cost are multiplied for missing an additional volume cabinet delivery
- Desired MR is the desired move rate as provided as input by the user of the tool
- Current MR is the current move rate as provided as input by the user of the tool
- Efficiency of workers during overtime = 70%
- Consecutive weeks in which hours of overtime > 0 must be =< 4
- C_{Hour} = 50
- $C_{Escalation}$ = 1.20
- C_{missed} = 2000

- X = $\begin{cases} 1 \; if \;\; k \leq D \\ 0 \; otherwise \end{cases}$
- Y = $\begin{cases} 1 \; if \;\; i \geq \;\; 0 \\ 0 \; otherwise \end{cases}$

4.3.2 Implementation of the DP problem

To incorporate the Dynamic Programming problem in the tool, we have realized a model using VBA to calculate all possible outcomes of the DP model as proposed in section 4.3.1. This model calculates the minimum costs of each state and for all stages, considering that given the current state in the current stage, the problem can reach the next stage in the state with limitations proposed in the transition function.

Following this, the optimal decision can be found by selecting the minimum future costs, given the current state and stage the problem is in. In Figure 18, we show part of the outcomes of a calculation of the costs for not delivering the additionally requested volume cabinets in the period up to the expected lead time for production location 1 given a current move rate of 3, and a desired move rate of 3.5.

Week 1					Week 2					Week 3					Week 4				
Cabinets r	Consecuti	Buildhour	Decision	Costs	Cabinets r	Consecuti	Buildhour	Decision	Costs	Cabinets r	Consecuti	Buildhour	Decision	Costs	Cabinets r	Consecuti	Buildhour	Decision	Costs
14	1	2	3	47581	14	1	2	3	733866	14	1	2	3	718936	14	1	2	3	704006
14	1	2	2	46581	14	1	2	2	749728	14	1	2	2	734798	14	1	2	2	719868
14	1	2	1	771670	14	1	2	1	758644	14	1	2	1	743714	14	1	2	1	728784
14	1	2	0	754496	14	1	2	0	742054	14	1	2	0	728540	14	1	2	0	713610
14	1	1	8	52581	14	1	1	8	697511	14	1	1	8	685069	14	1	1	8	672627
14	1	1	7	51581	14	1	1	7	703487	14	1	1	7	688973	14	1	1	7	674043
14	1	1	6	50581	14	1	1	6	705473	14	1	1	6	690959	14	1	1	6	676029
14	1	1	5	49581	14	1	1	5	713055	14	1	1	5	698125	14	1	1	5	683195
14	1	1	4	48581	14	1	1	4	716355	14	1	1	4	701425	14	1	1	4	686495
14	1	1	3	47581	14	1	1	3	727675	14	1	1	3	712745	14	1	1	3	697815
14	1	1	2	46581	14	1	1	2	732866	14	1	1	2	717936	14	1	1	2	703006
14	1	1	1	45581	14	1	1	1	748728	14	1	1	1	733798	14	1	1	1	718868
14	1	1	0	751008	14	1	1	0	738566	14	1	1	0	726124	14	1	1	0	712610
14	0	17	8	827141	14	0	17	8	812211	14	0	17	8	797281	14	0	17	8	782351
14	0	17	7	827141	14	0	17	7	812211	14	0	17	7	797281	14	0	17	7	782351
14	0	17	6	830127	14	0	17	6	815197	14	0	17	6	800267	14	0	17	6	785337
14	0	17	5	833710	14	0	17	5	818780	14	0	17	5	803850	14	0	17	5	788920
14	0	17	4	838010	14	0	17	4	823080	14	0	17	4	808150	14	0	17	4	793220
14	0	17	3	843170	14	0	17	3	828240	14	0	17	3	813310	14	0	17	3	798380
14	0	17	2	849361	14	0	17	2	834431	14	0	17	2	819501	14	0	17	2	804571
14	0	17	1	856792	14	0	17	1	841862	14	0	17	1	826932	14	0	17	1	812002
14	0	17	0	865708	14	0	17	0	850778	14	0	17	0	835848	14	0	17	0	820918
14	0	16	8	817225	14	0	16	8	802295	14	0	16	8	787365	14	0	16	8	772435
14	0	16	7	826141	14	0	16	7	811211	14	0	16	7	796281	14	0	16	7	781351
14	0	16	6	826141	14	0	16	6	811211	14	0	16	6	796281	14	0	16	6	781351
14	0	16	5	829127	14	0	16	5	814197	14	0	16	5	799267	14	0	16	5	784337
14	0	16	4	832710	14	0	16	4	817780	14	0	16	4	802850	14	0	16	4	787920
14	0	16	3	837010	14	0	16	3	822080	14	0	16	3	807150	14	0	16	3	792220
14	0	16	2	842170	14	0	16	2	827240	14	0	16	2	812310	14	0	16	2	797380
14	0	16	1	848361	14	0	16	1	833431	14	0	16	1	818501	14	0	16	1	803571
14	0	16	0	855792	14	0	16	0	840862	14	0	16	0	825932	14	0	16	0	811002

Figure 18: Calculated outcomes of the DP problem

To analyse the outcomes and determine the optimal decision, we assume that in stage 1 (week 1) the problem will be in the following state:

The current number of additionally requested cabinets not finished is the total additional number of volume cabinets requested. For this example, the number of additionally requested cabinets not finished is 14.

Currently, the company has not worked any consecutive weeks of overtime, meaning the state is 0.

The number of Building hours left to complete the next additional volume cabinet is equal to the total Building hours needed to complete a volume cabinet, meaning this state is 17.

Given this state, we find the optimal solution for every upcoming week that there is a larger requested move rate than the move rate capability of Benchmark for this volume cabinet. We present the optimal decision path in Figure 19.

Starting week	1		
Consecutive weeks with overtime	0		
Hours until next additional cabinet	17		
Decision strategy:			
Week	Hours of overtime	Total cost from this week	Total cabinets not delivered
Week 1	7	827141	14
Week 2	8	766644	14
Week 3	8	705147	13
Week 4	8	615193	12
Week 5	0	546199	12
Week 6	7	509049	12
Week 7	8	464899	11
Week 8	8	411480	10
Week 9	0	363624	10
Week 10	6	337825	10
Week 11	8	306026	9
Week 12	3	271527	9
Week 13	8	247028	8
Week 14	0	216112	8
Week 15	3	198196	8
Week 16	8	177280	7
Week 17	3	149350	7
Week 18	8	131420	6

Figure 19: Optimal decision path calculation

5 Conclusion and recommendations

In this chapter, we discuss the conclusion and recommendations for the people responsible for the planning and move rate capabilities at Benchmark. In this chapter, we answer the main research question: ***How can the responsiveness on move rate increases and the on-time delivery performance at Benchmark be improved?***

As the current 4M-analysis resulted in a low responsiveness on move rate increase needs, meaning that the required move rate cannot be realized in time, we provide an overview of the actions taken to improve the responsiveness and the on-time delivery performance that has suffered as a consequence of the low responsiveness.

Following this, we discuss the recommendations and future actions that need to be taken to further improve on the research done during this thesis.

5.1 Conclusion

The 4M analysis tool should result in an increase of the responsiveness when compared to the responsiveness in the current situation, and as a result also improve the on-time delivery performance.

To answer the main research question, we first answer the sub-questions: *"How does Benchmark currently utilise the 4M (Manpower, Machine, Materials, Methods) analysis to handle increased customer demand for volume cabinets?" and "What is the current capacity of Benchmark in terms of manpower, machines, materials and methods?".*

Currently, Benchmark uses a simple version of the 4M analysis by identifying the current move rate capabilities per cabinet and main 4M (sub-)factors. As we have presented in Table 1: Result of current 4M analysis

, the current 4M analysis does not give proper insight in the time needed to complete the required move rate increase, and it only presents the fact that an action needs to be taken, but this action is not quantified or put in perspective of when it needs to be taken. The fact that the user of the current 4M analysis does not know when the action needs to be taken or completed by performing the analysis makes that Benchmark is often late in responding to the required move rate increase, resulting in a lower on-time delivery.

Additionally, in chapter 2 we have answered the question of what the current capacity of Benchmark's production process is in terms of manpower, machines, materials and methods. Through interviewing employees responsible for different parts of the production process, we gained insight in the exact move rate capabilities per subfactor.

From chapter 2, we conclude that Benchmark currently utilizes a simple representation of the 4M analysis. Also, the current move rate capabilities are higher than the actual required move rate to fulfil the demand of customer A.

Next, in chapter 3 we answer the sub-question "*What factors can manpower, machines, materials, methods be broken down into and what are possible relations between these factors?"* by performing literature research. Literature about possible factors that are of influence suggests that Benchmark should look at expanding the 4M analysis into a 5M analysis with the additional factor of Money as it is essential for businesses to optimize the money they generate and to minimize their expenses at the same time. Additionally, we discover that we can use Dynamic Programming to provide the optimal decision of the amount of hours overtime that should be made every week to minimize the total costs for Benchmark when missing deliveries due to a demand increase from customer A.

In chapter 4 we designed an improved 4M analysis tool by answering the questions: *"How do the manpower, machines, materials and methods influence each other at Benchmark?", "How can we model the needs of manpower, machines, materials and methods as a consequence of demand increase?" and "How can the solution be implemented and assessed by Benchmark?"*

Firstly, the relations discovered between factors are described in chapter 4, which are used to develop the minimum requirements for the tool, as well as the calculations the tool has to make to provide accurate output.

To develop an effective 4M analysis model, we have defined the set of main requirements for the tool. After interviews and discussions with various stakeholders within Benchmark, we have selected the most important requirements being, input sheets for variables and all volume cabinets, output sheets for all volume cabinets, a concise overview of the output and a list of critical components per output.

The design and functionality of the tool are then explained afterwards, complemented with screenshots of the tool to visualize the 4M analysis tool.

Lastly, we answered the last sub-question by providing a user manual on how to operate the tool, enabling Benchmark to implement the 4M analysis tool. Afterwards, Benchmark can compare the current situation to the situation after implementation of the tool.

In summary, we have provided an improved 4M analysis tool, with which Benchmark can analyse the required actions to increase the move rate capability, and when to work overtime if the increase cannot be managed in time. The tool not only provides insight into the actions that need to be taken to increase the move rate capability, but also informs the user on when these actions need to be taken.

5.2 Recommendations

For future research, we advise Benchmark to mainly improve the data inputs given to operate the tool. Currently, the data used for the tool is partly based on experience from employees, in combination with the output they see from the specific production process part. In the future, and to make this tool more accurate Benchmark has to gather data about the input variables and analyse it to reduce the margin of error on the generated output.

Additionally, the DP model of the tool only considers working overtime as a solution for missed volume cabinets. Driven by future research, additional data on other solutions can be gathered, to give a more accurate representation of the optimal decision process. An example of how to expand on this model is by researching what the effect of not delivering a product to the customer is on the customer relation and what this would cost Benchmark.

Lastly, this research has not focussed on optimizing or altering the Methods as part of the 4M analysis. Therefore, we recommend Benchmark to research whether the current methods used are still optimal for the current situation, but also for possible future situations.

In this research, part of the data collection process is performed through interviews with experienced employees. To improve on the reliability of the tool, the data can be verified through measuring the output when changing the variables such as number of craftsmen working and the available room.

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Appendix A: 4M analysis tool design

Input sheets

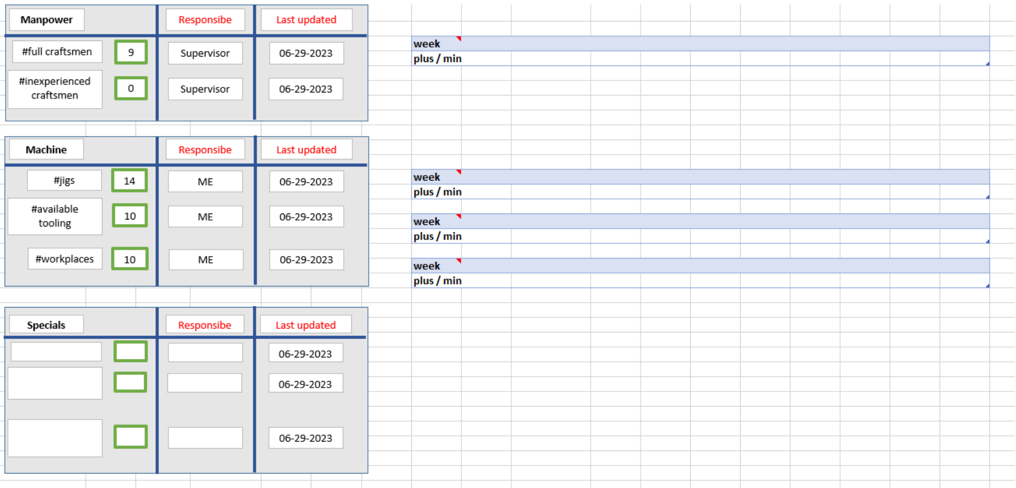


Figure 20: Input 2

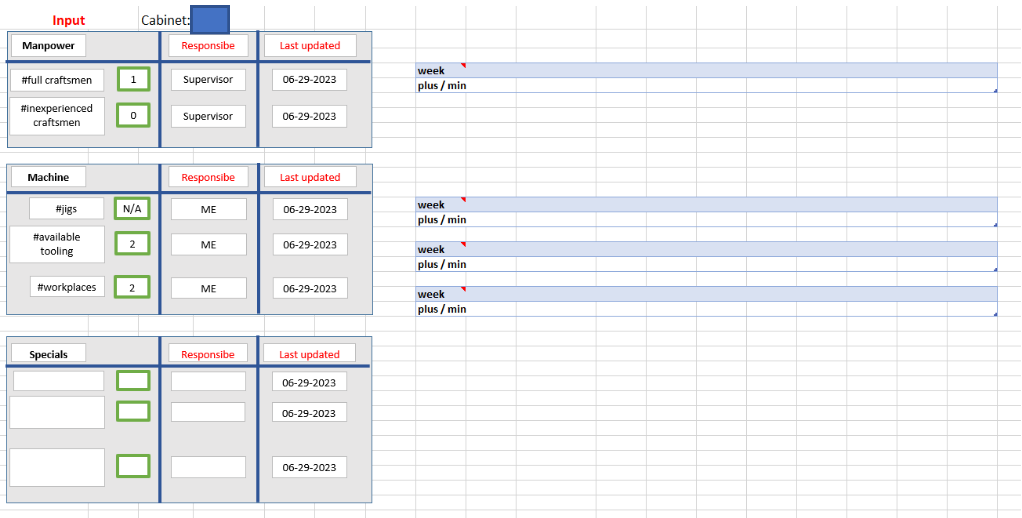


Figure 21: Input 3

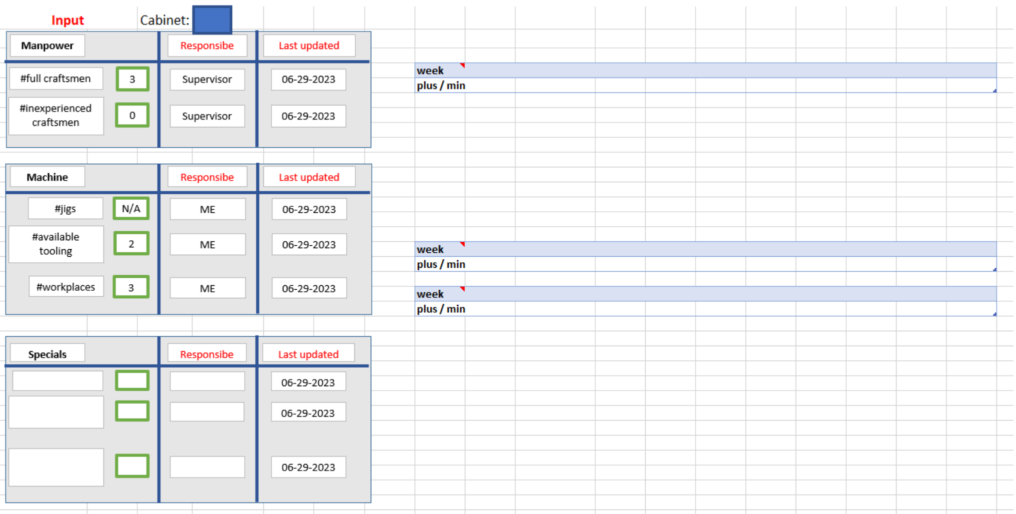


Figure 22: Input 4

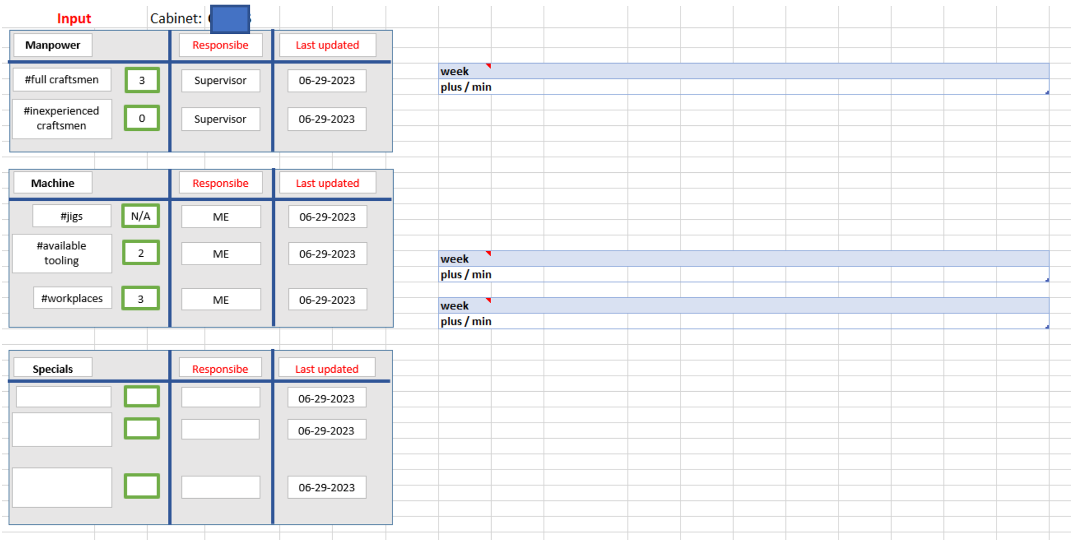


Figure 23: Input 5

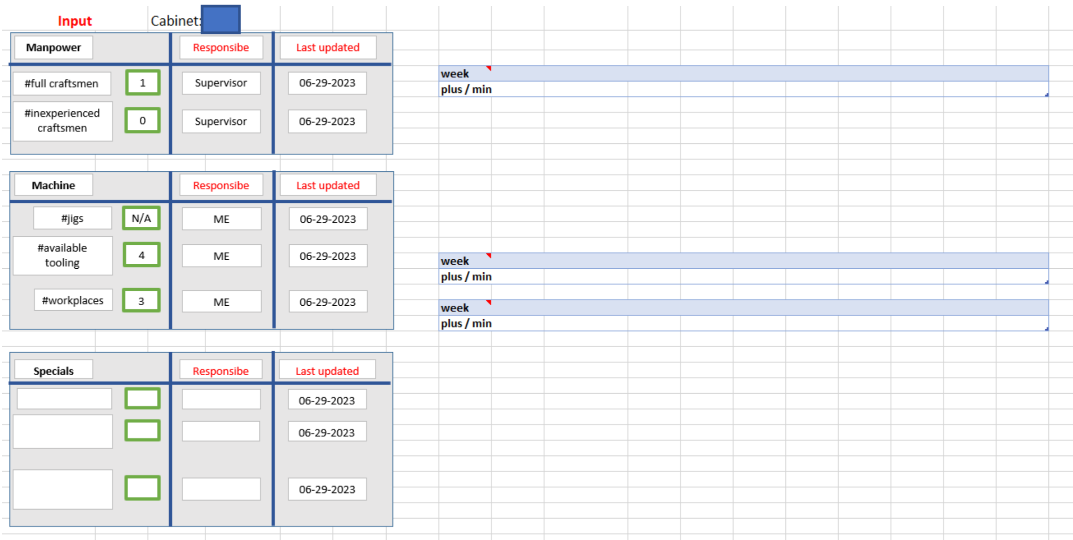


Figure 24: Input 6

Output sheets

4M Analysis Output

Hide / Unhide details

Ultimate start date based on desired week / Due date

Current Move Rate:	3
Desired Move Rate:	3,5
Move Rate Desired By Week:	2347

Last updated:	26/07/2023
Current date:	27/07/2023
Detail level:	Detailed
Ultimate start date based on:	MR desired by week

MR	No action required. The move rate is at or above the desired move rate for this factor at this week
MR	Action required to increase move rate. The move rate is below the desired move rate, but the desired by week has not been passed yet.
MR	Direct action required, move rate is below desired move rate and desired by week has passed.

Move rate capability plan

		Owner	Current	Needed	Needed Increase / Decrease	Lead Time (weeks)	Ultimate start date	Earliest due date
Manpower								
	Craftsmen	Supervisor	9	7	-2	14		2330
Machine								
Jigs	Jigs	Manufacturing Engineer	14	9	-5	16		2330
Workplaces	Workplaces	Manufacturing Engineer	10	7	-3	16		2330
	Tools	Manufacturing Engineer	10	7	-3	16		2330
	Amount of room	Manufacturing Engineer	247	105	-142	12		2330
Tester	MHCT	Tactical planner	112	191	79	23	2324	2401
	Safety	Tactical planner	10	17	7	20	2327	2350
	General	Tactical planner	57	57	0	12		2330
Materials								
Critical components	GoTo Critical Components	Strategic Buyer	3	3,5	0,5	44	2303	2422

Week -->	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2401	2402
Craftsmen	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5	4,5
Jigs	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Workplaces	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Tools	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Amount of room	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
MHCT	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3,5	3,5
Safety	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3,5	3,5	3,5	3,5	3,5
General	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5
Critical components	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Figure 25: Output sheet 2

4M Analysis Output

Hide / Unhide details

Ultimate start date based on desired week / Due date

Current Move Rate:	2
Desired Move Rate:	2
Move Rate Desired By Week:	2347

Last updated:	26/07/2023
Current date:	27/07/2023
Detail level:	Detailed
Ultimate start date based on:	Latest earliest due date

MR	No action required. The move rate is at or above the desired move rate for this factor at this week
MR	Action required to increase move rate. The move rate is below the desired move rate, but the desired by week has not been passed yet.
MR	Direct action required, move rate is below desired move rate and desired by week has passed.

Move rate capability plan

		Owner	Current	Needed	Needed Increase / Decrease	Lead Time (weeks)	Ultimate start date	Earliest due date
Manpower								
	Craftsmen	Supervisor	1	1	0	14		2330
Machine								
Workplaces	Workplaces	Manufacturing Engineer	2	1	-1	16		2330
	Tools	Manufacturing Engineer	2	1	-1	16		2330
Tester	Safety	Tactical planner	10	17	7	20	2330	2350
	General	Tactical planner	57	57	0	12		2330
Materials								
Critical components	GoTo Critical Componen	Strategic Buyer	2	2	0	42		2330

Week -->	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2401	2402	2403	2404	2405	2406	2407
Craftsmen	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Workplaces	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Tools	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Safety	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
General	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Critical components	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Figure 26: Output sheet 3

4M Analysis Output

Hide / Unhide details

Ultimate start date based on desired week / Due date

Current Move Rate:	5
Desired Move Rate:	5
Move Rate Desired By Week:	2347

Last updated:	26/07/2023
Current date:	27/07/2023
Detail level:	Detailed
Ultimate start date based on:	Latest earliest due date

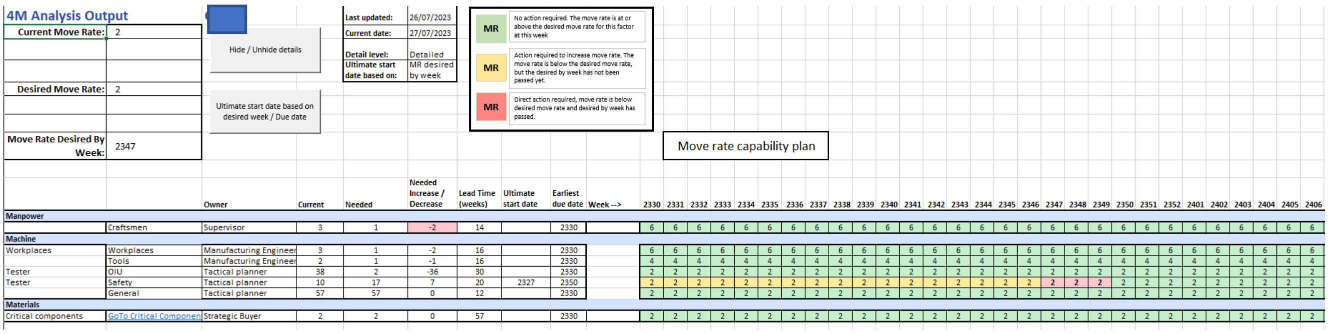
MR	No action required. The move rate is at or above the desired move rate for this factor at this week
MR	Action required to increase move rate. The move rate is below the desired move rate, but the desired by week has not been passed yet.
MR	Direct action required, move rate is below desired move rate and desired by week has passed.

Move rate capability plan

		Owner	Current	Needed	Needed Increase / Decrease	Lead Time (weeks)	Ultimate start date	Earliest due date
Manpower								
	Craftsmen	Supervisor	3	3	0	14		2330
Machine								
Workplaces	Workplaces	Manufacturing Engineer	3	3	0	16		2330
	Tools	Manufacturing Engineer	2	3	1	16	2334	2346
Tester	Safety	Tactical planner	10	17	7	20	2330	2350
	General	Tactical planner	57	57	0	12		2330
Materials								
Critical components	GoTo Critical Componen	Strategic Buyer	5	5	0	36		2330

Week -->	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2401	2402	2403	2404	2405	2406	2407
Craftsmen	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Workplaces	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Tools	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Safety	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
General	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Critical components	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Figure 27: Output sheet 4



4M Analysis Output

Current Move Rate:	2
Desired Move Rate:	2
Move Rate Desired By Week:	2347

Hide / Unhide details

Ultimate start date based on desired week / Due date

Last updated:	26/07/2023
Current date:	27/07/2023
Detail level:	Detailed
Ultimate start date based on:	MR desired by week

MR	No action required. The move rate is at or above the desired move rate for this factor at this week
MR	Action required to increase move rate. The move rate is below the desired move rate, but the desired by week has not been passed yet.
MR	Direct action required, move rate is below desired move rate and desired by week has passed.

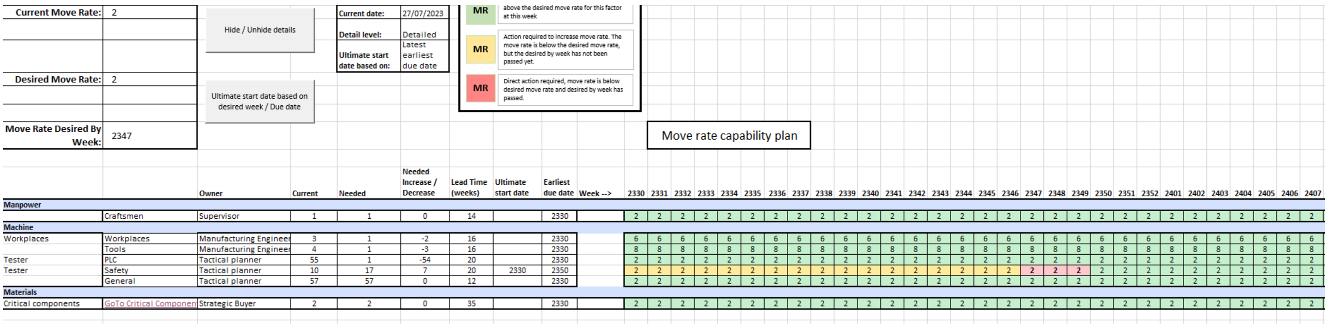
Move rate capability plan

		Owner	Current	Needed	Needed Increase / Decrease	Lead Time (weeks)	Ultimate start date	Earliest due date
Manpower								
	Craftsmen	Supervisor	3	1	-2	14		2330
Machine								
Workplaces	Workplaces	Manufacturing Engineer	3	1	-2	16		2330
	Tools	Manufacturing Engineer	2	1	-1	16		2330
Tester	OIU	Tactical planner	38	2	-36	30		2330
Tester	Safety	Tactical planner	10	17	7	20	2327	2350
	General	Tactical planner	57	57	0	12		2330
Materials								
Critical components	GoTo Critical Componen	Strategic Buyer	2	2	0	57		2330

Week -->	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345
Craftsmen	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Workplaces	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Tools	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
OIU	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Safety	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
General	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Critical components	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Week -->	2346	2347	2348	2349	2350	2351	2352	2401	2402	2403	2404	2405	2406
Craftsmen	6	6	6	6	6	6	6	6	6	6	6	6	6
Workplaces	6	6	6	6	6	6	6	6	6	6	6	6	6
Tools	4	4	4	4	4	4	4	4	4	4	4	4	4
OIU	2	2	2	2	2	2	2	2	2	2	2	2	2
Safety	2	2	2	2	2	2	2	2	2	2	2	2	2
General	2	2	2	2	2	2	2	2	2	2	2	2	2
Critical components	2	2	2	2	2	2	2	2	2	2	2	2	2

Figure 28: Output sheet 5



Current Move Rate:	2
Desired Move Rate:	2
Move Rate Desired By Week:	2347

Hide / Unhide details

Ultimate start date based on desired week / Due date

Current date:	27/07/2023
Detail level:	Detailed
Ultimate start date based on:	Latest earliest due date

MR	above the desired move rate for this factor at this week
MR	Action required to increase move rate. The move rate is below the desired move rate, but the desired by week has not been passed yet.
MR	Direct action required, move rate is below desired move rate and desired by week has passed.

Move rate capability plan

		Owner	Current	Needed	Needed Increase / Decrease	Lead Time (weeks)	Ultimate start date	Earliest due date
Manpower								
	Craftsmen	Supervisor	1	1	0	14		2330
Machine								
Workplaces	Workplaces	Manufacturing Engineer	3	1	-2	16		2330
	Tools	Manufacturing Engineer	4	1	-3	16		2330
Tester	PLC	Tactical planner	55	1	-54	20		2330
Tester	Safety	Tactical planner	10	17	7	20	2330	2350
	General	Tactical planner	57	57	0	12		2330
Materials								
Critical components	GoTo Critical Componen	Strategic Buyer	2	2	0	35		2330

Week -->	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345
Craftsmen	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Workplaces	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Tools	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
PLC	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Safety	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
General	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Critical components	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Week -->	2346	2347	2348	2349	2350	2351	2352	2401	2402	2403	2404	2405	2406	2407
Craftsmen	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Workplaces	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Tools	8	8	8	8	8	8	8	8	8	8	8	8	8	8
PLC	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Safety	2	2	2	2	2	2	2	2	2	2	2	2	2	2
General	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Critical components	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Figure 29: Output sheet 6

Critical components

Lead time	Component	Description	Buyer	Cabinet	Current Quantity per week	Desired Quantity per week	Last updated:	26/07/2023
217	ASM4022_668_34131-LF	PDU 24V P1 P4 CBL	BUY006	[redacted]	3	4		
217	ASM4022_668_35671-LF	PDU DIAG PQUBE P1 P3 CBL	BUY006	[redacted]	3	4		
217	ASM4022_668_35701-LF	PDU 24VDC SF PQ CBL	BUY006	[redacted]	3	4		
217	ASM4022_671_92141-LF	PDU UPSDISABLE P1 UPS CBL	BUY006	[redacted]	3	4		
217	ASM4022_668_34131-LF	PDU 24V P1 P4 CBL	BUY006	[redacted]	3	4		
217	ASM4022_668_35671-LF	PDU DIAG PQUBE P1 P3 CBL	BUY006	[redacted]	3	4		
217	ASM4022_668_35701-LF	PDU 24VDC SF PQ CBL	BUY006	[redacted]	3	4		
217	ASM4022_671_92141-LF	PDU UPSDISABLE P1 UPS CBL	BUY006	[redacted]	3	4		
212	ASM4022_668_34211-LF	PDU CABLEDETECT P3 P2 CBL	BUY006	[redacted]	3	4		
212	ASM4022_668_35711-LF	PDU 230VAC ATSOUT1 CP3X62 CBL	BUY006	[redacted]	3	4		
212	ASM4022_668_44971-LF	PDU 230VAC PSUIN CBL	BUY006	[redacted]	3	4		
212	ASM4022_668_45001-LF	PDU UPS230VAC P1 CVPT CBL	BUY006	[redacted]	3	4		
212	ASM4022_671_89741-LF	PDU 230VAC UPS OUTPUT CBL	BUY006	[redacted]	3	4		
212	ASM4022_668_34232-LF	PDU SERVICE TRAFO2OUT P3 CBL	BUY006	[redacted]	3	4		
212	ASM4022_478_00087-LF	HMI TOUCH PANEL 7 TFT	BUY030	[redacted]	3	4		
212	ASM4022_668_34271-LF	PDU 3PH-MON P1 P3 CBL	BUY006	[redacted]	3	4		
212	ASM4022_668_34181-LF	PDU INTERFACE230V P3 CVPT CBL	BUY006	[redacted]	3	4		
212	ASM4022_668_34211-LF	PDU CABLEDETECT P3 P2 CBL	BUY006	[redacted]	3	4		
212	ASM4022_668_34232-LF	PDU SERVICE TRAFO2OUT P3 CBL	BUY006	[redacted]	3	4		
212	ASM4022_668_34282-LF	PDU EMORELAY P3 P1 CBL	BUY006	[redacted]	3	4		

Figure 30: Critical components 2

Lead time	Component	Description	Buyer	Cabinet	Current Quantity per week	Desired Quantity per week	Last updated:	26/07/2023
207	ASM4022_636_53763-LF	RH CONTROL CAB MECH ASSY	EDI014	[redacted]	2	2		
177	ASM4022_471_77261-LF	REMOTE RST RP (GR+RR) 12V PPCA	BUY004	[redacted]	2	2		
157	ASM4022_439_98841-LF	SCREW HXS CAP LOW NICRSTL A2C	BUY004	[redacted]	38	38		
157	ASM4022_625_52381-LF	RH ECAB CASTER DOLLY TOOL	EDI014	[redacted]	2	2		
157	ASM4022_439_90841-LF	SCREW HXS CAP STL A2C M4X6	BUY030	[redacted]	4	4		
142	ASM4022_438_41441-LF	3PST+NO RELAY 24VDC 12A	BUY014	[redacted]	4	4		
107	ASM4022_439_96616-LF	WASHER SPR CURVED 2.6X5.1	BUY030	[redacted]	4	4		
87	ASM4022_439_90294-LF	SCREW HXS CAP SST A4-80 M4X10	BUY030	[redacted]	16	16		
77	ASM4022_476_23051-LF	ET200S 4X4 SPRING TERMINAL	BUY004	[redacted]	18	18		
67	ASM0051_244_00041-LF	RJ45 CABLE SMCB 0.30	BUY006	[redacted]	4	4		
67	ASM0051_244_00051-LF	RJ45 CABLE SMCB 0.70	BUY006	[redacted]	2	2		
62	ASM4022_640_14782-LF	RH CONTROL CAB HTEMP BRACKET	BUY030	[redacted]	2	2		
47	ASM4022_438_34353-LF	TERM SPR 2.5 MARKER 21-30 CNTR	EDI014	[redacted]	2	2		
47	ASM4022_438_34369-LF	TERMINAL SCREW 2,5QMM GE/GR	EDI014	[redacted]	14	14		
47	ASM4022_438_41310-LF	SPDT RAILMNT REL 230V 6A 6.2MM	EDI014	[redacted]	18	18		
47	ASM4022_439_96916-LF	WASHER SPR CURVED 5.1X9.2	BUY030	[redacted]	16	16		
47	ASM4022_439_96716-LF	WASHER SPR CURVED 3.1X6.2	BUY030	[redacted]	88	88		
47	ASM4022_439_96916-LF	WASHER SPR CURVED 5.1X9.2	BUY030	[redacted]	6	6		
47	ASM4022_439_96816-LF	WASHER SPR CURVED 4.1X7.6	BUY030	[redacted]	16	16		
47	ASM4022_438_34329-LF	TERM SPRING 6 BLUE 8.2MM	EDI014	[redacted]	10	10		

Figure 31: Critical components 3

Lead time	Component	Description	Buyer	Cabinet	Current Quantity per week	Desired Quantity per week	Last updated:	26/07/2023
177	ASM4022_438_31977-LF	SUBD PSLK LOW M3X5.6MM	BUY004	[redacted]	80	80		
172	ASM4022_471_93821-LF	FANUNIT MAINS CONN PCA	BUY030	[redacted]	5	5		
172	ASM4022_471_93891-LF	PC XT3.1 WS HV 1/3 CP PCA	BUY004	[redacted]	5	5		
118	ASM4022_453_90051-LF	LOCTITE 770	BUY030	[redacted]	0	0		
107	ASM4022_472_56922-LF	EMO REAR WSRC ASSY	BUY006	[redacted]	5	5		
62	ASM4022_472_45202-LF	PC LSPR6 WSE BACK COVER	BUY030	[redacted]	5	5		
62	ASM4022_472_45222-LF	PC LSPR6 WSM BACK COVER	BUY030	[redacted]	5	5		
62	ASM4022_472_45162-LF	PC SSPR3 WS1 BACK COVER	BUY030	[redacted]	5	5		
62	ASM4022_472_45182-LF	PC SSPR3 WS2 BACK COVER	BUY030	[redacted]	5	5		
47	ASM4022_439_96816-LF	WASHER SPR CURVED 4.1X7.6	BUY030	[redacted]	40	40		
47	ASM4022_439_96916-LF	WASHER SPR CURVED 5.1X9.2	BUY030	[redacted]	15	15		
47	ASM4022_439_96816-LF	WASHER SPR CURVED 4.1X7.6	BUY030	[redacted]	330	330		
47	ASM4022_439_96916-LF	WASHER SPR CURVED 5.1X9.2	BUY030	[redacted]	15	15		
47	ASM4022_439_96716-LF	WASHER SPR CURVED 3.1X6.2	BUY030	[redacted]	50	50		
47	ASM4022_439_96716-LF	WASHER SPR CURVED 3.1X6.2	BUY030	[redacted]	20	20		
47	ASM4022_439_96716-LF	WASHER SPR CURVED 3.1X6.2	BUY030	[redacted]	10	10		
47	ASM4022_439_92944-LF	SCREW CRS Z PNH SST M5X12	BUY030	[redacted]	20	20		
47	ASM4022_439_88055-LF	NUT CAGE ST ZN YE M6	BUY030	[redacted]	420	420		
47	ASM4022_439_97016-LF	WASHER SPR CURVED 6.1X11.8	BUY030	[redacted]	5	5		
42	ASM4022_470_28041-LF	EXTENDER FIXING TOP	BUY004	[redacted]	5	5		

Figure 32: Critical components 4

Lead time	Component	Description	Buyer	Cabinet	Current Quantity per week	Desired Quantity per week		Last updated:	26/07/2023
282	ASM4022_478_05072-LF	PORTSERVER 16P RS-232/422/485	BUY030		2	2			
272	ASM4022_438_35130-LF	PVC WIRE 1.5QMM 600V BK	EDI014		2	2			
206	ASM4022_478_05093-LF	SODIMM DDR3L 1333 2GB I-GRADE	BUY004		2	2			
157	ASM4022_439_98603-LF	SCREW HXS CSK NICRSTL A2C M3X8	BUY004		6	6			
157	ASM4022_439_90741-LF	SCREW HXS CAP STL A2C M3X6	BUY004		4	4			
157	ASM4022_439_90847-LF	SCREW HXS CAP STL A2C M4X25	BUY030		4	4			
157	ASM4022_439_90742-LF	SCREW HXS CAP STL A2C M3X8	BUY030		8	8			
157	ASM4022_439_90944-LF	SCREW HXS CAP STL A2C M5X12	BUY030		8	8			
127	ASM4022_478_00112-LF	PSU DIN RAIL 15V 3.4A	BUY030		2	2			
82	ASM4022_438_34170-LF	INSUL WIRE-END SLICE 1.5QMM 8	EDI014		20	20			
67	ASM4022_489_20405-LF	SPACER HEX M/F SST 8X25-M5	BUY004		8	8			
52	ASM4022_438_77040-LF	09P SUBD REC ANG PF PCB M3	EDI014		2	2			
47	ASM4022_438_34350-LF	TERM SPR 2.5 MARKER 1-10 CNTR	EDI014		12	12			
47	ASM4022_438_34366-LF	DIN RAIL TH/G MARKER END CLAMP	EDI014		2	2			
47	ASM4022_438_34797-LF	TERM SPRING 4 PE YEGR 6.2MM	EDI014		6	6			
47	ASM4022_438_34798-LF	TERM SPRING 4X4QMM END PLATE	EDI014		2	2			
47	ASM4022_489_53389-LF	PEN STYLUS TETHERED W/CORD	BUY004		2	2			
47	ASM4022_439_96916-LF	WASHER SPR CURVED 5.1X9.2	BUY030		4	4			
47	ASM4022_438_34323-LF	TERM SPRING 2.5 BRIDGE 2P 5.2	EDI014		2	2			
47	ASM4022_438_34333-LF	DIN RAIL TH/G TYPE END CLAMP	EDI014		8	8			

Figure 33: Critical components 5

Lead time	Component	Description	Buyer	Cabinet	Current Quantity per week	Desired Quantity per week		Last updated:	26/07/2023
172	ASM4022_471_93821-LF	FANUNIT MAINS CONN PCA	BUY030		2	2			
167	ASM4022_478_00091-LF	END CAP	BUY030		2	2			
157	ASM4022_439_90844-LF	SCREW HXS CAP STL A2C M4X12	BUY030		24	24			
157	ASM4022_439_90956-LF	SCREW HXS CAP STL A2C M5X70	BUY030		8	8			
157	ASM4022_439_91253-LF	SCREW HXS CAP STL A2C M10X50	BUY030		4	4			
157	ASM4022_439_97201-LF	NUT HEX SST A2-70 M10	BUY030		4	4			
157	ASM4022_439_97211-LF	WASHER SST 10.5X20	BUY030		4	4			
157	ASM4022_439_98805-LF	SCREW HXS CAP LOW NICRSTL A2C	BUY030		8	8			
157	ASM4022_439_90742-LF	SCREW HXS CAP STL A2C M3X8	BUY004		56	56			
157	ASM4022_439_90841-LF	SCREW HXS CAP STL A2C M4X6	BUY030		34	34			
157	ASM4022_439_90843-LF	SCREW HXS CAP STL A2C M4X10	BUY030		30	30			
157	ASM4022_439_90844-LF	SCREW HXS CAP STL A2C M4X12	BUY030		16	16			
157	ASM4022_439_90388-LF	SCREW HXS RDH SST A4-70 M6X16	BUY004		250	250			
118	ASM4022_438_34392-LF	TERM SPRING UT16-ST2.5/4 BRIDG	EDI014		2	2			
107	ASM4022_438_34729-LF	DIN RAIL E/NS 35N END-SUP	EDI014		22	22			
107	ASM4022_438_34318-LF	TERM SPRING 2.5QMM END PLATE	EDI014		10	10			
92	ASM4022_476_26901-LF	PHOTOELEC SMOKE DET 1-3.18%/FT	BUY030		2	2			
67	ASM4022_438_39504-LF	PA CBL TIE DIAM. 3.5/45MM NAT	EDI014		34	34			
62	ASM4022_668_78711-LF	MSDU FRONT PLATE	EDI014		2	2			
62	ASM4022_454_51341-LF	CABLE CLAMP BASE	BUY004		2	2			

Figure 34: Critical components 6

Appendix B: 4M analysis tool

As an appendix of this research, the 4M analysis tool will be provided alongside this document in the form of a Macro-enabled Excel file.

This tool contains confidential information and may not be shared.

Appendix C: 4M-analysis tool user manual

In section 0, we provide a user manual to operate the tool. The goal of this user manual is that every Benchmark employee that has an interest in performing or reviewing the 4M-analysis is able to operate the tool and interpret its output. Additionally, we provide future recommendations on how to improve the 4M-analysis and the accuracy of the optimal decision path generated by the optimization Dynamic Programming model.

Summary of steps

Sheet 'Startpage'
Step 1: Provide input for table 'Move Rate information per cabinet'
Step 2: Provide input for 'Planning horizon' and 'Move Rate desired by week'
Step 3: Check and update 'List of critical suppliers'
Sheet 'Variables'
Step 4: Check and update 'Global variables'
Step 5: Check and update 'Cabinet variables'
Step 6: Check and update 'Tester variables'
Sheet 'Input cabinet'
Repeat these steps for all cabinets that you want to analyse
Step 7: Check and update input 'Manpower'
Step 8: Check and update input 'Machine'
Step 9: Check and update input 'Specials' if applicable
Step 10: Provide input for known additional or leaving manpower and machines
Sheet 'Find Decision'
Step 11: Provide the starting state as input for calculating the optimal decision strategy
Sheet 'Startpage'
Step 11: Press 'Start Analysis' and select boxes you want to analyse

Step 1

The first step to operating the tool is providing the main input. The main input table is presented in figure 18 in the section marked 1 and can be found on the sheet 'Startpage'. In the first column labelled Cabinet, the user can provide the names of the volume cabinets that are currently being produced for customer A. Secondly, the next column 'Current MR' gives the opportunity to provide the current move rate capabilities of the volume cabinets. Lastly, the user has to choose between providing input

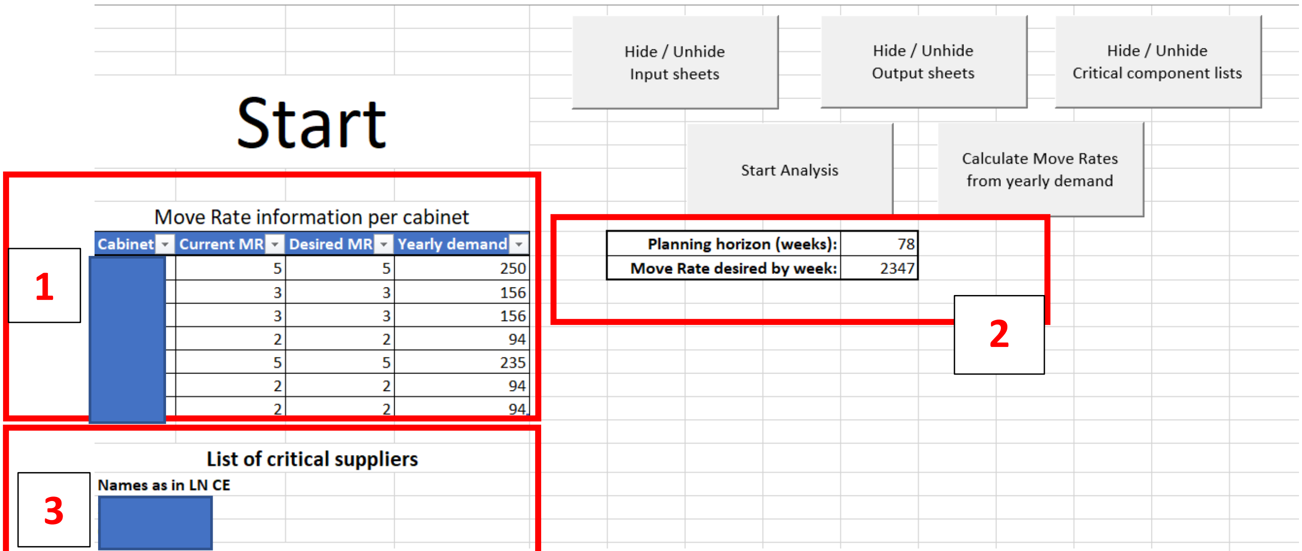


Figure 35: Step 1, step 2 and step 3

for either column 3 ‘Desired MR’ or column 4 ‘Yearly Demand’. If the desired move rate capabilities are known, they can be put in directly in column 3. If only the yearly demand is provided by customer A, the yearly demand should be put in column 4. Following this, the input in section 1 can be completed by pressing the button ‘Calculate Move Rates from yearly demand’, which will calculate the desired move rate capabilities per cabinet.

Step 2

Following this, the user provides input for the two variables in section 2. Here, the ‘Planning horizon’ and ‘Move Rate desired by week’ is given as input. The planning horizon is the amount of weeks the user wants to look ahead. The standard suggested input is 78 weeks (1.5 years). Additionally, the user can set the year and week number (yyww format) as a deadline on which the move rate increase should be realized.

Step 3

In section 3, the list of critical suppliers is shown. This list has to be updated and if applicable expanded. The names of this list have to be exactly equal to the names of suppliers in LN CE.

Step 4

On the page ‘Variables’, the global variables provides input in terms of variables concerned with manpower and machines. These input variables should be checked and updated by the user.

Global variables	GoTo
Cabinet variables	GoTo
Tester variables	GoTo

4

Global variables

Manpower	Value	Unit
1 FTE	35	hours/week
Efficiency inexperienced recruitment	70%	
rectuitment time junior	2	weeks
recruitment time medior	8	weeks
work-in period	6	weeks
#holiday weeks	5	weeks
Holiday capacity	20%	

Machine	Value	Unit
Lead time jigs	16	weeks
#hours jig is available per week	36	hours
Lead time additional room	12	weeks
max capacity utilization testers	70%	
Lead time new [redacted]	52	weeks
Lead time new [redacted]	40	weeks
Lead time new [redacted]	40	weeks
Lead time new [redacted]	12	weeks
Lead time new [redacted]	40	weeks
Lead time new [redacted]	40	weeks

Figure 36: Step 4

Step 5

Check and update the 'Cabinet variables' on the sheet 'Variables'.

5

Cabinet variables							
Manpower							
#craftsmen per MR	2	2	2	0,5	0,5	0,5	0,5
Machines							
#Backplate throughput time per jig	19	24					
#Connector plate throughput time per jig	32	44					
#Throughput regular jig			96				
#working places and tools per move rate	2	2	2	0,5	0,5	0,5	0,5
additional m^2 per MR	16	16	30				
available m^2	123,5	123,5	247				
m^2 used			180				

Figure 37: Step 5

Step 6

Check and update the 'Tester variables' on the sheet 'Variables'.

6

Tester variables						
Cabinet						
	10,9		0,3	0,4		
	12,0		0,9		1,0	
	20,2		1,0	0,2	1,0	
			2,0	26,7		
			0,3	0,2		
			1,0	0,1		1,0
		0,5	0,5	0,3		
Base hours used per tester	45,2	24,3	30,0	61,0	2,7	1,2
Capacity per tester (hours)	224,0	112,0	56,0	168,0	56,0	56,0
Number of testers	2,0	2,0	1,0	3,0	1,0	1,0
Available testing hours per tester	112,0	56,0	56,0	56,0	56,0	56,0
New tester delivered in week	2401					

Figure 38: Step 6

Step 7, step 8 and step 9

Steps 7 through 10 need to be repeated for all input sheets per cabinet, for this user manual we selected the input sheet for MDRC NXE + NXT. In section 7, the current number of full craftsmen and the number of craftsmen that are still in their work-in period need to be given as input. Additionally, the current date needs to be put in the column 'Last updated'. This information needs to be provided by the employee responsible as given in the middle column. The same principle holds for step 8, only then for the machine input. Whenever one of the inputs does not have standard input, put in 'N/A'. and go to step 9. When all values from the regular input in steps 7 and 8 are numerical, no specials are needed and therefore step 9 can be skipped.

Step 9 is different for all cabinets, but predefined for all current volume cabinets. For these volume cabinets, also put in the requested input and update the 'Last updated' field.

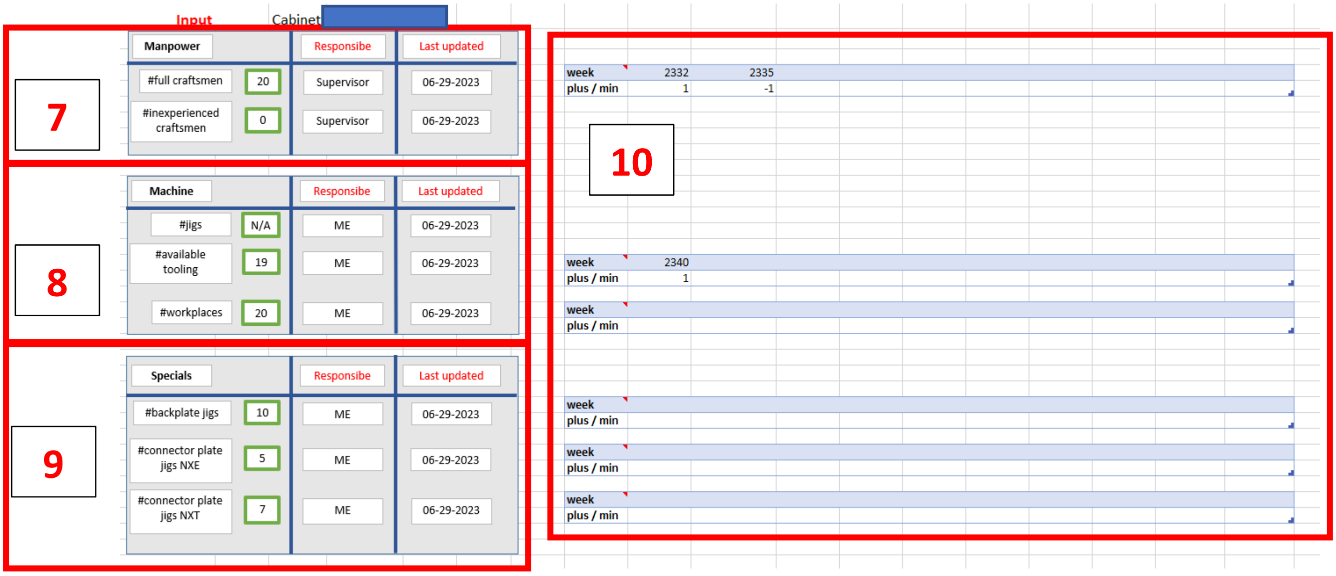


Figure 39: Steps 7-10

Step 10

Here, the already known arrivals and if applicable departures can be given of manpower, machines and specials. On the top row of the column, the year and week number must be provided, and in the bottom row, the amount of change must be provided. Note that these tables can be left empty if no additional resources are known to be arriving.

Step 11

The last step before initiating the simulation, is to provide the initial stage and state of the DP problem in the sheet 'Find Decision'. We advise Benchmark to always start in the following stages:

- Starting week: 1
- Consecutive weeks with overtime: 0
- Hours until next additional cabinet: Total hours needed to build an additional cabinet using all available craftsmen (In the case of NXE3600/3800 this is 17)

After the analysis has been completed, the optimal decision path can also be found in the sheet 'Find Decision'.

Starting week	1	11
Consecutive weeks with overtime	0	
Hours until next additional cabinet	17	

Decision strategy:

Week	Optimal Decision	Total cost from this week	Total cabinets not delivered
Week 1	7	827141	14
Week 2	8	766644	14
Week 3	8	705147	13
Week 4	8	615193	12
Week 5	0	546199	12
Week 6	7	509049	12
Week 7	8	464899	11
Week 8	8	411480	10
Week 9	0	363624	10
Week 10	6	337825	10
Week 11	8	306026	9
Week 12	3	271527	9
Week 13	8	247028	8

Figure 40: Step 11

Step 12

Start the simulation by clicking the button ‘Start analysis’ and subsequently selecting the boxes for what you want to analyse.

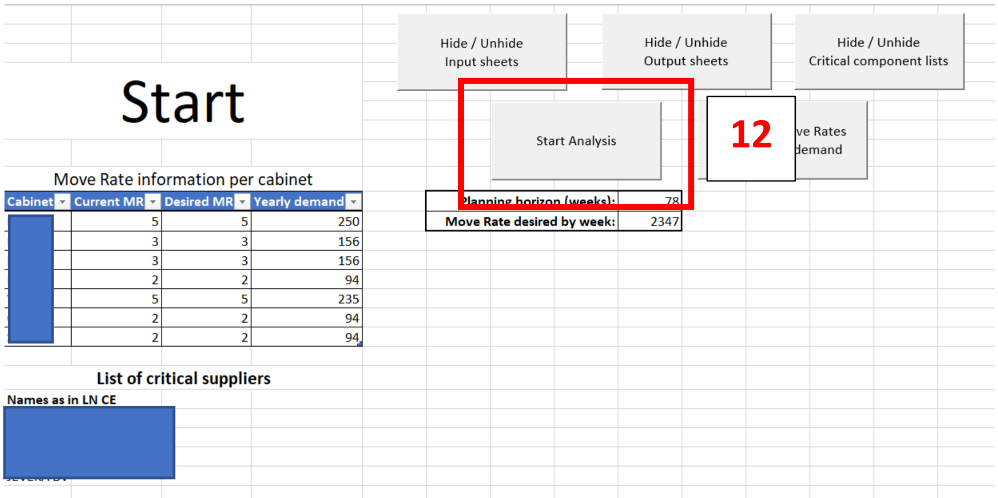


Figure 42: Step 12, press button

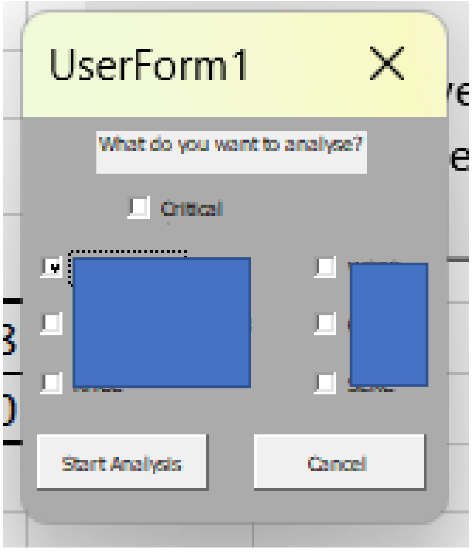


Figure 41: Step 12, select analysis choices