Decreasing the time spent on administrative actions in the scheduling process of TenCate Geosynthetics

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Bachelor Thesis

Decreasing the time spent on administrative actions in the scheduling process of TenCate geosynthetics.

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Management Summary

TenCate Geosynthetics is a company that produces geosynthetics and industrial fabrics, with multiple locations in Europe, one of those is located in Hengelo. The Dutch production plant has two different departments: the construction department and the weaving mill. The administration needed to guide the scheduling process takes up a significant amount of time for several employees. The focus of this thesis is to analyse the scheduling process of TenCate Geosynthetics and find a solution to decrease the amount of time spent on administrative actions of the scheduling process. Currently three employees spend 26 hours per week on administrative actions per week combined. This results into the following central research question of this thesis.

How can the time spent on administration of production schedule at TenCate geosynthetics be reduced?

Business process models in the BPMN language have been created to give insight into the scheduling process of TenCate. The analysis revealed that there are three different scheduling processes, the warping-, the construction- and the weaving mill scheduling process. An analysis of the root cause with the use of a cause-and-effect diagram revealed that double administration in the construction- and weaving mill scheduling process is the root cause for the extensive amount of time spent on administrative actions. Double administration of data occurs when the order of production or information about the production process is stored in both an Excel database and the ERP-database. TenCate uses SAP as their ERP-system. These systems are not connected in the current scheduling process, which means data needs to be processed by employees from one system to the other, which results in them spending more time on administration.

The proposed solution was selected by using the multi-criteria decision analysis methodology TOPSIS. This analysis showed that acquiring new scheduling software will eliminate the most steps in the scheduling process. The new scheduling software can eliminate double administrative actions performed by the employees. A new business process model is presented to show how the new process flows would look like. The main difference between the old and the new scheduling process is the elimination of double administrative steps.

After the new scheduling software was selected as best solution out of four possibilities, a sensitivity analysis showed that when time for implementation and/or budget is limited the solution where a new macro in Excel is the better solution. However, if Ten Cate is willing to invest €27,600 euros and 130 man hours for successful implementation of the new software, the time spent on administrative actions will be reduced by approximately 7 man hours a week, which is a time reduction of 21.7%.

The recommendation for TenCate after conducting the research is:

TenCate should consider acquiring new scheduling software, which will require investments of €27,600 and 130 man hours, which is needed for implementation time. However, the investments will pay itself back within 19 hours, since it saves 6.95 man hours per week. Time that employees can now spend on other tasks, which improves the efficiency of TenCate Geosynthetics.

Preface

Dear reader,

In front of you lies my thesis written for my bachelor assignment of the study Industrial Engineering and Management at the University of Twente. I have conducted my research as TenCate Geosynthetics at Hengelo. I have gotten the opportunity to develop myself at this noteworthy company and end three years of studying with this thesis.

I have learnt a great deal by conducting this research at TenCate, I learnt how to apply theories that I have learnt in the past 2,5 years to the practise. I also enjoyed learning so much about a new company and see theories be performed in practise. Furthermore, I have learnt how to approach real research and how each phase of a research takes place.

I want to thank the people of TenCate for giving me the opportunity to conduct my research at their company. Furthermore, I want to thank them for letting me conduct my research at their plant, which can be quite challenging in these strange times of the Covid-19 pandemic. I was always treated both friendly and professionally by the people of TenCate, for which I am thankful. Special thanks go out to my supervisor of TenCate, Herald Hagedoorn, who has helped my doing my research and tried to help where possible.

I also want to thank my supervisor from the university, Martijn Koot, who has helped me throughout the entire process. He was very helpful to me, especially whenever I was stuck. His feedback was of terrific value to me and was also of great value to the thesis.

I hope you enjoy this thesis,

Job de Beurs

Contents

1. Introduction

1.1 Company background

TenCate is a world leader in the provision of geosynthetics and industrial fabrics. Both are synthetics which are used to stabilise terrain, both on land and under water. The headquarters are located in the United States. TenCate has two commercial divisions, to serve the global market: the Geosynthetics division and the Industrial fabrics division. TenCate Geosynthetics has three manufacturing departments, all located in Europe, namely one in France, one in Austria and one in the Netherlands. The latter one will the focus of this project plan. TenCate Geosynthetics B.V. is located in Hengelo (Overijssel), where geosynthetics are manufactured. Further on this thesis TenCate Geosynthetics will be referred to as TenCate. The products manufactured at this production plant are textiles and synthetics which are used for applications in soil-, water- and road construction.

The production plant is divided into two distinct parts. The first part is the weaving mill, where woven fabrics are made, used for the road- and soil constructions. This department consists of x different types of machines. Each type can manage different materials, different thread thickness and different quantity of fabric. Some of the machines are exceptionally large and use over a couple of thousand different creels, which are filled with yarn. These machines have a large change-over time, therefore these machines run for about three months, manufacturing the same product. After production, the finished products are sent to the warehouse where they wait for shipment. Some products are semi-finished when leaving the weaving mill, those are managed by the construction part of TenCate. However, the construction part also manages materials which are sourced from other companies.

The other department of the plant is the construction site. Here multiple woven fabrics are sewed together, usually for water applications. So-called Geotubes and the main product are sewed together in a large production hall where the products are laid out. Two people are usually working on a large product. Once the product is finished, it is transferred to the warehouse.

TenCate Hengelo struggles with the scheduling process of the production planning. The three employees who are mainly involved with this process spend approximately 32 hours per week on the administration involved with the scheduling process of the production planning. TenCate believes this time can be reduced, which would mean the employees can spend part of their workweek on tasks that makes the overall manufacturing process better.

There is a scheduler who makes the planning for the weaving mill and schedules the orders for the construction part. Another part of the job is the fact that he is responsible for the communication between production and the sourcing department, as well as performing long-term-forecasting. The scheduler is working half of his time on the creation of the planning, distribution of the planning and keeping the internal supply chain up to date. So, he needs keep track of what orders are ready to be manufactured, what is finished manufacturing or whether machines are broken down which means that the manufacturing process takes longer. He gets help from the two manufacturing department heads. They give the part of the necessary information from the production floor to the scheduler via shared Excel sheets and meetings, the rest of the data is processed by a monitoring system in the production floor. The department head of the construction site plans in the employees, after seeing how many employees are necessary according to the scheduler. An overview of the production employees and their hierarchy is provided in Figure 1.

This figure starts with the production manager at the top since other parts of the company are not in the scope of this study. For all the processes Excel and the ERP system are used, the ERP system TenCate uses is SAP.

SAP is a complex ERP-system without an easy-to-use interface which makes it difficult to understand for the operators, therefore excel sheets are used for communication between the scheduler and the production floors.

SAP is used for scheduling of the weaving mill, since this is machine focused instead of employee focused. This means the planning is made for what goes on the which machine at what time, instead of determining how many employees need to work at a specific product or time. SAP is also used in the meetings with quality management, the research, development department and the test manager. The SAP planning shows a broad overview of all the machines in the weaving mill, whereas the Excels give a more detailed planning, more details are noted, such as the number of rolls, the dimensions of the end-product.

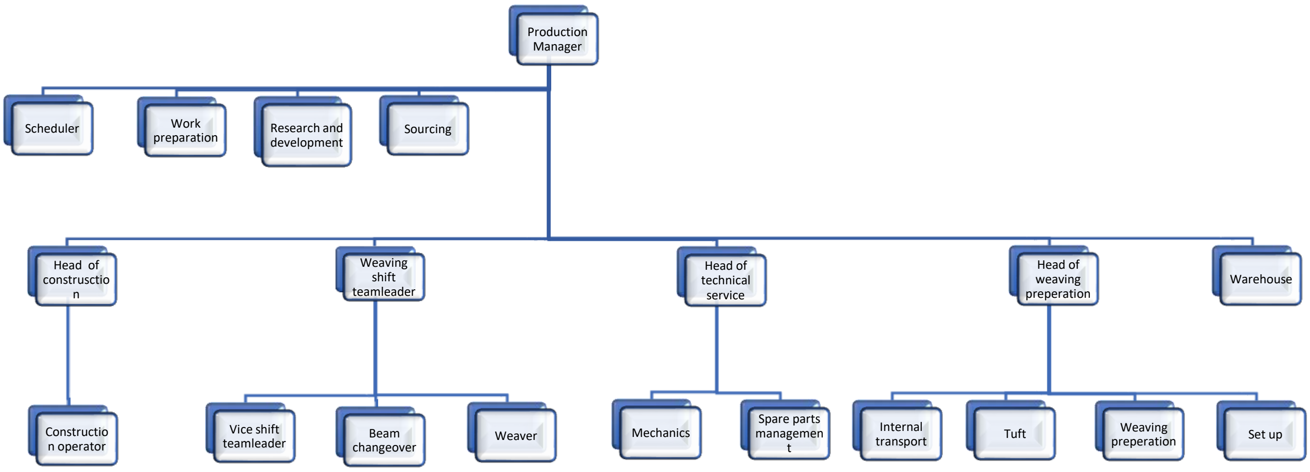

Figure 1: Organogram of TenCate

1.2 Research motivation

The current scheduling process is created by the employees along the way, with additions and changes being made throughout the years. It was not developed as a whole. When the production manager came to TenCate 1.5 years ago, he looked at the process with a new perspective. This perspective raised the question that the scheduling process was not optimal. Furthermore, he experienced a lack of overview on the scheduling process because of all the different files that were used.

During the meetings with TenCate where the problem was described, it became clear that nobody had the time to take a critical look at the process. TenCate had the idea that it could be improved in some way, since it was not a very logical process at that moment.

Extra interviews with stakeholders showed that employees were stuck in their way of doing it and a fresh look was welcome. Following the interviews, the problem was narrowed down to the administration of the scheduling process.

1.3 Problem description

This subchapter describes the core problem, the aim of the research and the solving approach. Along with this comes the intended deliverables of this research. In order to gain insight into the problems, interviews with the production manager were held. From there meetings with the heads of the departments were held to find a deeper understanding of the problems.

The problem identification should provide clear insight to what the core problem at TenCate is, then is shows what consequences this problem has to other processes at TenCate and it concludes describing the reality and the intended norm for this problem.

1.3.1 Core problem

The overall planning and scheduling are spread out over many different documents and two different systems, making it difficult to maintain a good overview of the process. The three people that are mostly involved in this process are: the supply chain coordinator and the two heads of both manufacturing departments. These departments are the construction department and the warping for weaving mill department. To make the schedules for the machines and the employees, keeping track of the production progress and administrating this takes up a significant amount of time for these three employees. The supply chain coordinator spends half of his time working on these administrative actions, while the others two spend roughly 15 percent of their time on these administrative actions. This inefficiency causes the employees to spend less time on other tasks of their job, this causes a backlog in the working activities.

This problem has not only got consequences for the scheduling process but for other processes and branches of the company as well. The many administrative actions, take up time of the employees that they cannot spend on other tasks and increase the chance of errors in the administration. This does not occur often, but errors need to be fixed and this will take up time, meaning deadlines cannot always be met. Whenever those errors do not occur, shorter delivery times can be achieved. Another consequence is involved with the machines, for which a less accurate planning can be made, due to time limitations. This results in more idle time of machines, meaning more inefficiency. This can occur due to a supply shortage or a schedule where it is scheduled to stand still. Overall, these actions take up time for employees, TenCate does believe that they can reduce op to 1 FTE, if the employees have to spend less time on administration. Figure 2 shows the consequences of the core problem.

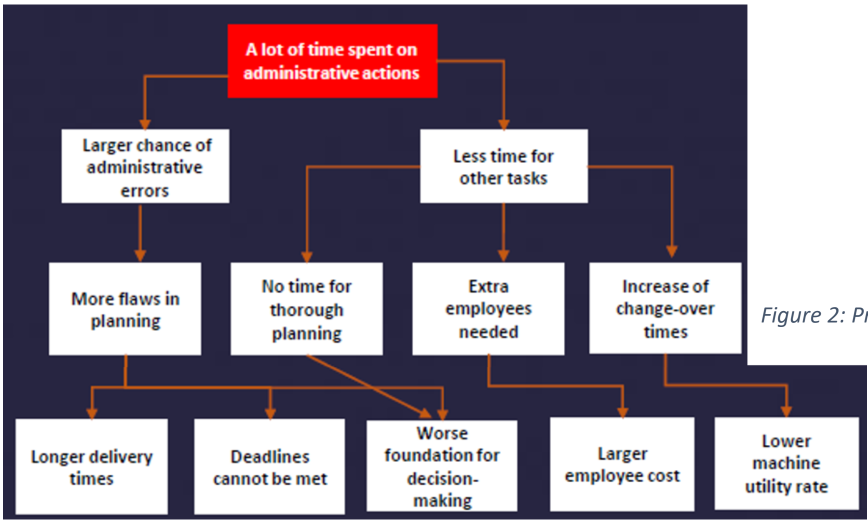

Figure 2: Problem cluster

TenCate has not find a way yet to reduce the administrative actions, it is difficult to implement new methods and ways without reassurance that it works, since the production processes needs to continue.

The employees do not have the time to work on alternate methods to reduce this since production processes need to continue. Therefore, this research should find a way to reduce time that these three employees spend on administrative actions.

Resulting into the core problem:

Too much time is spent on administrative actions that are involved with scheduling

1.3.2 Norm and reality

The variable of the core problem is the time spent on administrative actions. All three employees involved work 40 hours per week, so the scheduler spends 20 hours in a week on creating, administrating, and changing the schedules, this is the reality. These 20 hours are spent on drawing data from SAP to excel, keeping track of internal supply chain in both SAP and Excel and aligning these two programs. The heads of the two departments are workings about 6 hours each in the week on these administration tasks, which is the reality. The norm is to spend 50% less time on these actions, this leads to 10 hours spend by the supply chain coordinator and 3 per week by the heads of departments. The reduction should cause less backlog on the activities, furthermore it could free up time for evaluation of the schedules, which could lead to more efficient schedules. The problem owners are the production manager, the direct supervisor of all three employees and the plant manager in Hengelo.

1.4 Research design

1.4.1 Problem solving approach

The managerial problem-solving approach (MPSM) by Heerkens and Winden (2012) consists of seven phases. This research is designed by following these steps. In this section the design of this research is described by formulating the sub-research questions which must be answered to find the answer to the main research question. Table 1 gives an overview of the solving approach.

The first step of MPSM is to define the problem. This step is covered in section 1.3. The problem was found by gathering information out of semi-structured interviews and observation and use that information to create a problem cluster. The second step of the MPSM approach is to formulate the problem-solving approach, this is done by using D3 (Do, Discover and Decide) in order to describe for each step within the MPSM which activities are performed, which knowledge is required and what decisions must be made. (Heerkens and Winden, 2012).

Step three is of the MPSM is to analyse the problem. The analysis is done in three sperate parts. This research starts off with gaining an understanding of the scheduling process. Business process models are a convenient way to gain such and understanding. Therefore, a suitable modelling language has to be found. This modelling language was found by performing a literature review on Business Process Management (BPM). This part of the research is covered in Chapter 2 and answers the following research question.

1. *Which modelling language is the most suitable to provide insight on the scheduling process of TenCate?*

The second part of analysing the problem is to find out why there is a lot of administration involved with the scheduling process of the production. Semi-structured interviews with the head of the departments and the scheduler along with observations of the excel files and the ERP system, used in the scheduling process, have provided qualitative data that was used to find out which data is transferred between the computers systems and the employees. Quantitative data was found by the observation of historical production data. The use and transference of data are elaborated on in sections 3.1 and 3.2. These sections cover the second research question.

2. *What information is essential for the production order planning/schedules?*
    a. *What data that is used for Excel is drawn from SAP?*
    b. *What data is transferred from the scheduler to the heads of the departments*

The last part of the analysis is to use the knowledge found by answering the second research question for the creation of the business process models with the modelling language found in Chapter 2. The models have been discussed with the scheduler and the production manager to make them more accurate. The business process models give insight in the scheduling process and the administration of finished products once production is finished (Damelio, 2019). These insights contribute to finding the root cause, which should give a more detailed and clear description of what part of the process needs to be addressed by the possible solutions. The root cause is found by the use of a cause-and-effect diagram. This diagram was created by using business process models, to identify the possible root causes, and academic literature. These causes were discussed with the employees and the root cause was selected in consultation with the production manager and the scheduler. Sections 3.3 presents the created business process models and section 3.4 identifies the root cause, combined the answer the third research question.

3. *What is the main cause of the scheduling process and the process of administration after production being so time consuming?*
    a. *What does the scheduling processes look like?*
    b. *How do the processes of administration after production is finished look like?*
    c. *What is the main root cause for the extensive amount of time spent on administration?*

The fourth step of MPSM is to formulate solutions. These solutions were created by brainstorming with the scheduler and performing online research to similar problems. The production manager helped refining these solutions. The four solutions are described in section 4.1. The fifth step of MPSM is to choose one of the formulated solutions. The choosing is done by the use of a Multiple Criteria Decision Analysis (MCDA) (Ulubeyli & Kazaz, 2009), for which 8 criteria are formulated. These criteria and their weights are found by unstructured interviews with the production manager and the scheduler. This part of the research is covered in section 4.2. By the use of a framework created by Wątróbski, Jankowski, Ziemba, Karczmarczyk, & Zioło (2019) the most suitable MCDA methodology for this research is selected. This is followed by an explanation of the selected MCDA methodology. Academic literature is used to verify the explanation. The framework and explanation are presented in section 4.3. The actual analysis is done in section 4.4. Each solution has received a score for each of the 8 criteria, these scores have been determined by interviewing the stakeholders at TenCate and performing some of the steps in the process in person or observations of the performance of these steps. A sensitivity analysis on the criteria is performed to see the impact on the outcome of the MCDA when the weights of the criteria are changed. The analysis will result in advice for managers of TenCate on how to interpret the initial outcome of the MCDA followed by an advice on which solution is the best when circumstances differ. The sensitivity analysis is performed in section 4.6. All sections in Chapter 4 combined cover step 4 and 5 of the MPSM approach and answer the fourth research question.

4. *What is the best alternative solution for the problem?*
    a. *What methods can decrease the time spend on administration?*
    b. *What are the criteria for the methods and how are they weighed?*
    c. *What is the best methodology to compare the generated solutions?*
    d. *What is the best alternative solution according to the multiple-criteria decision analysis?*
    e. How does changing the weights of the criteria affect the outcome of the MCDA?

Step six of MPSM is to implement the found solution, which is done in Chapter 5. Unstructured interviews were conducted with the scheduler and the production manager to discuss what steps had to be made for successful implementation. A meeting with a representative of a scheduling software company named vPlan also helped identifying what steps are necessary for successful implementation. Chapter 5 is concluded by business process models to present a new proposed scheduling process after successful implementation of the selected solution. The models and the expected results of the solution are part ff the evaluation of the solution which is the seventh and last step of the MPSM. The results are calculated by comparing the old and the new scheduling processes and estimating the time which is saved per step in the process which is eliminated. These estimations are made by observing and interviewing the scheduler as well as assessing the Excel files used in scheduling process. Chapter 5 answers the fifth research question of this thesis:

5. *How can the found method be implemented efficiently in TenCate Geosynthetics?*

MPSM	Activity	Do	Discover	Decide	Section	Research question
Step 3: Analysing the problem	Data gathering	Literature review	Main concepts of BPM		2.1	1
			Concepts of Business process modelling		2.2	1
			Type of modelling languages	Choose most suitbale modeling language	2.3	1
	Data gathering	Semi-structured interviews	Activites done by employees	Which activities are used in scheduling process	3.1 & 3.2	2
			How databases are used	Which data transferrence is used for the scheduling process	3.2	2
		Observation of software		Which data transferrence is used for the scheduling process	3.2	2
	Making business process models	Unstructered interviews	What scheduling process looks like		3.3	3
		Observation of software			3.3	3
	Identification of Root cause	Create CED diagram	Four potential root causes	Determine the root cause	3.4	3
		Unstructured interviews			3.4	3
Step 4: Formulate the solutions	Generating solutions	Brainstorming		What solutions will be used for analysis	4.1	4b
		Online research			4.1	4b
		Reviewing with stakeholders			4.1	4b
Step 5: Choose solution	Setting up criteria	Unstructered interviews		Which criteria to use and what weights to give	4.2	4a
		Determine description of criteria		What a solution can score on a criterion	4.2	4a
	Gathering data on MCDAs	Literature review	Framework for deciding on MCDA methodology	Which MCDA methodology to use	4.3	4c
	Performing MCDA	Observation	Performance of each solution on each criterion	Decide whether solution will have enough improvement to wright implemention strategy	4.4	4d
		Unstructured interviews			4.4	4d
		Self performing of steps			4.4	4d
	Sensitivity analysis	Define goal of analysis		Decide if analysis is done by changing weights or scores	4.5	4e
		Discuss results of analysis		Decide wether different circumstances would lead to different advice for TenCate	4.5	4e
Step 6: Implementation	Define order of implementation	Semi-structured interviews			5	5
Step 7: Evaluation	Evaluate new solution	Make new process models	Differences between old and new situation	Make trade-of between costs and time saved	5	5

Table 1: Problem solving approach

1.4.2 Deliverables

The deliverables for TenCate are the results of answering the research questions. The deliverables for TenCate are:

- An extensive analysis of the current situation, including business process models of multiple scheduling processes.
- The definition of a root cause for the core problem of this research and thus a root cause of the inefficient scheduling process.
- An advice on how to solve the core problem in combination with an implementation strategy. This includes the investments and the estimated time reduction of the proposed solution.
- An advice on how to interpret the outcome of the MCDA and on how to deal with the core problem when the circumstances change by performing a sensitivity analysis.

2 Literature review on business process modelling

This chapter covers a literature review about business process management. First of all, a broader perspective of business process management is described, where the four dimensions are described. This is followed by more specific elaboration on the role of people and information systems in business processes. Then multiple interpretations of the lifecycle of business process management are discussed. The chapter is concluded with an answer on the research question described in Chapter one: Which modelling language is the most suitable to provide insight on the scheduling process of TenCate.

2.1 The main concepts of business process management

This section covers the literature review about the main concepts of business process management (BPM). In order to find a suitable modelling language more knowledge about BPM as a whole is useful since concepts of BPM are also used in process models.

2.1.1 The four dimensions of business processes

Business process management (BPM) is a discipline that combines the knowledge of information technology with the knowledge of management sciences and applies both these aspects on business processes (van der Aalst, 2013). Business process management (BPM) consists of a variety of concepts, methods and techniques which contribute to the design, administration, configuration, enactment and the analysis of a business process (Weske, 2019). So, BPM is involved in both creating and designing a business process as well as analysing and improving a business process. A business process is defined by Weske as "a set of activities that are performed in coordination in an organizational and technical environment" (Weske, 2019). These activities combined should realize a goal. A business process is determined by a single organisation, but it may interact with business processes from external organisations (Weske, 2019). Business processes can be classified in 4 main dimensions according to Weske (Weske, 2019).

These 4 dimensions are: business goals and strategies, organizational business processes, operational processes and implemented business processes. The first dimension specifies the goals and management strategies of a business. The goals that are formulated point out the long-term objectives set by a business. Strategies are ways to realise the set objectives. This is the first level of business processes. Once this level is determined, the next level should be entered: organisational business processes.

This second level works on organisation level, where the business processes are specified by their inputs, outputs, expected results as well as the dependency on other organizational processes (Mathias Weske, 2019). Inter-organisational business processes form an aspect of this level where there is looked at the process between organizations on the same higher level (Yongchareon, liu, Yu, & Zhao, 2015). An example of this level of business process is for instance the managing of raw materials from suppliers. Organizational business processes require multiple operational business processes. (Mathias Weske, 2019). At this third level the activities and the relationship between these activities are specified (Mathias Weske, 2019). Operations are described by business process models, which show a graphical overview of the tasks performed, the relationships between them and the behaviour of a process (Mathias Weske, 2019) (Erasmus, Vanderfeesten, Traganos, & Grefen, 2020). Implemented business processes contain information regarding the execution of the process activities themselves, furthermore the technical and organizational environment is elaborated. The lowest level allows enactment of the process on organizational and/or technical platform (Mathias Weske, 2019). Overall, the first level needs to be determined in order to determine the level below that. Once the implemented business processes are determined and eventually realised, the operational level can be realised. By determining and realising the process at the lower levels along the set goals en strategies, long term objectives can be realised eventually.

2.1.2 Human-centric- and system-centric processes

Business processes can be further classified into human-centric and system-centric processes (Georgakopoulos, Hornick, & Sheth, 1995). This means that a process can be focused on human activities or tasks performed automatically by an information system. However, this classification can be specified further. Namely, a classification of business processes where there is made a distinction between type of interactions. A person-to-person (P2P), a person-to-application (P2A) or an application-to-application (A2A) process (Dumas, Van der Aalst, & Harry, 2005). P2P processes involve mostly humans. The process consists of human interaction and intervention (van der Aalst, 2013). There do exist tools that support P2P processes; however, these are not used for fully automated activities and are primarily used for interaction between actors supported by computers (van der Aalst, 2013). The opposite of a P2P process is an A2A process, these are processes where the activities of the operation are only performed by software systems (van der Aalst, 2013). These software systems act autonomously, without human involvement (van der Aalst, 2013). However, the most business processes can be appointed to the P2A category. People use software and where both are integrated in the processes. Moreover, it involves processes that allow for human only interaction as well as autonomously operating software which all contribute to the goals of the process (van der Aalst, 2013).

2.1.3 Lifecycle of business process management

Business process management has four key activities for managing the processes (van der Aalst, 2013). These are model, act, analyse and manage (van der Aalst, 2013). This means the BPM does not stop after a process is designed, once the process is designed, it should be implemented in the business. The implemented process should be analysed, to see whether improvements can be made or not. This needs to keep happening, because if circumstances change new problems might occur. Therefore, business process management is a continuous process that calls for continuous analysing and managing in order the create the optimal process (van der Aalst, 2013).

So, in BPM continuity plays a significant role. Therefore, managing processes has a cycle of activities which must be performed. All concepts of BPM can be assigned to a phase in lifecycles of BPM. The phases depend on each other and follow each other up in a logical way.

Weske describes a cycle with 4 steps, Design & Analysis, configuration, enactment and evaluation, the cycle can be seen in Figure 3. Whereas Van der Aalst describes a cycle of three steps, namely: (Re)design, implement/configure, run & adjust, this cycle can be seen in Figure 4.

This lifecycle allows for analysis to occur throughout phase one and three. Where a model-based analysis occurs at the design step and a data-based analysis takes place when in the running and adjusting phase. Weske has chosen to create an extra phase of evaluation, where process mining occurs. This can be seen as an overlap between BPM and data mining, using mined data for BPM. However, in general these lifecycles cover the same steps. First a problem must be identified, then the process should be looked into on an in-depth scale which is followed by the creation a process model. This model should be validated and verified before configuring it, which means it can be implemented after software selection and testing.

When the process is running, data should be gathered for analysis. As a result of this analysis a process can be redesigned or adjusted. Weske has implemented one extra aspect of the lifecycle. In the centre of the lifecycle administration and stakeholders are placed, these should cooperate to maintain BPM in a business and define a planning and strategy.

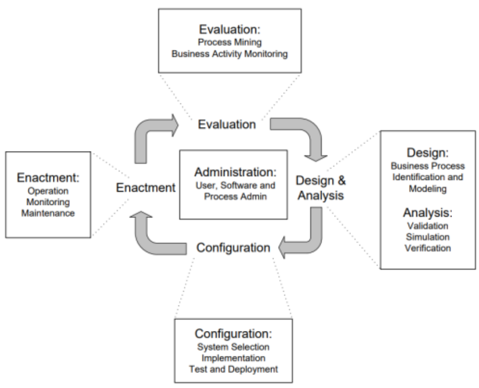

Figure 3: Lifecycle of BPM according to Weske (Weske, 2019)

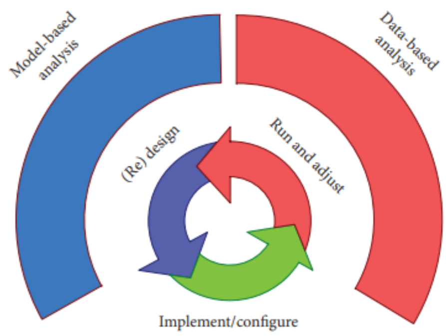

Figure 4: Lifecycle of BPM according to van der Aalst (van der Aalst, 2013)

A paper by Macedo de Morais, Kazan, Inês Dallavalle de Pádua, & Lucirton Costa from 2014, analysed the different BPM lifecycles and proposed a framework for choosing a suitable lifecycle. They analysed seven different lifecycles and showed their differences. As main frame for identifying shared phases between most of different lifecycles ABMPMP was used. This approach contains five phases namely: planning and strategy, analysis, design and modelling implementation, monitoring, control, and refining (European Association of Business Process Management, 2014). Most lifecycles for BPM check the middle boxes however some do stand out. They use steps to align their BPM with their strategy and planning as well as focusing on refinement of the process (Macedo de Morais, Kazan, Inês Dallavalle de Pádua, & Lucirton Costa, 2014). Weske for instances aligns the strategy to the BPM by involving stakeholders and administration.

Lifecycles are used to capture the essence of continuity of BPM and keep improving business processes on each level. In order to combine the different dimensions of business processes with the lifecycles a clear link towards the strategy of a business is important. Additions proposed by Burlton in a book from 2010 Vom brocke and Roseman can help (Vom Brocke & Rosemann, 2010). The most important of these additions are validation of the strategic directions, determining the relationship stakeholders have with one another and make a priority for changing processes with taking all stakeholders into account.

2.2 Concepts in business process modelling

There are many concepts in BPM, as mentioned before they can usually be fitted into a phase of the lifecycle. For this literature review, the broader concepts involving business process modelling will be reviewed so the choice of a modelling language is more substantiated. Modelling is an important factor in BPM, it creates clear overview of the process looks. It can be used to simulate processes and eventually make it better (Mathias Weske, 2019). Models can help identify inefficiencies and redundancies and eventually actors can eliminate those.

Conceptual models represent the concepts of a certain field. For these conceptual models there is a unified modelling language, which can show relationships between concepts in a certain field (Mathias Weske, 2019). While this is more abstract, other more specific models such as operational business process models exist as well. This means there are more levels on which models can be made. Each model describes the level below, the levels mentioned by Weske are Meta-object modelling, metamodeling and instance modelling (Weske, 2019). For the higher level models the unified modelling language is used, which is widely used in the modelling field (Weske, 2019).

Business process models specify process orchestrations. Process orchestrations provide detailed views on activities within a business and the constraints regarding execution. The activities are logically sequenced and a flow can occur. Several languages exist which can be used for process modelling on the operational level. More elaboration on these languages will be done further on in this literature review. However, some basics in business process modelling do exists and are called control flow patterns. These patterns return in the several modelling languages. Their biggest value comes from the fact that they can be reused (Butt & Fitch, 2021). They are used for developing and specifying workflows and they consist of different types of splits and joins (Butt & Fitch, 2021). These steps within a sequence flow form the basis of modelling languages.

Most business process models are made to sequence activities to facilitate analysis, improvement and enactment of business processes. However, there is a concept in BPM that can be added, namely: Business decision modelling (Mathias Weske, 2019). Business decision modelling focuses on the illustration and elaboration of decisions in business processes. The main additions that come with decision modelling are elaborations on how a decision is made, what data is used for decision making, what policies are considered when making the decision and who is responsible for the making of the decision (Mathias Weske, 2019). By using decision modelling notation this elaboration can be done graphically, thus increasing the knowledge that can be represented in a business process model. Decision modelling does not offer a resolution mechanism but instead provides a clear overview and representation of the decisions (Hasić & Vanthienen, 2019). Decision modelling becomes increasingly important in the field of BPM as is integrates well with the goal of process improvement.

Business process choreographies are created to investigate business-to-business collaborations and to create a better understanding of collaborative processes (Mathias Weske, 2019) (Meyer, Pufahl, Batoulis, Fahland, & Weske, 2015). Business choreographies describe how individual processes interact with each other, including information regarding the message flows between the processes (Meyer, Pufahl, Batoulis, Fahland, & Weske, 2015). Process choreographies can provide specifications on collaborations rules or agreements, it even can be used for setting up collaboration standards in industries (Mathias Weske, 2019). Setting up clear rules and standards is especially convenient for processes that (partly) consist of autonomously operating information systems, which perform a significant number of actions (Mathias Weske, 2019). Process choreographies can be expressed in several modelling languages just as orchestrations can (Mathias Weske, 2019).

2.3 Business process modelling languages

As mentioned before, business process models can be expressed in different languages with each of them having different properties (Weske, 2019). Therefore, there is a most suitable option for a goal of one's business process model. The languages have different graphical features, do sometimes overlap and can have synergies (zur Muehlen & Indulska, 2010). This subchapter covers the modelling languages for process orchestrations described by Weske (Weske, 2019). The languages will be introduced and their differences will be pointed out.

The first modelling language to be discussed is the use of Petri nets. Petri nets can be used for modelling both dynamic systems as static structures (Mathias Weske, 2019). The Petri nets itself explains the static structure of a process while the tokens that move through the model are used for making dynamic systems (Mathias Weske, 2019). Petri nets stand out from the rest on a mathematical perspective, since it can provide mathematical formalisation (Mathias Weske, 2019).

Event driven process chain (EPC) is the next language to be discussed. EPC focuses on the representation of the domain concepts and processes instead of information provision (Mathias Weske, 2019). As the name states, this language is useful for processes that occur after events. Actions occur after events have taken place. It stands out from the rest in its simplicity. The symbols are clear and there is not an overly broad spectrum of types of splits and joins (Mathias Weske, 2019). It is developed as part of the ARIS framework, which also covers other levels of abstraction regarding organisational business processes and strategies (Mathias Weske, 2019) (Guizani & Ghannouchi, 2021).

Yet another workflow language (YAWL) is a language that has been purely designed to support the control flow patterns (Ter Hofstede, Van der Aalst, Adams, & Russell, 2014) (Mathias Weske, 2019). YAWL is a state transition diagram like Petri nets; however, YAWL covers the duration of the activities in the process where Petri nets do not (Mathias Weske, 2019). YAWL also is more specific on the types or joins and splits (Ter Hofstede, Van der Aalst, Adams, & Russell, 2014). However, it has little constructs and is therefore easily understood (Ter Hofstede, Van der Aalst, Adams, & Russell, 2014).

Graph based workflow languages are similar languages that are useful for processes that make intensively use of software systems (Mathias Weske, 2019). Procedures performed software systems can be clearly graphed, both the input and output parameters can be depicted (Mathias Weske, 2019). This also means that data flows can be well described, since output parameters can be linked to activities that follow. However, this language does have limitations when it comes to advanced workflow patterns and cyclic process models (Mathias Weske, 2019).

Business process model and notation (BPMN) is a very extensive language, with loads of constructs. It allows for easy distinction between sections of the models by introducing pools and lanes (Mathias Weske, 2019). BPMN is a notation with the goal of removing communication gaps amongst several stakeholders with different backgrounds (Trienekens, Kusters, Balla, & Kelemen, 2013). Data objects and message flows can also be well expressed in this language (Mathias Weske, 2019). However, the extensity means it is a hard language to master. For instance, there are many types of splits and joins and types of events, with each another symbol. This means that is also not immediately clear how the process precisely looks. Furthermore, it is seen that often text is written next to these models to express the models better, this is because it has so many options that clarity must be provided sometimes (Guizani & Ghannouchi, 2021). These texts can raise problems regarding consistency and reusability (Guizani & Ghannouchi, 2021).

For providing a clear overview about the differences between the languages, they should be compared and the most suitable one will be selected. For selecting the criteria which are used for comparison, three articles were used (Trienekens, Kusters, Balla, & Zador Daniel Kelemen, 2013) (Pereira & Silva, 2016) (Guizani & Ghannouchi, 2021). These articles present frameworks with criteria and a combination of the criteria mentioned here are used. The criteria are (1) readability, so it is clear for stakeholders, (2) ease of learning, so learning the language does not take up too much time. The third criterion is flexibility, which means that models can be adjusted easily without putting an unnecessary amount of effort into it. The fourth criterion is tool support, which means whether software for designing the models is accessible. The fifth criterion is the coverage of process elements, this mentions whether the language is extensive or not. Extensive language can cover more various types of processes (Trienekens, Kusters, Balla & Kelemen, 2013) (Guizani & Ghannouchi, 2021) (Pereira & Silva, 2016). Table 1 shows how each language scores on each criterion. The scores come forth from personal evaluation based on statements made in the literature (Weske, 2019), (van der Aalst, 2013).

Table 2: Scores of different business process modelling languages on 5 criteria

	Readability	**Ease of learning**	**Flexibility**	**Coverage of process elements**	**Software support**
Petri nets	Clear and simple model that is easy to read for all background.	Due to its simplicity, it is easy to learn.	Small adjustments can be made easily. Hence a good flexibility.	Poor since data flows from and to software systems and no duration of activities is specified.	Good amount of modelling tools.
EPC	Clear language that has good readability due to its simplicity.	Quite easy language to learn due to its simplicity.	Medium flexibility, since based on events. This causes the fact that these events cannot move much.	Covers most elements of the process, however not suitable for non-human interpretation. Furthermore, cyclic sequences cannot be covered.	Support is limited since it is part of ARIS family.
Graph-based workflow languages	Can provide unclear overviews that require in-depth reading. Since in- and output numbers are listed, readability can be hard.	Does not make use of standard patterns therefore hard to learn in comparison to other languages.	Flexibility is difficult when modelling with software systems, since the in- and output values cause a more fixed model.	Especially useful for processes with software systems, data dependencies can be clearly graphed.	Enough tools are available since it does not require many special constructs/symbols.
YAWL	Familiar concepts to most people cause good readability.	Medium difficulty, due to complex synthetics. Regular flow is not difficult to learn.	Medium good flexibility, more changes need to occur in comparison with petri nets.	More specifications than petri nets, however not suitable for processes with transactional software systems. Medium score.	Open-source software, but few options.
BPMN	Good readability for stakeholders with different backgrounds. More difficult to read for people without pre knowledge.	Due to extensiveness, it is medium difficult.	Medium to good flexibility due to its extensiveness.	Due to versatility, it covers many elements of processes. Good for use of data and message flows.	Large base of software to support this language.

The BPMN language is deemed most suitable since it can model data flows and messages well in combination with de modelling of process flows. Furthermore, it is fairly easy to understand and plenty of tools are available. These criteria are deemed more important since they have more effect on the results of the model. The second and third criterion have more effect on the creation of the models and even though using BPMN makes it more difficult to learn and to make changes, the difficulty in comparison to other languages is not deemed an obstacle.

2.4 The use of business process management in this research

BPM is an important part of this research, it was used mostly for problem identification, problem description and for implementation. The literature study was performed to find out what the most important concepts and constructs of BPM are and to find out the differences between modelling languages. BPM is very suitable for gaining knowledge and insight about business processes and has the aim to improve these processes. Since this research focuses on a business process and improving the process and making it more efficient, BPM is used as backbone of this research. From all the constructs and concepts in BPM, this study focuses on operational business processes. Since the process that involves the problem is also an operational business process, that only concerns employees of TenCate. Furthermore, the problem can be classified as a P2A business process with both human and software involvement. To gain insights in solely the activities that occur, the message flows and the roles that databases play in the process, orchestration models are the best models to design. Several languages exist for designing these models, the BPMN language was defined as the most suitable language to provide insight on the scheduling process of TenCate. It is a very extensive language, which can be understood by the supervisors from both the university as TenCate. Furthermore, there are plenty of tools to model in. BPMN also has the possibilities for modelling databases, which is necessary for modelling the scheduling process. For all of these reasons BPMN will be used in this thesis to model the scheduling processes.

3. Current processes of TenCate

In this chapter the transfer of data between employees and the current scheduling process of TenCate will be described. This chapter will provide the answers for the following research questions:

1. *What information is essential for the production order planning/schedules?*
    a. *What data that is used for Excel is drawn from SAP?*
    b. *What data is transferred from the scheduler to the heads of the departments*
2. *What is the main cause of the scheduling process and the process of administration after production being so time consuming?*
    a. *What does the scheduling processes look like?*
    b. *How do the processes of administration after production is finished look like?*
    c. *What is the main root cause for the extensive amount of time spent on administration?*

The description is supported with business process diagrams of different processes. These process diagrams visualise the process and should make the linkage between the actors, software programmes and databases.

However, in order to understand how and where the scheduling process fits into TenCate, a larger view at the activities of TenCate is necessary, therefore the core business of TenCate is described first. At the end of the chapter the root cause of the problem is formulated to specify what part of the processes the possible solutions must address to improve these processes.

3.1 Core business of TenCate

TenCate Geosynthetics produces woven and non-woven synthetics used for civil purposes. The largest part of the factory is used for woven fabrics. There is also the part where Geotubes are made at the construction part of the factory. Trucks with yarn come to the plant, to deliver the raw materials. Most of these materials are threads and yarn. These materials are warped before the weaving process can begin. After that the materials are set up either on creels, which go directly behind the machine, or on looms. This must be done before the weaving process can begin. From there the creels and looms go to the weaving machines where the threads and yarn need to be set up for the machine. Setting up the creels takes up several days, so these machines have a significant change over time. At this point the weaving process begins. The x large machines that use creels can run op to several months for one order, the machines that use looms have smaller running times for one order. The orders usually exist of many rolls of the woven synthetics. Once a roll is finished it goes to the inventory.

TenCate sells from their inventory, so production is used to keep the inventory levels between a minimum and maximum level. Form this information it can be concluded that TenCate uses a make-to-stock model. When an order from a client comes in, the scheduler checks whether enough inventory is left after the order is shipped. The construction part of the factory uses material from inventory and sew woven materials, to form for instance Geotubes. These are large tubes that are used for dewatering or marine structure construction and erosion control. It should be mentioned that the construction department also uses material that is delivered straight from other companies. As mentioned before, the products leave the plant from the finished product inventory.

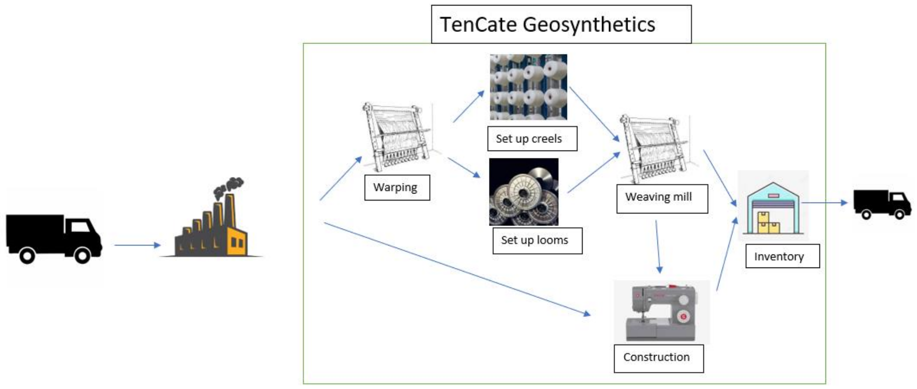

Figure 5: Visual representation of core business of TenCate

Figure 5, showed above, describes the main business process of TenCate Geosynthetics. The scheduling process which is described in-depth in this chapter starts when the raw materials have arrived. The schedules show the order of production, this includes the preparation part of the production. These schedules are based mostly on the demand and the inventory levels of both the raw materials and the finished products. The schedules are used throughout the production floor, they are communicated with the employees via various ways. In the next part of this chapter the process of scheduling orders will be reviewed.

3.2 Overview of different schedules

Scheduling is an important part of a production company such as TenCate. Due to the different types of machines and products used by TenCate, the company works with different schedules to inform the production floor what products should be made when and on what machines. These schedules are made and updated every day by the scheduler. Updates include new orders, adjusting the order of production and changing the machine for an order.

TenCate has multiple divisions/areas where a production process occurs. For each division/area a separate schedule is made, in order to inform the team leaders what needs to be done. Each process starts with an incoming order from a client, the sales department of TenCate then communicates this with the scheduler. The scheduler then checks the inventory level to determine whether production is necessary after shipment of the order. The scheduler checks if there is enough safety stock left after selling, since almost all the products of TenCate are sold from inventory. If this is not the case, the production process starts. Every production process starts with the scheduler, who enters the order in SAP. From that point the production process is different for every type of product sold by TenCate.

As mentioned before TenCate Geosynthetics has two different production floors. The construction part and the weaving mill, both of these parts use different schedules. The weaving mill also has an element where the weaving preparation occurs. This requires a separate production schedule.

So, the scheduling process of TenCate can be split up into multiple scheduling processes. For every schedule there is a different Excel file, which the scheduler works in. The scheduler works in this file with the head of the specific part of the factory. In general, the scheduler enters his schedule first in SAP and then puts it in the Excel file. These Excel files are used to make create a clear overview for the employees, as well as an information source between the production and the scheduler. At the construction part and the weaving preparation part the operators fill in printed sheets when working, at the end of the shift they deliver the sheet with remarks about their shift and the running times. The head of the two departments then fill in this information in the Excel sheet for the scheduler to see. The weaving mill uses a loom data monitoring system to see the running times of the machines, the leader of each shift fills this data in the Excel file of this system. This system gathers the data of the machines and monitors when they are running and when they are not.

So, in general the first workorders are entered in SAP by the scheduler, followed entering them in Excel as well. These Excel files allow for easier communication easier due to its interface, which is clearer for the employees that work in production. The Excel files contain databases imported from SAP, where specifications of orders are listed. These files also function as a mean of communication between the production floor and the scheduler. SAP is used for communication throughout the company, every order is entered in SAP and the orders are also signed up and finished in SAP.

The three Excel files that are used by the scheduler are the Weekly planning of the weaving mill, the warping planning for the weaving preparation and the construction schedule for the construction department. These are the most important scheduling processes of TenCate, of which a business process diagram is made in respectively Figures 6 and 7. Looking at the larger differences between these schedules, three main factors cause that these schedules are different. The scheduling horizon, the volatility of the schedule and the fact whether the schedule is based on machines or employees, an overview of this can be seen in Table 2. The schedule horizon shows how far ahead schedules are made. Good forecasting is crucial when scheduling far ahead. The other factor is volatility, a volatile schedule means that the order of production can change easily. This means the schedule is reviewed and changed more often, which requires good communication. The last factor has to do with the basis of the schedule, a machine-based planning means that the orders are appointed to a machine. Each machine has its own order of production. Some machines are the same, which means a change in the schedule can also mean that an order needs to be produced on a different machine. These scheduled are made first in SAP. A person-based schedule focuses on the availability of employees instead of machines. So, an order can be produced whenever employees are available. It is difficult to make a schedule based on person in SAP, therefore person-based schedules are made in Excel at TenCate Geosynthetics. An overview of the schedules and their characteristics is show.

	Weaving mill	Construction	Warping
Schedule horizon	6 to 12 months	5-6 weeks	6 to 12 months
Volatility of schedule	Low volatility	Medium volatility	Medium volatility
Machine or person based	Machine	Person	Machine

Table 3: Characteristics of different schedules

3.2.1 The use of data in the scheduling process

This subchapter describes how data is used in TenCate. It provides an overview on what data and information is used by whom, why that specific data is used and the method of transference of that data and information.

3.2.1.1 The use of data

In the scheduling process a lot of data is transferred between actors. This data is generated, used and transferred on a daily basis. During the process multiple databases are used. The largest databases are located in SAP. The inventory levels, the norm for the hours of working time and the bill of materials are the most important databases for the scheduling process, according to scheduler. The work preparer fills the databases in SAP, the bill of materials for every product is made together with a norm for the amount of hours production should take. These databases are transferred to the Excel files, in order to have an efficient Excel file. The inventory levels are all maintained in SAP and modules that are connected to SAP. The raw material inventory levels are adjusted whenever an order is produced, this is done by the heads of the department.

3.2.1.2 Data in Excel transfer

In excel data is transferred by adding numbers and remarks in shared excel files, which can be found on a locally hosted server of TenCate. Each actor has its own tasks in the excel files. This will be discussed more in detail in paragraph: 3.2.3 In the Excel files the progress of the order is shown by the use of colour coding.

The text of the orders is either red, blue or black. Red means that the preparation of the order is not ready, so it cannot be produced yet. If the text is blue, all the preparations have been made and a start can be made to produce the order. The black colour shows that production is finished. This is one of the methods of keeping the scheduler up to date of what is happening with at the production floor. Remarks and comments about the order can also be placed in these files. These comments can tell for example whether an irregularity with production has occurred or what type of changeover is coming up. Furthermore, the files show the order of scheduling, the place or machines where the product should be produced as well as specifications such as size and material type.

3.2.1.3 Data in SAP transfer

Data in SAP is transferred by actors changing items in the system. The ERP-system is interconnected throughout the company. The ERP-system is therefore very convenient for data transferring. When zooming in on the scheduling processes, SAP is used to adjust the inventory levels. It is also used to create orders in the system, this is done by the scheduler so others can see that the order must be made. The heads of de departments then can apply the order for beginning of production. They also mention if one is ready in SAP. For the weaving mill, there is a scale where the finished products are scanned. This is automatically registered in SAP, this way there can be measured how many rolls are produced, this way SAP can calculate how long the order will take to finish. The database filled by the work preparer tells the scheduler how long it takes for one product to be finished.

3.2.1.4 Personal data transfer

The scheduler goes over the schedules on a daily basis with the heads of the departments. In these meetings problems on both the production floor and the sales division are discussed. Most important topic is the order of production, answering the question whether priorities are changed or not. These meetings are a straightforward way of communication between the actors at TenCate.

The distinct types of data along with the different methods of transferring the data is listed below in Table 4. All data transfer includes mostly quantitative data (sizes, amount and time it takes to produce and the article numbers) and some qualitative data (Comments about the specifications)

Platform	Purpose	Method	Who
Excel	Communicate schedules to head of the departments	Sharing Excel sheets, with the schedule with colour coding and comments	Schedulers shares the schedules with the head of the production departments
SAP	Keeping track of the inventory and upcoming demand as well as production times.	Interconnected ERP system, where people from different departments at Ten Cate work in.	Salespeople give the upcoming demand; the scheduler provides long time schedules and the work preparer provides production times.
Personal	Sharing details about production and sharing changes in priority.	In person meetings	Scheduler with head of production departments

Table 4: Methods of data transference

Table 4 provides an overview on how data transfer occurs, by who and why it is done. These factors are needed to gain insight on what the employees need to make the schedules and to see how the employees use the software. Furthermore, it shows what information employees interchange without the use of software, this if often a time-consuming way of information transfer. This information is necessary to make the business process models and map the use of the software applications in these models.

3.3. Business process models

This subchapter elaborates on three scheduling processes and shows business process models to support this elaboration.

3.3.1. Weekly planning

The schedule for the weaving mill is made per week in Excel, this schedule is called the weekly planning. The process of scheduling for the weaving mill is mapped in Figure 6, larger images of the process can be found in the Appendix. It starts with the sales department receiving an order. They pass this on to the scheduler who checks whether there is enough inventory left after shipment. If an order needs to be made, is starts in SAP. The scheduler begins scheduling in SAP and then copies this schedule to Excel. SAP calculates how long each order should take, based on the specifications such as type of material and time it takes to produce which are filled in by the work preparer. This way the scheduler can also see on what day the next order comes up.

The scheduler schedules per machine, meaning there is a priority order per machine. However, an order can be replaced on another machine if it needs to be produced sooner. When the scheduler enters the schedule in the Excel file, a daily schedule forms itself via VLOOKUP's. The team leaders of each shift then print out the daily schedules for the operators. The operators fill out remarks and/or irregularities on paper. The team leaders then enter these remarks in the Excel sheets. The running time of the machines in the weaving mill are kept track by a loom system. It shows how long a machine has been running. The team leaders enter this information in the Excel sheets. This information is useful for the scheduler and the production manager. Structural problems can be detected and it can be easily detected where delays occurred. This information can help improve the process. The business process model also depicts the connection between the weaving mill and the warping part of TenCate (See Figure 7). Since every product that gets weaved also needs to get warped. It shows from where the warping process gets input from the weaving mill scheduling process. The warping scheduling process is elaborated and depicted in Figure 8.

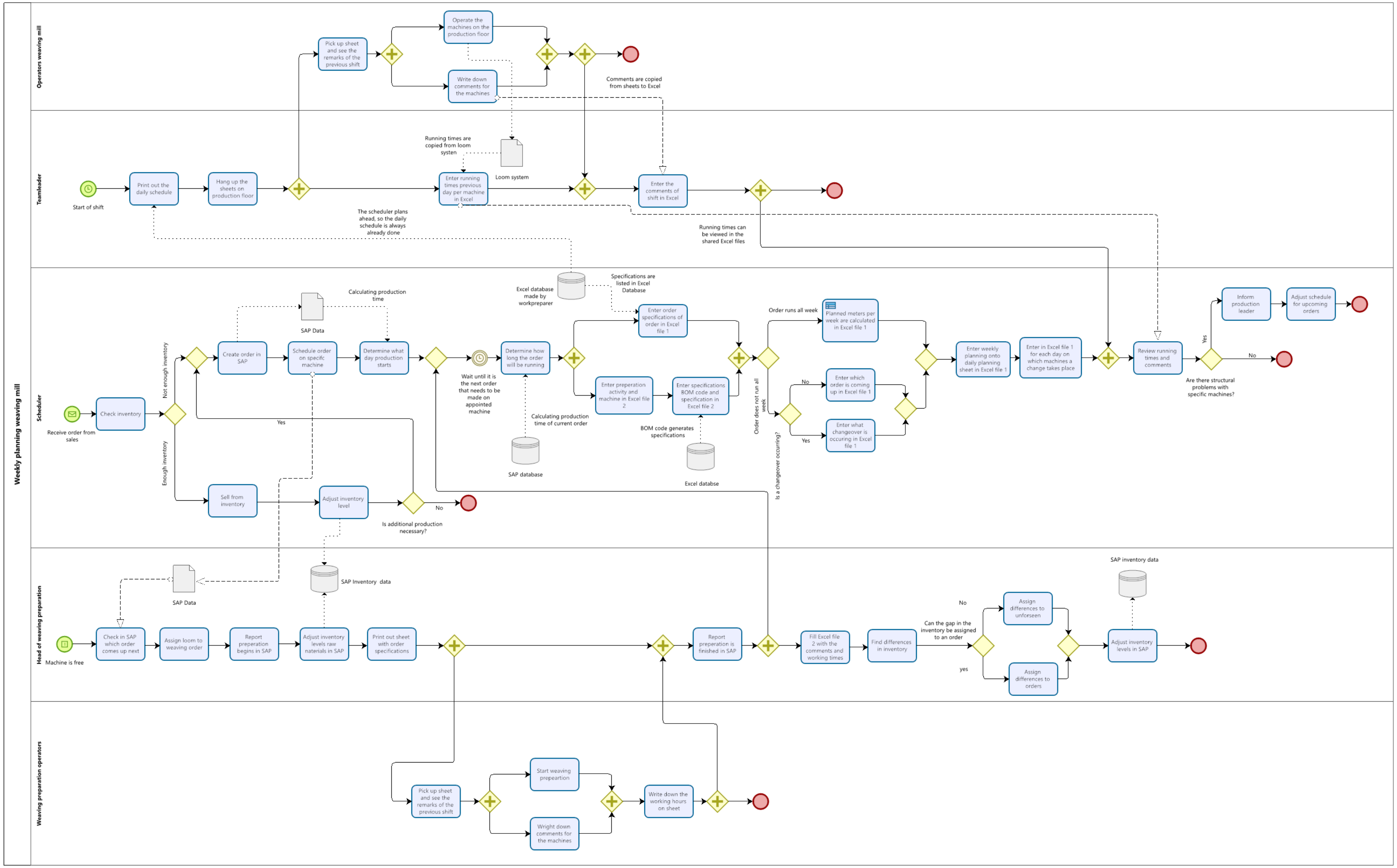

Figure 6: BPMN of weekly planning scheduling process

3.3.2. Construction

The construction schedule is different than the other schedules, since this schedule is person based instead of machine based. This means employees should be available for an order to be scheduled. The construction site has 5 areas where production can occur. Three of these five are large and require two employees, the other two require one employee. Previous methods were tried to make the schedule in SAP, however these all failed. Therefore, the orders are created in SAP, but the schedule is made in Excel. This means more is done within the Excel sheet in comparison to the other schedules. However, the orders are created in SAP and the orders are marked as ready to start and finished in SAP. These last two actions are performed by the head of the construction department. The schedule of the construction site is more volatile, so the schedule is changed more often. Reasons for this can be a change of priority changes occurring due to information from the sales department, a shortage of employees or shortage of materials. This volatility causes the fact that this schedule is reviewed more often than the schedule of the weaving mill. The head of construction delivers the orders to the construction floor in a printed sheet. The operators fill these sheets in, make remarks and time how long the order took to make. The head of construction enters this data in excel for the scheduler. Furthermore, the same colour coding system in excel as the weaving mail schedule is used in this schedule. After that the specifications are also entered in SAP and the inventory levels are adjusted in SAP. The business process diagram can be seen below in Figure 7.

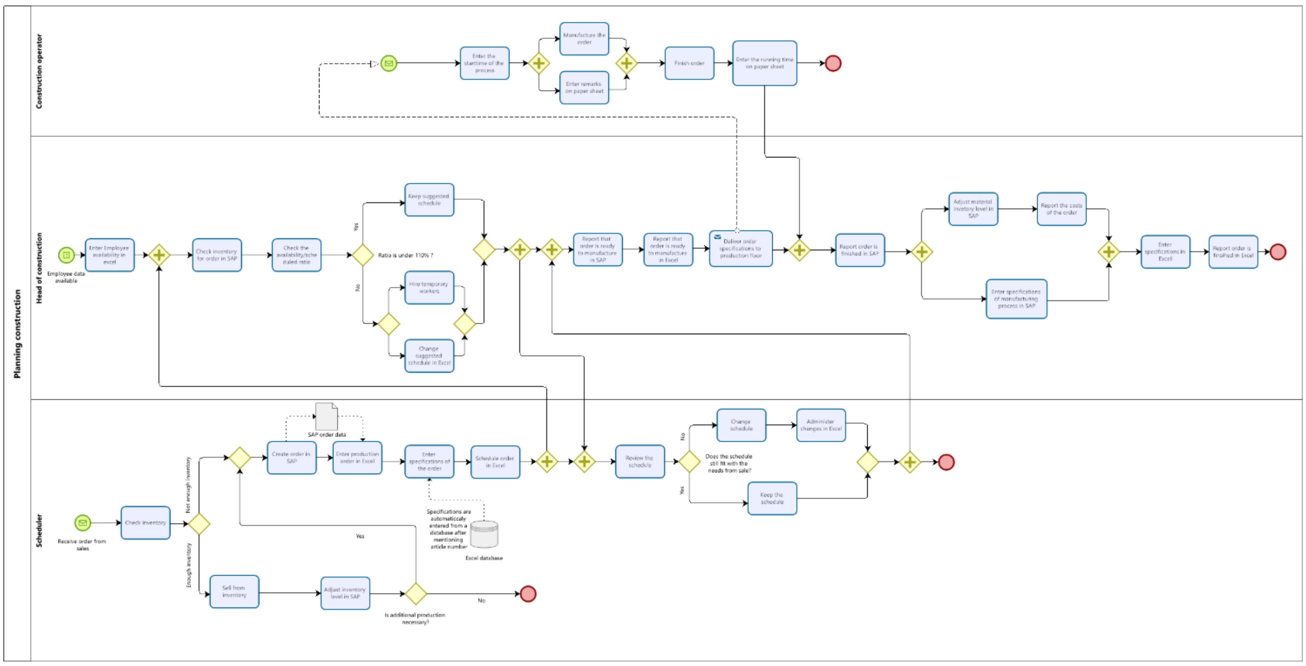

Figure 7: BPMN of construction scheduling process

3.3.3. The warping planning

The schedule for warping is machine based since the warping is performed on machines (See Table 3). Preparation means to properly arrange the yarns before weaving can start. Since this schedule is machine based, the scheduling process starts in SAP. The schedule similarly volatile as the construction part. The head of the weaving preparation part does the same actions in SAP, such as marking an order ready to produce, marking it as finished and adjusting the inventory levels. The priority schedule is mostly communicated via SAP. The scheduler determines the priorities, which have to do with the weaving mill priorities, since the warping occurs before the weaving. He also enters the order of priority in the excel for the set-up schedule after production is finished, this excel is used for communication between the employees.

The head of the warping department assign beams to orders in SAP, so make sure every beam is retraceable. This process has the same comments and feedback from the operators as the other processes. In Figure 8 the BPMN of the warping scheduling process is depicted.

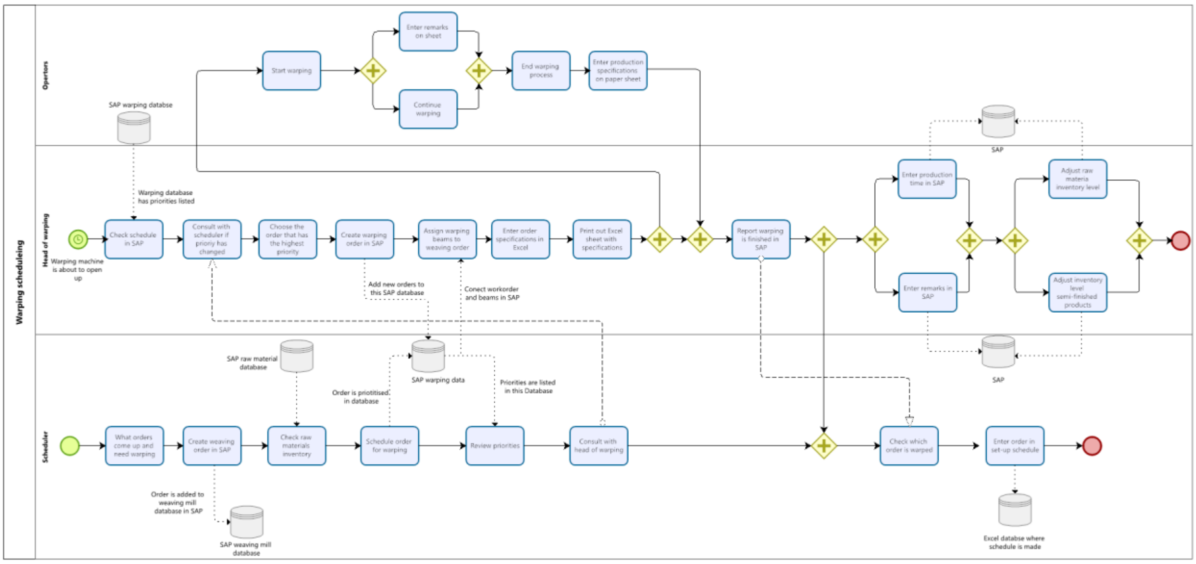

Figure 8: BPMN of warping scheduling process

3.4. Identification of the root cause

The business process models presented in Chapter 3.3 help understanding the scheduling process and can help identifying possible root causes. For the identification of actual the root cause, a cause-and-effect diagram (CED), also known as a fishbone diagram, is used to find out the different potential problems of the scheduling process. Where the process models can identify inefficient factors in the process, a CED can provide a clear visual representation of the connection between these inefficient factors and the core problem. Therefore, it helps finding the root cause of the main problem: too much time is spent on administrative actions. The identification of the root cause shows what part of the scheduling process needs to be changed by the potential solution.

3.4.1. Cause-and-effect diagram

As mentioned, the identification will occur via a cause-effect diagram, this can the method used to find the cause of the core problem. The problem cluster in Chapter 1 was used to find the core problem. The business process models mapped the scheduling processes at TenCate to create an understanding about these processes. Furthermore, the models can help to identify possible root causes. The cause-and-effect diagram (CED) can help sort the root causes of the problem found in Chapter 1. The relationship between a given problem and the factors that can influence this problem are graphically illustrated. (Ahmed & Ahmad, 2011) This method focuses on the content of the problem without taking history and personal interests into account (Doggett, 2005). According to Doggett there are three main tools for root cause selection, the Cause-and-effect diagram, the interrelationship diagram and the current reality tree (Doggett, 2005). After consulting the proposed framework by Doggett (Doggett, 2005), the CED was chosen as method for this thesis. The reason for this is the extensive knowledge on the problem, found by making the business process models. The business process models helped understanding the process as well as understanding the problem. For creating a CED extensive knowledge in required according to Doggett (Doggett, 2005). The CED was created by analysing both the business process models made in Chapter 3.3 and the Excel files and discussing those with employees from TenCate.

Furthermore, the input gathered from interviews with the employees of TenCate helped to create the CED as well, since they pointed out what their problems with the process where. They all experienced different problems, not always matching. However, after discussions they could see that their problem would fit under one of the 4 possible root causes. Figure 9 presents the cause-and-effect diagram.

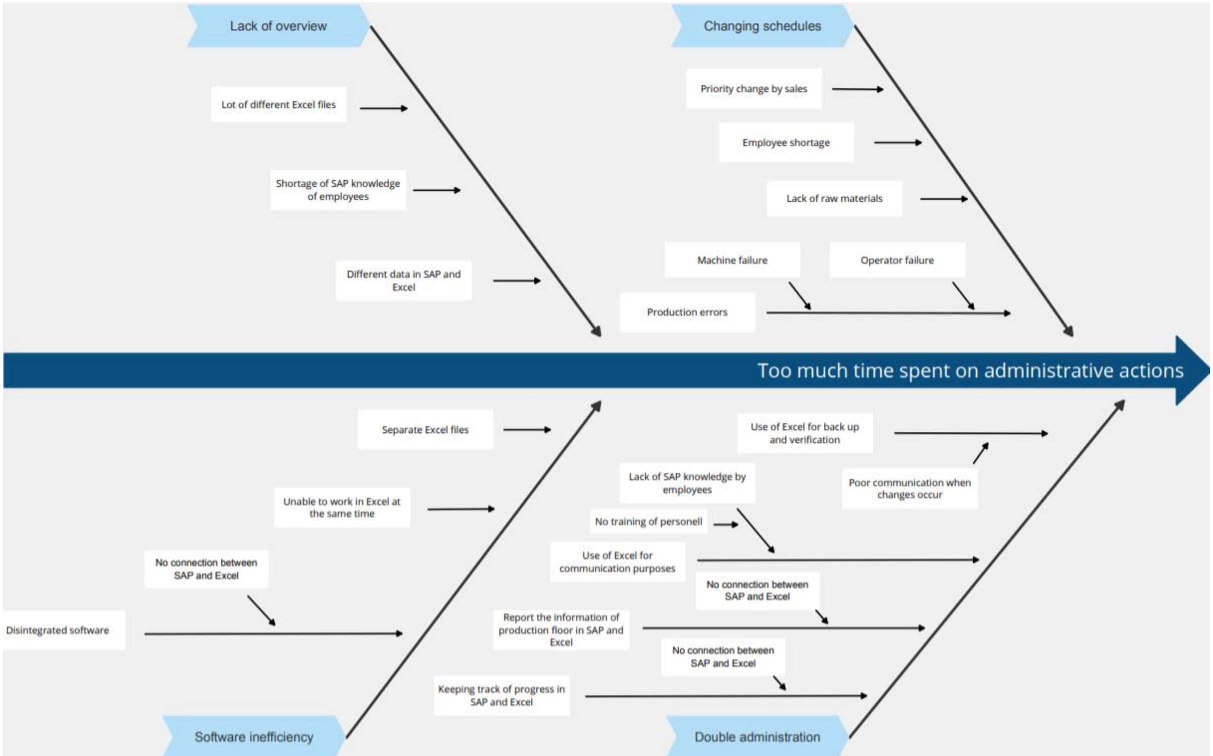

Figure 9: Cause-and-effect diagram

3.4.2. Possible root causes

There are four main areas which eventually lead to the abundancy of time spent on administrative actions. These areas are causes of the problem, each cause has sub causes, which can have a sub cause as well. These are all described in the cause-and-effect diagram above. The four main areas are the inefficiency of the software, the lack of overview, the changing of the schedules and the double administration of data. In the next paragraph, the causality between the area and the problem will be briefly described.

The software inefficiency of TenCate comes forth from the two programmes that are used, which are SAP and Excel. Since these are not interconnected, the systems must be maintained separately. Furthermore, the excel files are also not integrated, meaning multiple Excel files are used at the scheduling process. These inefficiencies cause more administrative actions done by the employees. Databases need to be transferred from SAP to Excel and employees get information from one file and use that for other files. The use of two software programs also brings along other problems, described in the next Alinea.

Data is stored in separate locations, the Excel files and SAP. This causes a lack of overview for the employees, resulting in extra documentation of data in new Excel files.

Employees like to have a document for their own, to increase their overview, which results in more time spending on the administration of the processes. The scheduler has a proper overview of what occurs; however, he needs to elaborate on this overview many times and needs to document this elaboration.

SAP can provide a good overview however it is difficult software to understand, therefore employees cannot us it properly, meaning extra Excel files, which all require additional administration, must provide the overview. All these reasons lead to more time spend on administrative actions.

As can be seen in the CED in Figure 9, a lot of sub causes exist that lead to double administration of data. Multiple reasons exist for this double administration. Double administration leads to extra time spent on administrative actions, since the employees must do more administration.

The double administration means that data is stored in both SAP and Excel or sometimes in two separate Excel files. The reasons for this vary from, verification, lack of SAP knowledge to communication. Furthermore, double administration is also the separation of different tasks that can be combined into one action. Even though this is not copying the data exactly it is entering linked data twice in the same file, while it is possible to do it in one time. However, administration in two systems causes extra work as does administrating data that can be linked to each other twice, meaning the employees spend more time on administrative actions.

Whenever schedules change, due to various reasons, the listed schedules need to change as well. So, whenever schedules change more often, more administration work is required. The priorities might need to be adjusted, sometimes new machines or personnel needs to be appointed to an order. So, these changes causes adjusting of the schedules in SAP and Excel, these adjustments cost time. The changes in the schedule can occur due to a change of priorities ordered by the sales department, machine failure, human errors of the employees, a shortage of employees or a shortage of raw materials. Most of these causes lie outside of the scheduling process and ask for complex solutions.

3.4.3. Selection and elaboration of the root cause

In this research the cause of double administration will be tackled to reduce the time spent on administrative actions. This area as root cause is chosen for three reasons. First of all, this is an area which can have a considerable influence on the core problem. To see where in the scheduling processes the double administration occurs, circles have been drawn around the business process models of the weekly planning and the construction schedules. This is shown in Figures 10 and 11, in the legends below the figures all the circles are elaborated. When circles do have the same colour, they either administrate the same data or the administration can be covered into one action. The legends below the figures show what type of action is double. The tables also tell how much time, spent on the administration, the elimination of double actions can reduce. The second reason is the fact that the other areas require more complex solutions, throughout the whole company. These complex and broad solutions are outside the scope of this study. For instance, the changing schedules require solutions that could come from areas such as the sales department, employee hiring strategy and machine maintenance. Using these types of solutions would mean that more assumptions had to be made. After consultation with the production manager, the decision was made to focus on scheduling process itself since this would mean less assumptions have to be made, increasing the chance of actual reduction being achieved. Therefore, the cause that will be handled in this research is the area of double administration. The third reason this cause will be tackled is since it has interrelationships with the other areas. As can be seen in the CED in Figure 9, the lack of connection between SAP and Excel is placed under software inefficiency as well as the double administration area.

As mentioned before employees use extra files, which means double administration, for their own verification and to fill up the lack of overview. If the schedule needs changing and the changes need to be administered in multiple places, the changes will once again cost administration time. These interrelations between the areas are the third reason for choosing double administration as root cause for the core problem.

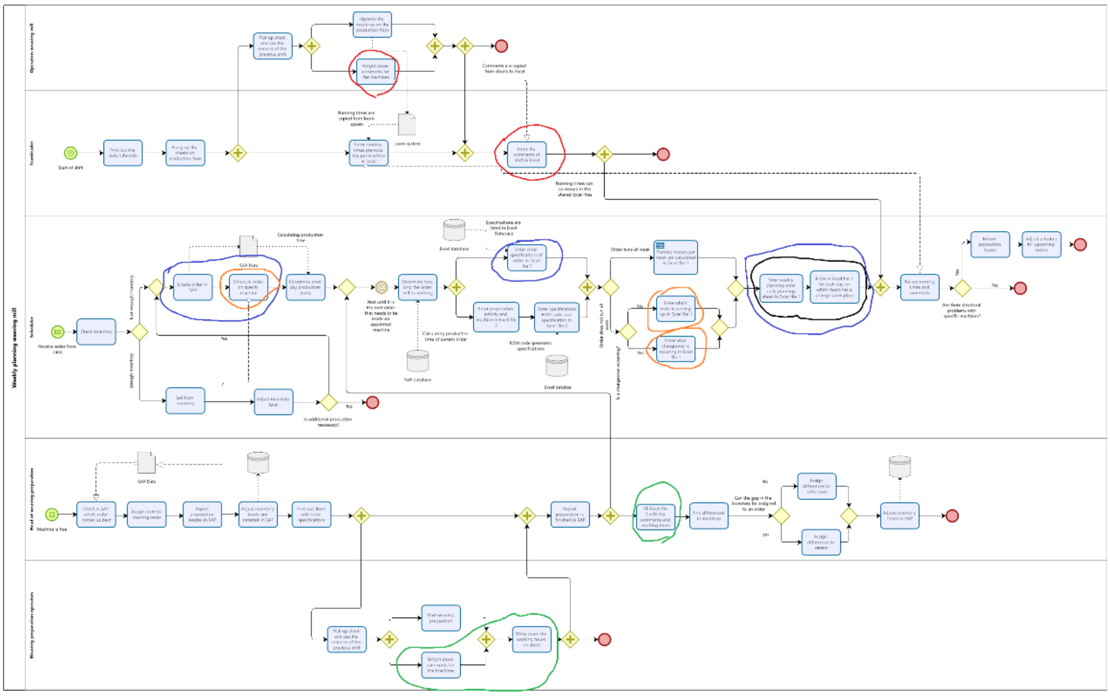

Figure 10: Double administration in BPMN of weekly planning scheduling process

Table 5: Legend of Figure 10

Colour	Type of double administration	Amount of time reduction when double administration would be reduced
Black	These actions all handle with translating a weekly planning to a daily planning order in Excel. These can be combined into one action.	2 minutes per step, with 2 steps turning into 1 this would save 2 minutes per production order.
Blue	These actions all administrate the same production specifications in separate places. The activities in the most left circle administer in SAP, the activities in the other two circles administer the same data in Excel.	3 minutes per step, with 5 steps turning into 2 this would save 9 minutes per production order.
Orange	The activities handle administrations of the changeovers. The activity in the left circle covers this in SAP, both the activities on the right covers this in Excel.	2 minutes per step, with 3 steps turned into 1 this would save 4 minutes per production order.
Green	These actions both mark the same order as finished in two different systems namely Excel and SAP.	3 minutes per step, with 3 steps turning into 1 this would save 6 minutes per production order.
Red	These activities cover the same production specifications, the one on paper the other on Excel.	2 minutes per step with 2 steps turning into 1 this would save 2 minutes per production order.

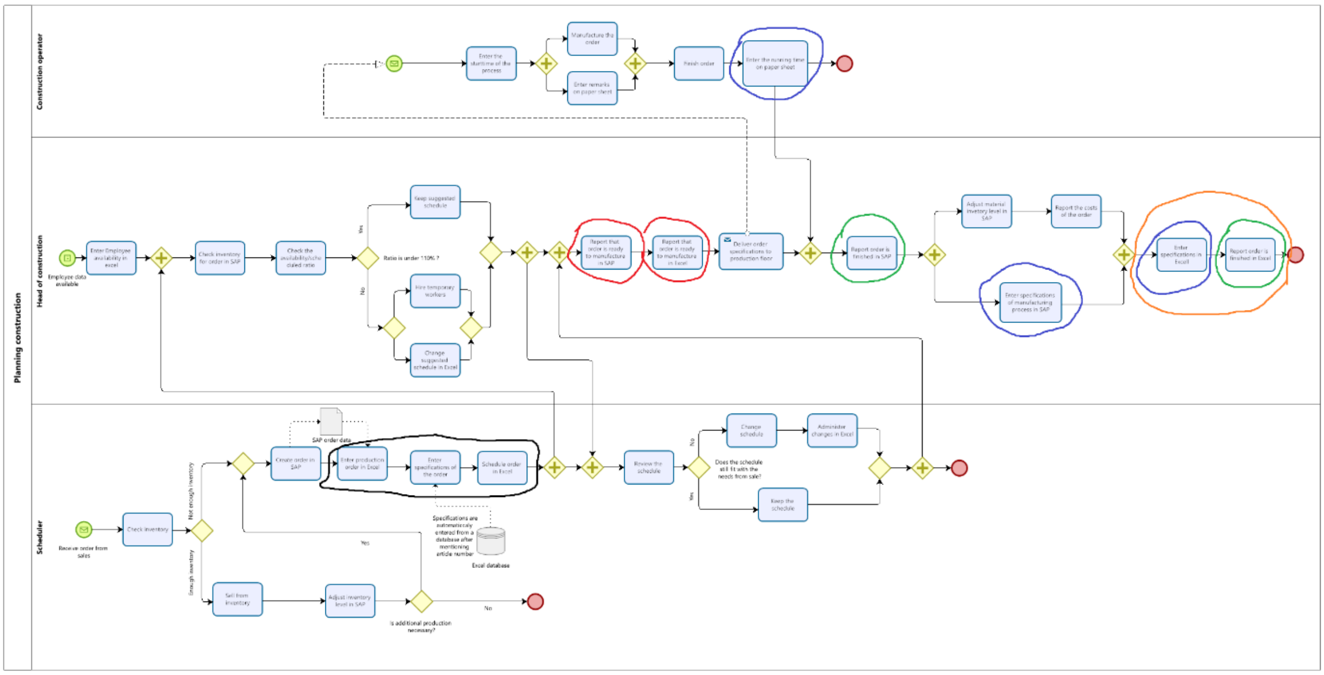

Figure 11: Double administration in BPMN of the construction scheduling process

Table 6: Legend of Figure 11

Colour	Type of double administration	Amount of time reduction when double administration would be reduced
Black	These actions all handle with entering the complete order in Excel. These can be combined into one action.	2 minutes per step, with 3 steps turning into 1 this would save 4 minutes per production order.
Blue	These actions all administrate the same production specifications in separate places. (Paper, SAP, Excel)	3 minutes per step, with 3 steps turning into 1 this would save 6 minutes per production order.
Orange	These actions can be combined into one action since the order is finished if production specifications are entered in Excel.	3 minutes per step, with 2 steps turned into 1 this would save 3 minutes per production order.
Green	These actions both mark the same order as finished in two different systems namely Excel and SAP.	3 minutes per step, with 2 steps turning into 1 this would save 3 minutes per production order.
Red	These actions both mark the same order as ready to produce in two different system namely Excel and SAP.	2 minutes per step with 2 steps turning into 1 this would save 2 minutes per production order.

As shown in Figures 10 and 11, double administration occurs multiple times in this process. The legend describes what is done for each circled step in the process. If two steps have the same colour this means they represent the same notation of data in a different location. On average in both figures 30% of the steps have a circle around them and are thus some form of double administration in the process. The legends show estimations on how much time per production order is saved. These were based on meetings with the scheduler of TenCate, testing the excel files and observing the scheduler when performing the task. With on average 4 new orders each week for the weekly planning and 15 for the construction site, the new solution will save an estimated 92 minutes per week for the weekly planning and minutes per week 306 minutes per week for the construction planning. Which means an estimated decrease of approximately 6.5 man hours per week of the time spend on administration if the double administration is eliminated of the scheduling process. This would mean the employees will spend 25.5 hours on administration, which is a decrease of 20% in comparison with the reality of 32 hours described in Chapter 1.3.2.

However, it should be noted that in this scenario only the elimination of the double administration steps is measured and that it is unlikely that the scheduling process will not change in other ways when these steps are eliminated. To discover a more realistic image a solution and implementation strategy should be researched. This is done in respectively Chapters 4 and 6.

3.5. Conclusion

This chapter has provided the answers to the following research questions, namely:

- *What information is essential for the production order planning/schedules?*
    a. *What data that is used for Excel is drawn from SAP?*
    b. *What data is transferred from the scheduler to the heads of the departments*
- *What is the main cause of the scheduling process and the process of administration after production being so time consuming?*
    a. *What does the scheduling processes look like?*
    b. *How do the processes of administration after production is finished look like?*
    c. *What is the main root cause for the extensive amount of time spent on administration?*

This was achieved by describing the scheduling processes in-depth and describing the transfer of data between the employees of TenCate. This mainly involves using Excel files and an ERP system. This information is necessary to make the business process models and map the data transference in these models. The business process models show how the process of scheduling and the administration after production looks like. This helped identifying possible root causes. The root cause was determined using a cause-and-effect diagram, the root cause is described as the double administration of data in two software programs. Solely eliminating the double administrative steps reduces the time spent on the scheduling process by an estimate of 6.5 man hours per week. However, this merely describes the elimination of steps and does not consider how the new scheduling process would look like. This will be described in the next chapters of this thesis.

4. Multi criteria decision analysis

This chapter will cover the part where solutions for the problem are generated and ranked. The ranking is performed by a multi-criteria decision analysis. Before performing this analysis, the best and most suitable methodology van a multi-criteria decision analysis is selected. This decision analysis will compare the different solutions and several criteria that were selected together with employees of TenCate. The analysis leads to a best solution out of the generated solutions for the problem described in Chapter 3.

4.1 Generating alternative solutions

Four alternative solutions have been obtained by brainstorming with the scheduler of TenCate. After the four ideas were worked out, they were discussed with the production manager and adjustments were made after his comments. These solutions will be compared by a multiple criteria decision analysis (MCDA). The methodology will be selected later in this chapter. The four alternative solutions will each be briefly explained in this section, including characteristics regarding the criteria.

4.1.1 Computers for production

The first alternative is to purchase the computers and put those on both production floors. These computers should replace the printing phase that is done by the head of both the warping and the construction department. This way the operators can fill their performances directly in the Excel files instead of writing them down on pieces of paper. This way the heads of both the departments do not have to copy the filled in papers in Excel, which means less double administration in the process.

This solution requires three computers, two at the weaving department and one at the construction department. The computers also have the potential to take away the step where the heads of both the departments will not have to print out the working sheets and hang them up. They can be viewed by the operators on the screen of the computer. So, all the paper communication between the head the departments and the operators on both departments will be replaced by electronic communication, reducing the amount of double administrative steps throughout the process. The software for this solution will be excel, a simple programme which means it is the same software that is currently used by TenCate and a connection between the current excel files can be made.

4.1.2 Macro for construction Excel file

The second alternative is to create an extra database in Excel that is transferred from SAP data for the construction department. Since these workorders are all created in SAP but the scheduling occurs in Excel this application of data can reduce the time employees spend on administration. The idea is to download the SAP database with all workorders and transfer this to the existing excel sheet for construction planning. Then via a macro the right data can be filled in using this Excel database. This means that there will be no double administration in both excel and SAP for the specifications of orders since these are downloaded from SAP and uploaded to Excel. Via a macro the specifications are entered into the correct place. It is especially useful when there is need for reprioritising, since this requires new actions and the Excel would only require entering the new priority without deleting the previous one, thus eliminating double administrative steps. This is alternative, if chosen, will be integrated into the current scheduling process with little costs. This solution focuses on the activities of the scheduler regarding communication with the head of construction. This way the specifications will be listed only once by hand, at the SAP phase, in Excel the specifications are generated automatically via a macro.

4.1.3 New scheduling software

The third alternative is to make use of new planning software that will take over the entire Excel part of the scheduling process. This should provide a clear overview and will make sure that all the schedules are in one place. Ideally this software can be linked with SAP, because this would mean that excel is no longer necessary meaning the double administration regarding specifications, priority of order is no longer necessary. The software also had the potential to eliminate the sheets of paper used on the production floor, eliminating double administrative steps with regards to comments of operators on both paper and Excel. A programme suitable for this is vPlan, which allows for automated actions, good connection to the operators via tablets that can access the system, registration of the work done by the operators and capacity planning (vPlan, 2021).

Both long term and short-term planning is doable as well as scheduling both people and machines, which are respectively necessary for the construction department and the weaving mill. However, using this programme has a steep price and will and requires significant changes in the current structure of TenCate. Employees will need to learn how the program works and it needs to be designed for the situation of TenCate, which is possible in vPlan (vPlan, 2021).

4.1.4 Hub Excel file

The fourth and last alternative solution is to create a hub Excel sheet that is linked with the other existing Excel sheets. The hub sheets should fill up all the other sheets and provide overview. Then from there a schedule can be made that automatically fills up all the existing sheets. This central workbook can provide long term overview in Excel and can be used as a central overview. Integration can be done quite easily since the formats for the current excel workbooks can be used for integration while the usual business goes on.

The workbook can be saved on the TenCate server which makes it available to anyone, however it will be filled in mostly by the scheduler. A hub excel file can eliminate the administration of the same order on different excel files, since this can be done in the one hub excel file.

4.2 Setting up the criteria

A multiple-criteria decision analysis (MCDA) is a process suited to make decisions between several alternatives, which are presented in de previous chapter. However, before selecting a suitable MCDA methodology, criteria need to be specified. This is because criteria definitions have an influence on the selection process. Together with employees from TenCate, criteria have been specified. Some criteria are more important than others and thus weigh heavier. This was decided in consultation with employees with TenCate. The criteria can be classified as process focused criteria or business focused criteria. The one focuses on process improvement and the others take the broader effects for TenCate into account.

The 8 different criteria are listed in Table 7, this table also shows what a solution can score on each criterion and what each potential score means. Some criteria have categorised scores to make the score quantifiable. C2 also has a categorised score since it is difficult to determine the exact time. The combination of these criteria gives a good image of what specification the solution should meet.

Criterium	Name	Description	Criterium	Optinal scores	Meaning of scores
C1	Costs	Yearly operating costs of the solution for TenCate.	C1	The actual costs	Yearly costs
C2	Connection between employees	Time it takes for scheduling data entered by one employee to reach a production employees.	C2	1	20 minuts +
				2	10 to 20 minutes
				3	5 to 10 minutes
				4	Instant to 5 minutes
				5	Instant
C3	Connevtiviy with the current software	Time it takes before integration of the solution with the existing software is successful.	C3	The actual amount of weeks it takes to integrate the solution with the existing software	The actual amount of time it takes to integrate the solution with the existing software
C4	Degree of customisation options	To what extent is the solutions customizable to TenCate's wishes and needs	C4	1	Not customizable to TenCate's wishes and needs
				2	Customization options that suits TenCate's wishes and needs
				3	Customization options tailored to TenCate's wishes and needs
				4	Completely customizable to TenCate's wishes and needs
C5	Implementation time	The amount of manhours are spent on implementing the solution to TenCate	C5	The actual amount of time expressed in hours it takes to implement the solution	The actual amount of time it takes to implement the solution
C6	Reduction of steps in scheduling process	The amount of steps in the production process that are reduced by the proposed solution.	C6	The actual amount of steps that are reduced in the scheduling process	The actual amount of steps that are reduced in the scheduling process
C7	Security	Risks of system and/or software failure	C7	1	Very high risk
				2	High risk
				3	Medium risk
				4	Low risk
				5	Very low risk
C8	Usability	How hard is it for the employees to learn how to use the new solution	C8	1	Very hard (Takes much time to understand and requires lessons for employees to understand)
				2	Hard (Takes much time to understand and requires motivation from employees)
				3	Medium (Takes some time to understand but is doable)
				4	Easy (Takes little time to learn but is understood quickly)
				5	Very easy (Takes little time to learn and is understood immediately)

Table 7: The criteria with a description and an explanation of the scores

4.2.1 The weights of the criteria

The weights for the criteria are listed below, they are weighed between 1 and 10. As can be seen the reduction of steps of the process is the most important criterion. Other criteria like user friendliness and ease of implementation both effects how well the solution fits into TenCate, which is important to TenCate, where usability is deemed more important since this will have an effect a longer period than the implementation process does. Costs was given medium low scores since a significant investment can be worth it when a significant amount of time reduction is achieved. Security was also given a medium score, since a system that always fails is not desirable but when a system often works this criterion has not got as much influence on the time reduction as other criteria, which have a larger weight. Connectivity between employees and software were too important to combine with user friendliness however deemed less important by TenCate and the researcher. Since production communication is an important yet small part of the process it was given a medium low score of three, which is the same as the customisation weight. This was chosen since customisation to the needs of TenCate is beneficial but not essential. The weights are listed in Table 8.

Table 8: Weights of criteria

Criterion number	Criterion specification	Weight	Percentage
C1	Costs	3	8.57%
C2	Connection between employees	1	2.86%
C3	Connectiviy with the current software	3	8.57%
C4	Degree of customisation options	3	8.57%
C5	Implementation time	6	17.14%
C6	Reduction of steps in scheduling process	9	25.17%
C7	Security	4	11.43%
C8	Usability	6	17.14%
	Sum	**35**	**100%**

4.3 Multi criteria decision analysis

The solutions will be compared with a MCDA. There are many methodologies for performing such an analysis. To select a suitable method a generalised framework was used, this framework was created to make an overview of known MCDAs and to point out the differences between these methodologies (Wątróbski, Jankowski, Ziemba, Karczmarczyk, & Zioło, 2019). The methodologies are divided in four main descriptors, then there are a second and a third level of descriptors as well.

4.3.1 Selecting a MCDA methodology

Below the descriptors from the framework are listed in Table 9, including the hierarchy levels. The options classify the different methodologies, they are stated as a number meaning a mathematical approach with sets and subsets can be used (Wątróbski, Jankowski, Ziemba, Karczmarczyk, & Zioło, 2019).

Table 9: Table with descriptors from framework Wątróbski, Jankowski, Ziemba, Karczmarczyk, & Zioło (2019)

Hierarchy level	Descriptor	Options	Meaning
Top	1 (Weights)	0	No
		1	Yes
	2 (Scales of comparison)	1	Qualitative
		2	Quantitative
		3	Relative
	3 (Uncertainty of decision problem)	0	No
		1	Yes
	4 (Decision problematics)	1	Choice
		2	Classification
		3	Ranking
		4	Classification and choice
Middle	1.1 (Type of weights)	1	Qualitative
		2	Quantitative
		3	Relative
	3.1 (Type of uncertainty)	1	Input data
		2	Preferences
		3	Both
	4.1 (Type of ranking)	1	Partial
		2	Total
Bottom	3.1.1 (Type of input data uncertainty)	1	Criteria
		2	Variants
		3	Both
	3.1.2 (Applied thresholds)	1	Indifference
		2	Preference
		3	Both

To select a suitable methodology, the options for each descriptor are chosen, the results are presented in Table 10. First of all, there is de weight descriptor, since criteria will differ from importance the MCDA needs to include weighted criteria. Due to the fact that there are eight criteria, which each having a different importance, quantitative weighing is the most logical option. Since there is no standard to compare the criteria to, relative weights are not suited. Solutions will be compared on a quantitative scale; the criteria can score a mark on a criterion. So even though the data for some criteria is qualitative, the scaling will be cardinal, so quantitative. This is done because it is easier to quantify qualitative data than the other way around. There is the possibility to scale each option relatively to another option, however for this study this was not opted since there is no base performance which can be held as a standard to compare to. A quantitative scale is the more logical and suitable option in this research. The problem decision does not have any uncertainties. There are no preferences since the study is performed unbiased by someone who does not have an interest in TenCate. The input data does contain estimations, however since the estimations are made by the same person supported with objective data, there has been assumed that the uncertainty is neglectable. The aim of the analysis is to choose a solution out of several ones, therefore a methodology which results in a total ranking suits this problem best. In conclusion these scores result in the scores listed, if the descriptor was not applicable then it is left out of the table. When applying the framework to this problem, the scores are zero if the descriptor is not applicable.

Table 10: Scores of this research on each applicable descriptor of framework by Wątróbski, Jankowski, Ziemba, Karczmarczyk, & Ziolo (2019)

Descriptor	Options	Meaning	Score
1 (Weights)	0 1	No Yes	**1**
1.1 (Type of weights)	1 2 3	Qualitative Quantitative Relative	**2**
2 (scale of comparison)	1 2 3	Qualitative Quantitative Relative	**2**
3 (uncertainty of decision problem)	0 1	No Yes	**0**
4 (decision problematics)	1 2 3 4	Choice Classification Ranking Classification and choice	**3**
4.1 (Type of ranking)	1 2	Partial Total	**2**

According to the paper by (Wątróbski, et al., 2019) these scores bring up eight different methods to choose from, namely: EVAMIX, MAUT, MAVT, SAW, SMART, TOPSIS, UTA and VIKOR. This set can be further divided into three subsets, the first being MAUT, MAVT, SAW, UTA and SMART, which are all based on the same principle, the latter four are special cases of the MAUT method. (Wątróbski, Jankowski, Ziemba, Karczmarczyk, & Ziolo, 2019). In the Multi-Attribute Utility Theory, each criterion has several alternatives that provide solutions by the multiplication of the priority scale (Ramadiani, Heliza Rahmania Hatta, Nurlia Novita, & Azainil, 2018). These methodologies rank the solutions on an [0,1] interval (Kailiponi, 2010). TOPSIS and VIKOR are both based on another principle (Wątróbski, Jankowski, Ziemba, Karczmarczyk, & Ziolo, 2019), namely the distances of the aggregated function to the (non) ideal solution. TOPSIS minimises the distance to the ideal solution and maximises the distance to the non-ideal solution, whereas VIKOR only minimises the distance to the ideal solution (Wątróbski, Jankowski, Ziemba, Karczmarczyk, & Ziolo, 2019). Furthermore, TOPSIS uses a vector normalisation and VIKOR a linear normalisation. The last subset only consists of EVAMIX, which focuses on analysing both quantitative and qualitative data (Andalecio, 2010). It uses both and ordinal (qualitative) and cardinal (quantitative) criteria (Işık & Adalı, 2016).

Since the criteria will evaluated solely on a cardinal scale, the EVAMIX is not the most suitable method. Then there are the options left from the other two subsets. Both subsets contain suitable methodologies, however the MAUT methodology requires significant amount of effort and extreme extensive amount of data (Velasquez & Hester, 2013). MAUT can also account for preferences, which however is not applicable for this analysis (Velasquez & Hester, 2013). Other methodologies like SMART and SAW require less effort and data, however still considerably more than for instance TOPSIS (Velasquez & Hester, 2013). Furthermore, TOPSIS and VIKOR are both well suited for this analysis and have an uncomplicated process (Velasquez & Hester, 2013).

As mentioned before both TOPSIS and VIKOR are based on an aggregated function representing closeness to the ideal solution. However, the VIKOR method has the outcome of a ranking index based on solely the closeness to ideal solution and the TOPSIS method has a ranking based on closest to ideal solution and furthest from non-ideal solution, so two reference points (Opricovic & Tzeng, 2004). It should be mentioned that the TOPSIS methodology does not consider the relative distances from these points (Opricovic & Tzeng, 2004). VIKOR can be used to determine the best solution out of asset of conflicting solution (Suniantara & Putra, 2019). However, since this is not the case for this analysis, TOPSIS is MCDA that was chosen in for the research. It is very well suitable and has an uncomplicated process.

4.3.2 TOPSIS as an MCDA methodology

The TOPSIS methodology consist of 6 steps, these steps are listed below and are copied from a study on ranking efficient units in Data Envelopment Analysis (Lotfi, Fallahnejad, & Navidi, 2011). Before beginning the TOPSIS methodology, a performance matrix must be constructed. Here the alternative (solutions) and the criteria are put in a matrix. The structure of such a matrix is depicted in Table 11 This structure is important to understand the TOPSIS methodology.

Table 11: Structure of performance matrix

	Criterion 1	Criterion 2	...	Criterion n
Alternative 1	X_{11}	X_{12}	...	X_{1n}
Alternative 2	X_{21}	X_{22}	...	X_{2n}
⋮	⋮	⋮	⋮	⋮
Alternative m	X_{m1}	X_{m2}	...	X_{mn}

Step 1. Calculation of normalized performance matrix: The normalized value n_{ij} is calculated as:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, i = 1,2, \dots, m, j = 1,2, \dots, n \qquad (1)$$

Step 2. Calculation of the weighted normalized performance matrix: The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = n_{ij}\, w_j, i = 1,2, \dots, m, j = 1,2, \dots, n \qquad (2)$$

where $w_j = \frac{W_j}{\sum_{k=1}^{n} W_k}$, $j = 1,2,\dots,n$ so that $\sum_{i=1}^{n} w_i = 1$ with W_j is the original weight given to the set criteria c_j , $j = 1,2,\dots\dots,n$

Step 3. Determination of both the positive (A^+) and the negative (A^-) ideal solution, these are respectively the best or worst score on each criterion depending on if a higher score is better or worse for the outcome:

$$A^+ = \{v_1^+, \dots, v_n^+\} = \{(max\, v_{ij} | i \in I)\}, \{(min\, v_{ij} | i \in J)\}$$

$$A^- = \{v_1^-, \dots, v_n^-\} = \{(min\, v_{ij} | i \in I)\}, \{(max\, v_{ij} | i \in J)\} \qquad (3)$$

Step 4. Calculation of the separation of each alternative from the positive ideal (d+) and negative ideal (d-) solution measures, using the n-dimensional Euclidean distance:

$$d_i^+ = \sqrt{(v_{ij} - v_i^+)^2}\ ,\ i = 1,2,\ldots,m$$

$$d_i^- = \sqrt{(v_{ij} - v_i^-)^2}\ ,\ i = 1,2,\ldots,m \qquad (4)$$

Step 5. Calculation of the relative closeness to the ideal solution:

$$S_i = \frac{d_i^-}{d_i^+ + d_i^-}\ ,\ i = 1,2,\ldots,m$$

Step 6. Ranking the preference order: The closer the S_j is to 1 implies the higher priority of the j'th alternative.

4.4 Performing TOPSIS to find the best alternative solution.

First of all, a performance matrix following the concept of Table 11 must be made to see how well each alternative solution scores on each criterion. The explanation of the scores is presented in Table 7. The scores have been determined with the help of interviews with the scheduler and both the heads of the departments in combination with performing some of the steps in the process in person. The scores are estimations which are substantiated by an explication of all the steps necessary to evaluate the score. The elaboration can be found an Excel file which can be found in the appendix A. The normalised performance is presented in Table 12. A performance matrix with weights which are described as w_j, j $= 1,2, \ldots, n$ and denominators which are described as $\sqrt{\sum_{i=1}^{m} x_{ij}^2}$ for each criterion is constructed.

Table 12: Performance matrix

	C1	C2	C3	C4	C5	C6	C7	C8
Solution 1 (Computers for operators)	1800	4	1	3	15	1	4	2
Solution 2 (Macro for construction)	600	3	2	4	20	3	3	3
Solution 3 (New scheduling software)	27600	5	8	3	130	14	4	3
Solution 4 (Excel hub workbook)	2100	3	2	3	70	4	4	3
Denominator	27745	7.681	8.544	6.557	149.750	14.900	7.550	5.568
Weights	0.086	0.029	0.086	0.086	0.171	0.257	0.114	0.171

After the performance matrix, a normalised performance matrix (see Table 13) can be constructed where the performance of each alternative solution on each criterion is divided by the denominator $\sqrt{\sum_{i=1}^{m} x_{ij}^2}$. This is the first step of the TOPSIS methodology.

Table 13: Normalised performance matrix

	C1	C2	C3	C4	C5	C6	C7	C8
Solution 1 (Computers for operators)	0.0649	0.5208	0.1170	0.4575	0.1002	0.0671	0.5298	0.3592
Solution 2 (Macro for construction)	0.0216	0.3906	0.2341	0.6100	0.1336	0.2013	0.3974	0.5388
Solution 3 (New scheduling software)	0.9948	0.6509	0.9363	0.4575	0.8681	0.9396	0.5298	0.5388
Solution 4 (Excel hub workbook)	0.0757	0.3906	0.2341	0.4575	0.4674	0.2685	0.5298	0.5388

At step two the weighted normalized performance matrix is constructed (see Table 14) where each normalized performance is multiplied by the weight of the criterion. Step 3 is also included in this table, where the maximum and minimum scores per criterion are listed, which are respectively described as A^+ and A^-.

Table 14: Normalized weighed performance matrix

	C1	C2	C3	C4	C5	C6	C7	C8
Solution 1 (Computers for operators)	0.0056	0.0149	0.0100	0.0392	0.0172	0.0173	0.0606	0.0616
Solution 2 (Macro for construction)	0.0019	0.0112	0.0201	0.0523	0.0229	0.0518	0.0454	0.0924
Solution 3 (New scheduling software)	0.0853	0.0186	0.0803	0.0392	0.1488	0.2416	0.0606	0.0924
Solution 4 (Excel hub workbook)	0.0065	0.0112	0.0201	0.0392	0.0801	0.0690	0.0606	0.0924
A^+	0.0853	0.0186	0.0803	0.0523	0.1488	0.2416	0.0606	0.0924
A^-	0.0019	0.0112	0.0100	0.0392	0.0172	0.0173	0.0454	0.0616

The next step is a calculation of the separation of each alternative from the positive ideal, represented as d_i^+ , and negative ideal represented as d_i^- , solution measures, using the n-dimensional Euclidean distance. However, criteria 1,3 and 5 perform better when the scores are lower as can be seen in Table 7. Therefore, the minimum scores (A^-) are used for the calculation of d_i^+ and the maximum scores (A^+) of these criteria are used for the calculation of d_i^-. The results of the calculations are also put into a matrix, with the fifth step included. This is a calculation of the relative closeness to the ideal solution. This calculation is represented with the following formula: $S_i = \frac{d_i^-}{d_i^+ + d_i^-}$, $i = 1,2,...,m$ Table 15 below presents the results.

Table 15: Euclidian distances to (least) ideal solution of the alternative solutions

	d_i^+	d_i^-	S_i	Rank
Solution 1 (Computers for operators)	0.226898	0.169879	0.428147	4
Solution 2 (Macro for construction)	0.190939	0.169553	0.470338	2
Solution 3 (New scheduling software)	0.171439	0.227088	0.569818	1
Solution 4 (Excel hub workbook)	0.184655	0.135665	0.423529	3

The S_i score which is closest to 1 is closest to the ideal solution and therefore is solution 3 is the best alternative solution out of these four, the rank is highlighted in green in Table 15. Therefore, this is the proposed solution for which an implementation report will be written in Chapter 6.

4.5 Sensitivity Analysis

In this section a sensitivity analysis on the MCDA of the previous chapter is conducted. The analysis shows for each criterion if a change of weight also causes a change of the best answer. This is useful for managers of Ten Cate, since they can see what the outcome of the MCDA will be if circumstances change or their opinions regarding the weights of the criteria change. This chapter will describe the outcome of the sensitivity analyses of criteria 1,5 and 6. These analyses provided the most interesting data for managers, since they showed the most substantial changes in the outcome when changing the weights. Managers can use the data to make business decisions on the core problem depending on the economic situation of Ten Cate. The analyses on the other criteria did not show substantial changes in the outcome and are therefore not described in this chapter, however the results are listed in the appendix.

The analysis was performed by using 5 different weights for a certain criterion and followed by normalising the other weights. Next the outcomes of the five different MCDA'S could be plotted into a scatter plot. This showed a polynomial function, with a R-squared value that approaches 1 for each function, meaning that the plotted line represents the 5 different outcomes of the MCDA that were used as input for the line well. So, it can be assumed that the plotted line can be used for interpretation of the scores of the solution when the weights are changed.

The first criterion that will be described is criterion 1, which are the yearly costs of one of the four solutions, which is depicted in Figure 12. This graph shows how well the solutions perform when changing the importance of the yearly costs of the solutions. As can be seen solution 3 is highly affected by this criterion. If financing becomes harder or there is little money to invest due to a recession for instance, solutions 3 performs worse, due to its excessive costs. To be more precisely, solution 2 becomes better than solution 1 when the normalised weight of criterion 1 is 0.14089. This means that solution 2 becomes better than solution 3 when the weight of criterion 1 is 5.24, the original weight to criterion 1 given is 3.

To conclude this figure shows that it is important for a manager at Ten Cate to consider how much the company want to invest in the solution, since solutions 1,2 and 4 perform better when the costs become a particularly important criterion.

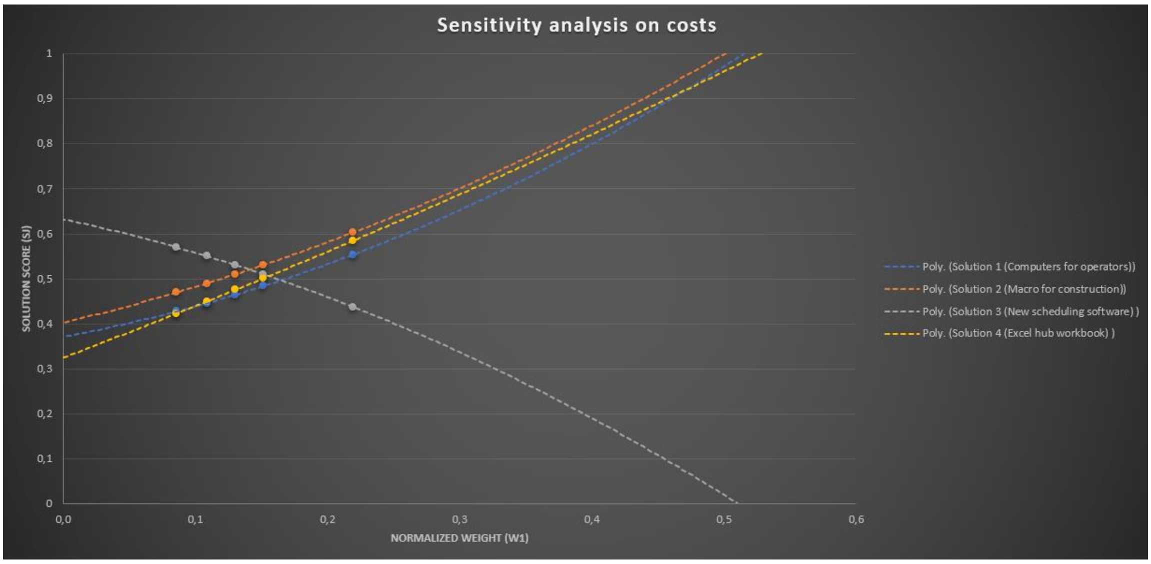

Figure 12: Sensitivity analysis on the criterion costs

Figure 13 shows the effects of changing the weight of the implementation time of the solutions. The graph tells that it matters how fast a manager wants to have a well working solution. The best solution, the third one, performs worse as the implementation time becomes more important, whilst solution 1 and 2 perform significantly better when implementation time becomes more important. To be more precisely, solution 2 becomes better than solution 1 when the normalised weight of criterion 5 is 0.21203. This means that solution 2 becomes better than solution 3 when the weight of criterion 5 is 7.8, the original weight given to criterion 5 is 6. Therefore, it can be concluded that it is important to determine how long it may take to have a well-functioning solution for the problem, since it has a significant impact on the outcome of the MCDA.

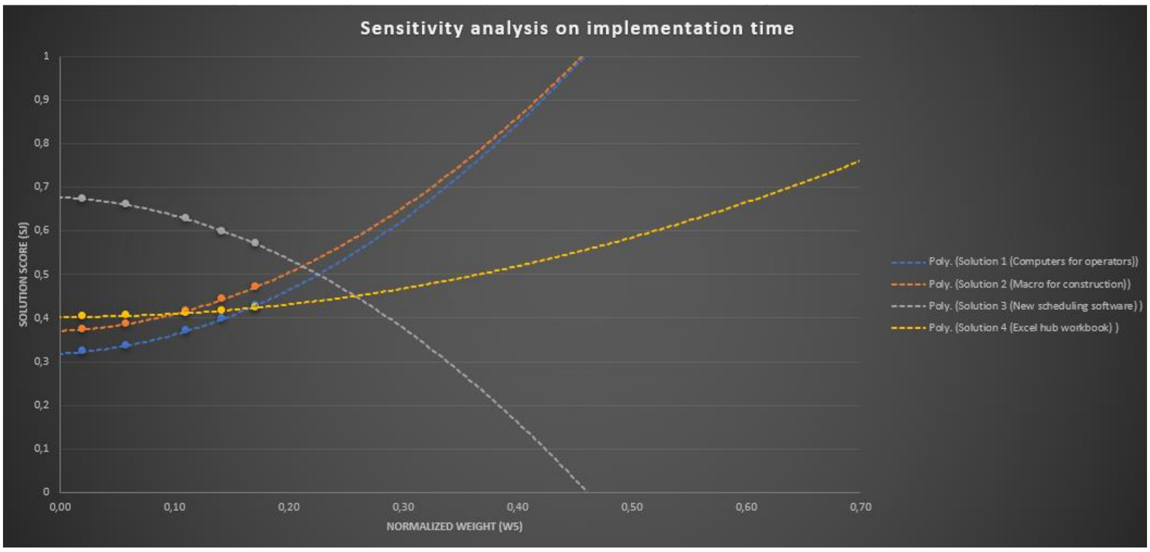

Figure 13: Sensitivity analysis on the implementation time criterion

Criterion 6 gives information on how many steps in the scheduling process a new solution reduces. At the initial assessment of the weights this came out as the criterion with the highest weight. It tells the most about the effectiveness of the solution out of all the criteria. It can be seen in Figure 14 that solution 3 is the best scoring solution when criterion 6 becomes more important. In fact, solution 2 becomes better than solution 1 when the normalised weight of criterion 1 is 0.14089. This means that solution 2 becomes worse than solution 3 when the weight of criterion 6 is 7.33, the original weight given to criterion 6 is 9. The graph shows that solution 3, the new scheduling software, is the best solution when it is important to thoroughly deal with core problem presented in Chapter 1. This solution has the most impact number of administrative steps in the scheduling process.

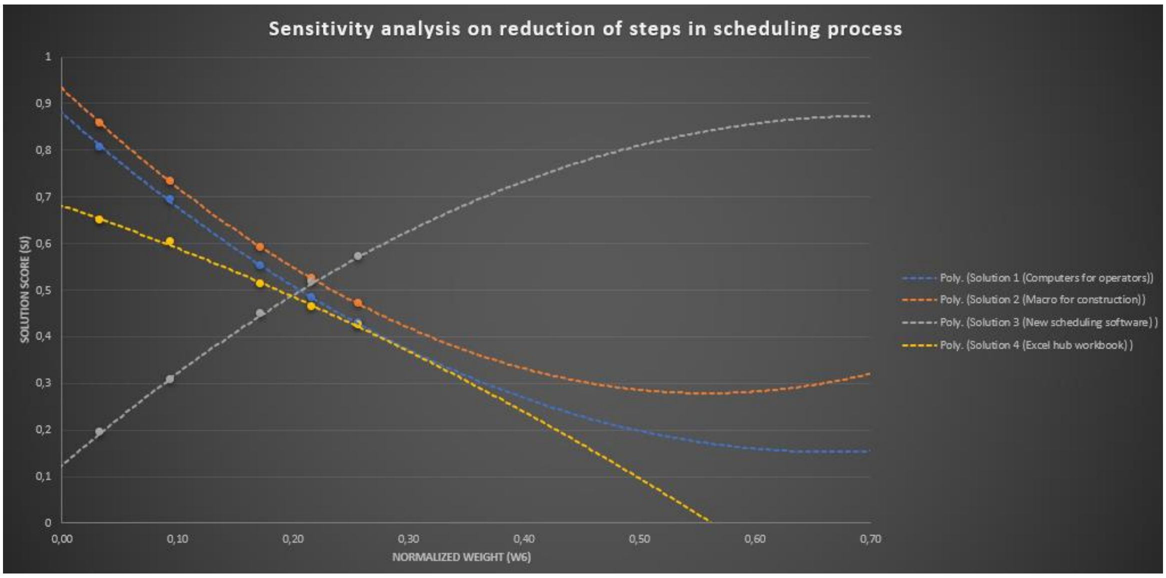

Figure 14: Sensitivity analysis on the reduction of steps criterion

This chapter will be concluded with an advice on how to interpret the outcomes of the MCDA and the sensitivity analysis. When aiming for a solution which fully operates in a small amount of time which is also not expensive, solution 2, a macro for the construction site, is the best option. It comes out on top when C1 en C5 have a high weight. So, when there is little investment budget for some reason there could be opted for solution 2 instead of solution three, which came out on top in the previous chapter.

Solution 2 should also be considered seriously when it is important to deal quickly with the scheduling problem. It is the best solution when the implementation time becomes important to Ten Cate. However, if Ten Cate wants to deal with the problem thoroughly, if they are willing to invest a considerate amount of money and time, then new scheduling software is the best solution to go for. It will reduce the administrative steps the most of all the four proposed solutions.

4.6 Conclusion

This chapter provided a selection process for the most suitable multi-criteria process, the TOPSIS methodology was selected after performing an MCDA. TOPSIS is a well-suited methodology which does not require extensive amount of data. Furthermore, TOPSIS has a relatively uncomplicated process in comparison to other suited methodologies. Before performing this analysis, the criteria and their weights have been determined, they were based on meetings with the scheduler and production manager of TenCate.

The analysis was performed to compare four different solutions, which all eliminate a type of double administrative step, the best solution that came out of the MCDA was solution three, acquiring new scheduling software. A sensitivity analysis showed that solution 2, where a macro is created in the Excel files, can become the better solution when costs and implementation time become more important. However, if the goal is to reduce the time spent on administration as much as possible, solution 3, the acquiring of new scheduling software remains the best option.

5. Implementation report

This chapter will elaborate on how TenCate can implement new scheduling software, which came out as best solution in Chapter 4. Firstly, an overview of the steps that need to be taken to implement the solution is presented. This is followed up by a BPMN of the new solution implemented accompanied with the expected time reduction in the scheduling process after implementation of this solution. The implementation plan came together after meetings with the scheduler and the production manager as well as with a representative of vPlan. A company that supplies scheduling software. This representative said that implementation usually takes 3 to 4 months, however it is not full time working of course. So, for TenCate, as mentioned in the scoring table in Chapter 4, it will take an estimate of 130 man hours.

The steps that TenCate can take in order to achieve successful implementation of new scheduling software are listed below. Between brackets the responsible employee is mentioned:

1. Conduct research into different providers of scheduling software. (Scheduler and production manager)
2. Select two or three providers for orientating meetings, where the current scheduling process and the wishes can be explained. (Scheduler and production manager)
3. Setting up criteria that must be met by a potential provider. (Scheduler, production manager and executive of plant)
4. Meet for concluding meetings with two or three providers to verify whether they can meet the criteria set up in step 3. (Production manager and executive of the plant)
5. Select provider for the software based on meetings (Executive of the plant and production manager)
6. Develop in detail the new scheduling process as a business process model. (Scheduler together with representatives of software supplier)
7. Start codesigning the software and set-up of the software together with provider. Make sure integration with current software is successful. (Scheduler together with representatives of software supplier)
8. Meet with employees for their input and wishes for the details. These details should include the interface used by the employees and the possible functionalities of the system. (Scheduler and production manager with the rest of the production employees)
9. Finishing the details of software design. (Scheduler and representative of software company)
10. Start training people how to use to software together with the provider. (Representatives of software company)
11. Evaluate after three months and make changes where necessary. (Scheduler and production manager)

The new proposed weekly planning process and construction scheduling process are respectively presented in Figure 15 and Figure 16. As can be seen the following type of administrative actions are no longer required:

1. Manual input of inventory levels in SAP.
2. Double input of scheduling order
3. Writing comments both in excel and on paper
4. Enter specifications of order on two different software systems
5. Printing out schedules and deliver them to production floor

In these scenarios the new scheduling software can be operated from the near the machines, for instance via smartphones and the scheduling software can be connected to the SAP system.

This means that inventory levels can be adjusted by finishing an order at the production floor. 3 out of the 5 administrative actions that are no longer required to perform are steps that directly eliminate double administrative steps in the scheduling process. Furthermore, the first and fifth action are involved with double administrative actions indirectly. The manual input of inventory levels does no longer had to be put in manually, whilst it used to mean that operators noted how much products were finished and then the scheduler had to manually enter the new levels in SAP. The fact that paper sheets are no longer needed means that no longer comments in both excel and paper have to be written down, which are double administrative steps.

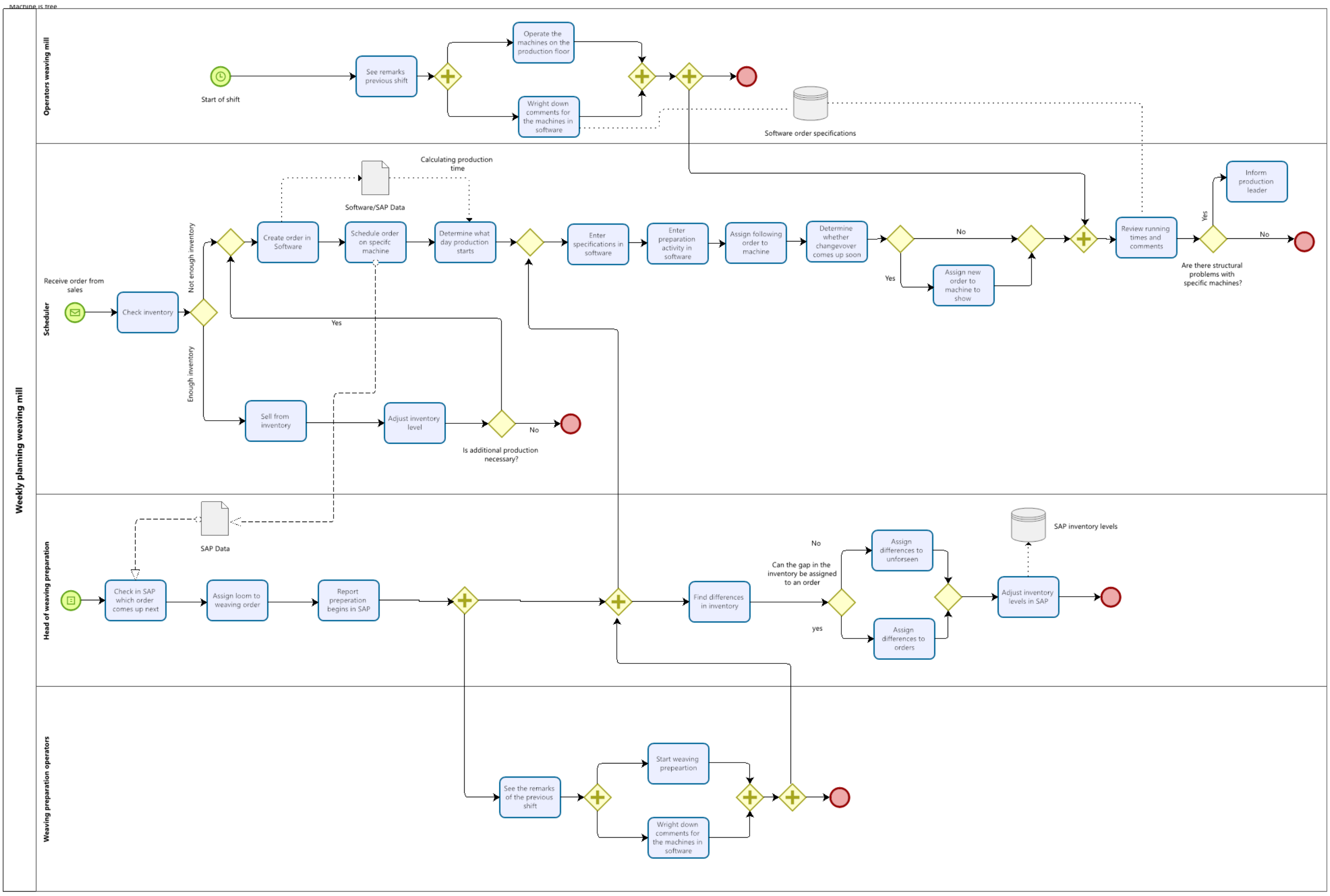

Figure 15: New scheduling process when software is implemented (Weekly planning)

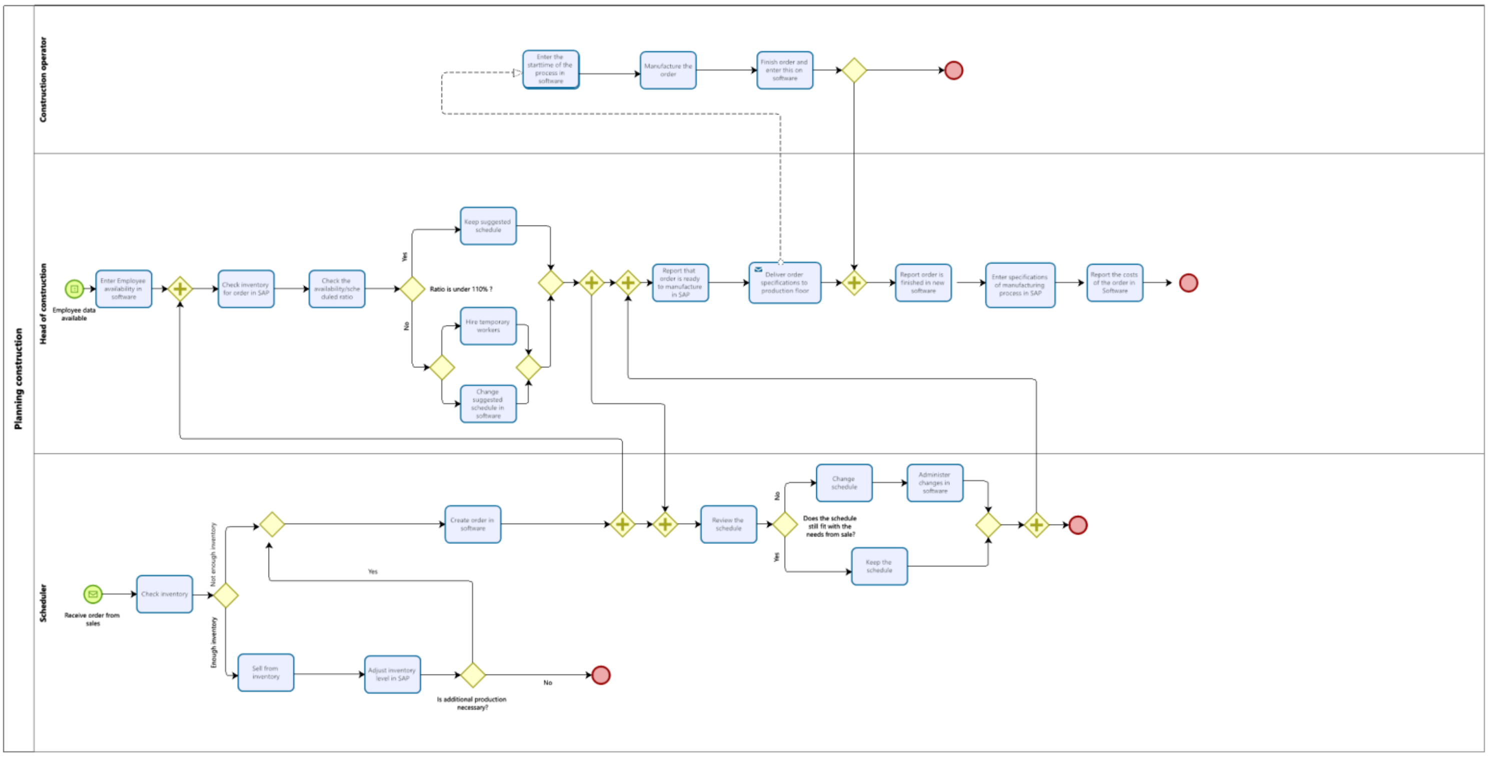

Figure 16: New scheduling process when software is implemented (Construction)

Now that the new processes are depicted, it is necessary to show how much time the new proposed scheduling will save per step that can be eliminated. The 5 different types of steps were counted and for each step was estimated how much time this step costs. These estimates were based on meetings with the scheduler of TenCate, assessing the excel files and observing the scheduler when performing the task. Tables 16 and 17 show the of steps of respectively the weekly planning process and the construction planning process. These tables are similar to the Table 5 and 6 in Chapter 3, however there is a difference. In Table 5 and 6 the possibilities of eliminating double administrative steps are described. In the tables below and the accompanying process models in Figures 15 and 16 a more detailed and worked out situation is described, which looks similar to the models in Figures 10 and 11 since the scheduling software, as only solution, has the ability to eliminate almost all double administrative steps.

Type of step eliminated	Estimated time reduction of step	Number of steps that are eliminated	Total estimated time reduction
Manual input of inventory levels in SAP	2 minutes per production order	3	6 minutes
Double input of scheduling order	2 minutes production per order	4	8 minutes
Writing comments both in excel and on paper	3 minutes per production order	2	6 minutes
Enter specifications of order on two different software systems	3 minutes per production order	3	9 minutes
Printing out schedules and deliver them	2 minutes per production order	2	4 minutes

Table 16: Estimated time reduction of new solution for weekly planning process

Type of step eliminated	Estimated time reduction of step	Number of steps that are eliminated	Total estimated time reduction
Manual input of inventory levels in SAP	2 minutes per production order	2	4 minutes
Double input of scheduling order	2 minutes production per order	2	4 minutes
Writing comments both in excel and on paper	3 minutes per production order	1	3 minutes
Enter specifications of order on two different software systems	3 minutes per production order	2	6 minutes
Printing out schedules and deliver them	2 minutes per production order	1	2 minutes

Table 17: Estimated time reduction of new solution for construction scheduling process

The tables show that for each new scheduled production order in the weekly planning process, new scheduling software will reduce the time spend on administrative actions by an estimate of 33 minutes and for each new scheduled production order for the construction scheduling process this is an estimate of 19 minutes.

With on average 4 new orders each week for the weekly planning and 15 for the construction site, the new solution will save an estimated 417 minutes per week, which is 6.95 man hours on a weekly basis. However, this is a total of 6.95 man hours for the scheduler, the heads of the departments and the production employees combined, since they are all involved in the process and all of them will save time. This is a reduction of 21.7% of the time spent on administration by the employees of TenCate.

In the performance matrix presented in Table 12 the estimated time it takes to implement new scheduling software is 130 man hours of TenCate. The scheduler and production manager combined spend approximately 120 man hours in the implementation of the software, equal to three weeks of work. This estimate comes from a meeting with a company who recently acquired new scheduling software, this company is Multistiq. This is a textile company located in the region of Twente. The hours are spent on the steps described in this chapter, most of this time is spent on setting up criteria, meetings with potential suppliers and designing the process to TenCate's wishes. The other 10 hours combined are used for the operators to understand how to use the software.

Implementing the software thus costs 130 hours, however when 7 man hours are weekly saved after successful implementation, the investment will be paid back within 19 weeks. It should be emphasised that the new scheduling software processes and the time reduction are estimates and can in fact be different from reality when the new scheduling software would be fully implemented. However, Figures 15 and 16 give a good indication of what the new process could look like and how much time it will save in the scheduling processes. It is possible for TenCate to get the exact numbers, in order to do so they will have to time how long each step takes. Software systems can usually see how long the software is being used. When the new process is fully operating, the new process can also be timed, this way the exact difference between the current scheduling process and the renewed one can be measured.

6. Conclusions and recommendations

This chapter starts off with a summarisation of the research steps that have been taken and the end-results. The recommendation part of this chapter begins with recommendations to TenCate involved with the proposed solution, followed by a discussion and ends with suggestions for further research.

6.1 Conclusions

The scheduling process of TenCate was not optimal according to the production manager of TenCate, the process took up an extensive amount of time and two different types of software were used to administer the schedules. The core problem is stated as follows: too much time was spent on administrative actions that are involved with the scheduling process. In order to find a solution for this problem the following research question was presented:

How can the time spent on administration of production schedule at TenCate geosynthetics be reduced?

This question could only be answered by researching the scheduling process. This research led to an in-depth understanding of the scheduling process, which is necessary to identify the main cause of the problem. After finding the main cause, by using a cause-and-effect diagram, an analysis of potential solutions resulted in a proposed solution for the problem. The last research topic was to find an implementation strategy which goes into the specifics of transforming the proposed solution from a concept to reality.

To find out the basics of the scheduling process the use and transferring of data between employees was researched and described, which helped analysing the scheduling process. This analysis led to the conclusion that there were three different schedules and thus scheduling processes at TenCate, for all of which a business process model was created. The language used for these models is BPMN, which was identified as a suitable modelling language in the literature review on business process management. A cause-and-effect diagram made after meetings with the employees helped to find the root cause of the core problem which is the double administration occurring in two of the three scheduling processes. The places where double administrative actions occurred were identified by using the created business process models. The double administration mostly occurs because of the use to software systems, both Excel and SAP, which are not integrated at TenCate. Approximately 30 percent of the steps of the scheduling processes was involved with double administration. Therefore, this part of the scheduling process became the focus of the four generated possible solutions.

The possible solutions are:

1. Buying computers for the operators
2. Implementing macros in existing excel files used by the construction schedules
3. Acquiring new scheduling software and
4. Making a hub Excel file.

The possible solutions, for reducing the time the employees of TenCate spent on administrative actions involved with the scheduling process, were compared using a multi criteria decision analysis. TOPSIS was found to be a suitable for the analysis. After performing the MCDA, new scheduling software was found to be the best solution for reducing the time spent on administrative actions, since it eliminates the most (double) administrative steps in the scheduling process out of all four solutions. The criteria which are used in the MCDA and their weights are presented below in a copy of Table 8.

Table 8: The criteria for the MCDA and their weights

Criterion number	Criterion specification	Weight
C1	Costs	3
C2	Connection between employees	1
C3	Connectiviy with the current software	3
C4	Degree of customisation options	3
C5	Implementation time	6
C6	Reduction of steps in scheduling process	9
C7	Security	4
C8	Usability	6

In order to gain more insight on the meaning of the outcome of the MCDA, a sensitivity analysis was conducted. This made it possible to show what will be the outcome of the MCDA if circumstances change or a point of view regarding the weights of the criteria changes. The sensitivity analysis was concluded with an advice where two different strategies lead to two different best scoring solutions. If speed and low investment costs are more important, a new macro is the favourable solution. If reduction of the steps in the process and therefore more time reduction is more important, the more expensive solution of new scheduling software is the best option.

In the implementation plan a stepwise approach to implement new scheduling software at TenCate is proposed. New scheduling software reduces the most steps in the scheduling processes and came out the MCDA as best solution. The scheduling software removes the need for double administrative actions since it can be linked to the ERP system. The removal of these type of steps results in an estimated weekly reduction of 6.95 man hours in the scheduling process of TenCate. This reduction can only be realised with an investment of both approximately €27,600 euro's and 130 man hours. To conclude: TenCate Geosynthetics can reduce the time spent on administrative actions of the production schedule with the implementation of a new scheduling software, which is able to remove over 12 double administrative steps in the scheduling processes.

6.2 Recommendations

The recommendation for TenCate is to invest in new scheduling software to improve the scheduling process. By acquiring, designing and implementing new scheduling software, the double administration of data can be eliminated which can save an estimated of almost 7 man hours per week. This is not a cheap and quite a time-consuming investment, however it will take of pressure of employees en allow them to work on other tasks, contributing to the added value of TenCate and reducing the backlog of activities. Since costly hours can now be spent on useful tasks instead of double administration, this investment is worth the costs and time. It will cost money to acquire the software, for which a fee has to be paid and it takes time to fit the software to the needs of TenCate. If TenCate is not willing to make these investments, they can opt for the solution to create a macro in the excel sheets, which is cheaper is faster to implement however will not improve the scheduling process as good as new scheduling software.

6.3 Discussion

This research includes some limitations. In this section the limitations are explained and the way to deal with these limitation is elaborated.

The foremost limitation of this research is not seeing the actual implementation due to the time limitations. This thesis does not have concrete prove of the time which is actually saved since the new scheduling software has not been implemented and therefore the new process cannot be measured exactly. However, since the main difference between the old and the new process is the elimination of steps, which could be measured the result provide a solid indication.

Due to the small amount of exact quantitative data on the performance of the process, such as actual time spent on activities of the process, estimations the performance of the process were ought to be made. In attempt to make the best estimations as possible, the estimations were made with the help of interviews with employees in combination with performing some of the steps in the process in person and observing the employees.

Employees had created parts of the processes themselves, therefore the subjects were biased on the performance on some parts of the process. Therefore, the interviews had to go back and forth to check comments made by an interviewee by another interviewee. Furthermore, not all employees did see the same urge of this problem as the production manager, which made it more difficult to focus on the problem of this thesis. However, after performing more interviews the telling wat other employees mentioned the core problem did come forth.

Part of this research was conducted when subjects were not available due to for instance holidays. This meant limited access to some data at mostly the end of this research. Furthermore, there was limited access to the ERP-system for the researcher since this is a very expensive license and the employees who did have a license had to use it themselves most of the time. Meaning that the ERP system could not be researched extensively.

6.4 Further research

This thesis has explored and mapped the scheduling process of TenCate. The researched has raised more issues which could be interesting to research.

The problem that was researched into this thesis was raised by a new appointed production manager who looked at the processes at TenCate with a new perspective. It could be beneficial for TenCate to model/map more of their processes, so new employees/interns understand the processes at TenCate sooner and easier. For instance, to give a clear insight in the supply chain of TenCate or the internal structure of the company, which was briefly touched in this thesis by the organogram. Providing a better insight in the processes and structure of TenCate by using models might also provide more information on the effects of this research on other parts of TenCate Geosynthetics. This can eliminate inefficiencies between two parts of the company. In general, business process models can help getting a better understanding of the ways the company works for employees, executives, new employees and other stakeholders.

In this research the sensitivity analysis was based on changing the weights of the criteria, however it is also possible to do a sensitivity analysis based on the performance of the solutions on each criterion. This would contribute to the validity of this research since it would show more about the accuracy of the measurements.

This research includes gaining understanding of the use of data within the scheduling process. The results were presented in business process models. However, conducting more research to create a data structure could both gain more understanding about the use of data within TenCate for both the researcher as for the stakeholders at TenCate.

At last, it would be interesting to use more MCDA methodologies to choose a solution. More methodologies were suitable and it would be interesting to see whether this would lead to a different choice of solution to implement. This would also add more validation to the choice of the solution.

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Appendix A

Below there is a hyperlink to the Microsoft Excel document where the performance matrix with the explanation for each score. Furthermore, the complete TOPSIS analysis and the sensitivity analysis can be reviewed in this document. The rest of the appendix is filled with on overview of the sensitivity analysis.

https://d.docs.live.net/6fb43952316591c9/Bachelor%20opdracht%20Job/Thesis/Performance%20matrix%20-%20na%20feedback.xlsx

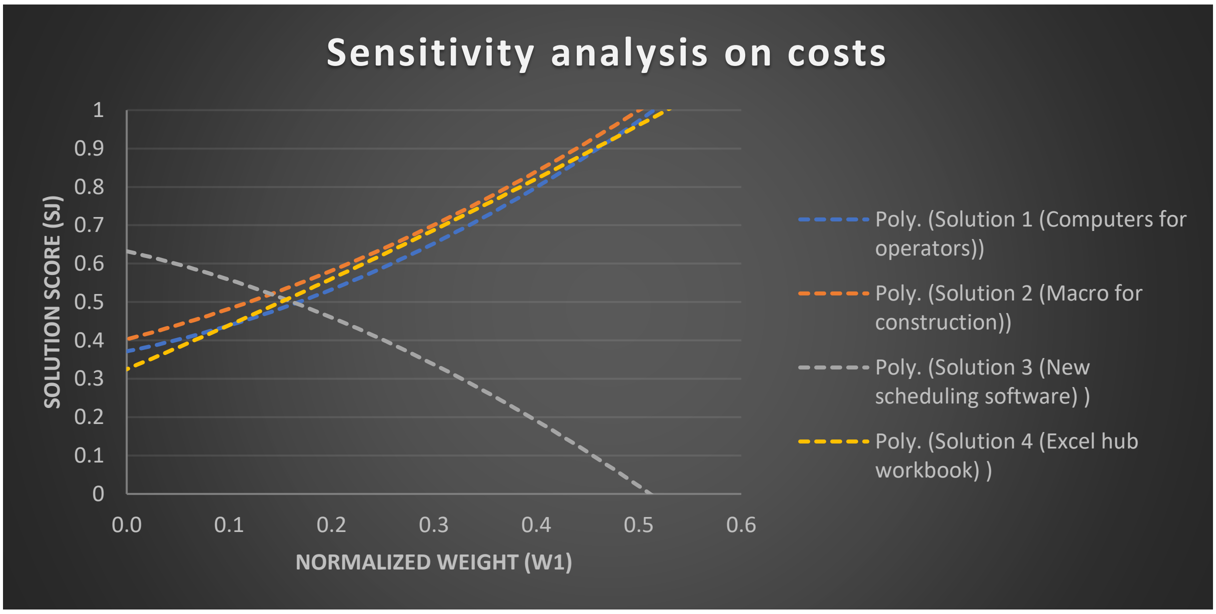

Figure 17: Sensitivity analysis on costs

	Initial assessment	Sensitivity C1 (+90%)	Sensitivity C1 (+60%)	Sensitivity C1 (+30%)	Sensitivity C1 (+200%)
Normalized weight C1	0,085714	0,151193634	0,130434783	0,108635097	0,219512195
Solution 1 (Computers for operators)	0,428146598	0,484312022	0,464555971	0,445516422	0,554122101
Solution 2 (Macro for construction)	0,470337778	0,531463269	0,510340793	0,48960877	0,603428667
Solution 3 (New scheduling software)	0,569817925	0,510137351	0,530950186	0,551184894	0,437778424
Solution 4 (Excel hub workbook)	0,423529021	0,501634709	0,475655131	0,449193788	0,584926432

Table 18: Performance matrix for sensitivity analysis for C1

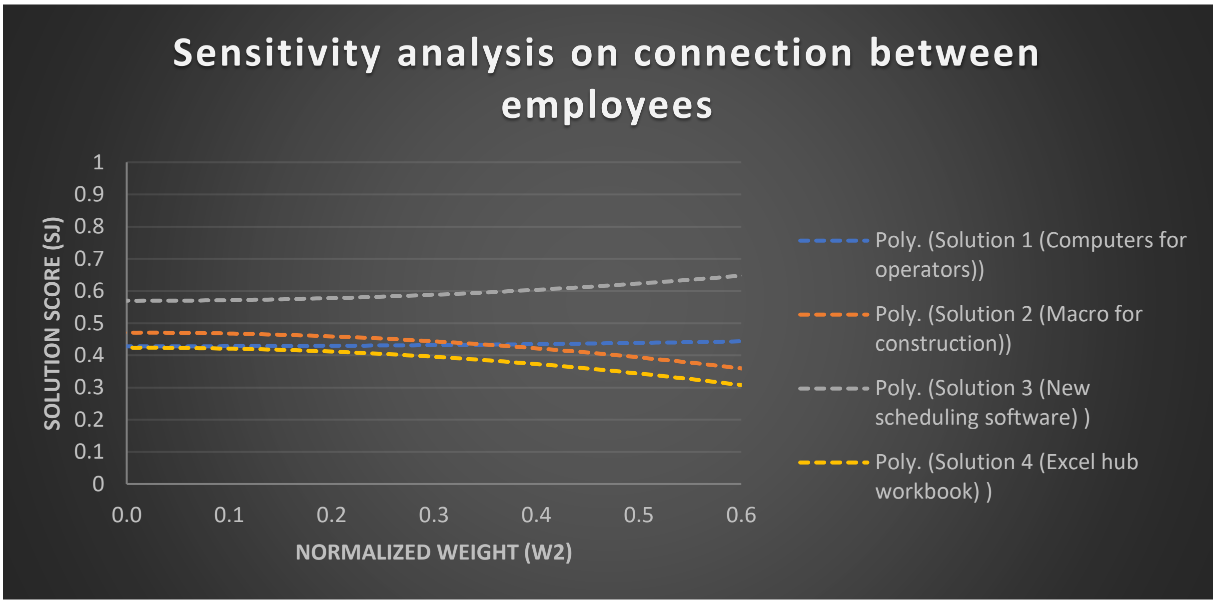

Figure 18: Sensitivity analysis on connection between employees

	Initial assessment	Sensitivity C2 (+90%)	Sensitivity C2 (+50%)	Sensitivity C2 (+200%)	Sensitivity C2 (+300%)
Normalized weight C2	0,028571	0,052924791	0,042253521	0,081081081	0,105263158
Solution 1 (Computers for operators)	0,428146598	0,428213852	0,428178824	0,428352333	0,428531366
Solution 2 (Macro for construction)	0,470337778	0,469845264	0,470101649	0,468834464	0,467534243
Solution 3 (New scheduling software)	0,569817925	0,570160719	0,569982226	0,570865401	0,57177414
Solution 4 (Excel hub workbook)	0,423529021	0,423013042	0,423281611	0,421954855	0,420595201

Table 19: Performance matrix for sensitivity analysis for C2

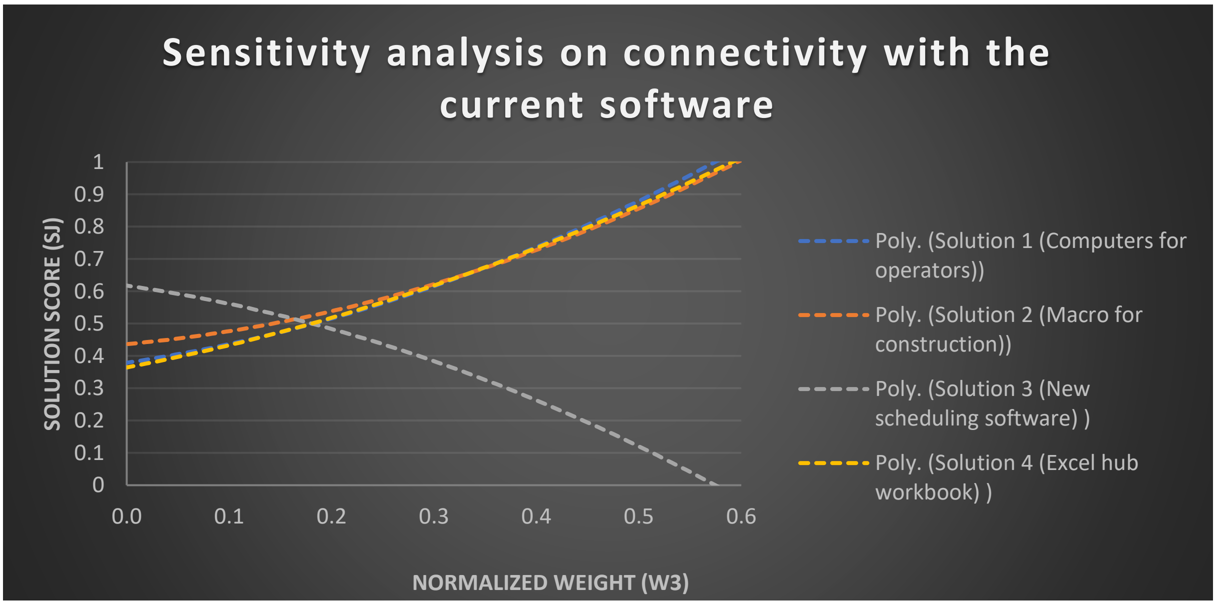

Figure 19: Sensitivity analysis on connectivity with the current software

	Initial assessment	Sensitivity C3 (+50%)	Sensitivity C3 (+90%)	Sensitivity C3 (+200%)	Sensitivity C3 (+300%)
Normalized weight C3	0,085714286	0,123287671	0,151193634	0,219512195	0,272727273
Solution 1 (Computers for operators)	0,428146598	0,45199348	0,473770591	0,53529363	0,585628012
Solution 2 (Macro for construction)	0,470337778	0,488161477	0,504953048	0,554512521	0,596675624
Solution 3 (New scheduling software)	0,569817925	0,54634361	0,524856455	0,46394818	0,413947864
Solution 4 (Excel hub workbook)	0,423529021	0,450129843	0,473816758	0,53815715	0,588376173
Solution 4 (Excel hub workbook)	0,423529021	0,423013042	0,423281611	0,421954855	0,420595201

Table 20: Performance matrix for sensitivity analysis for C3

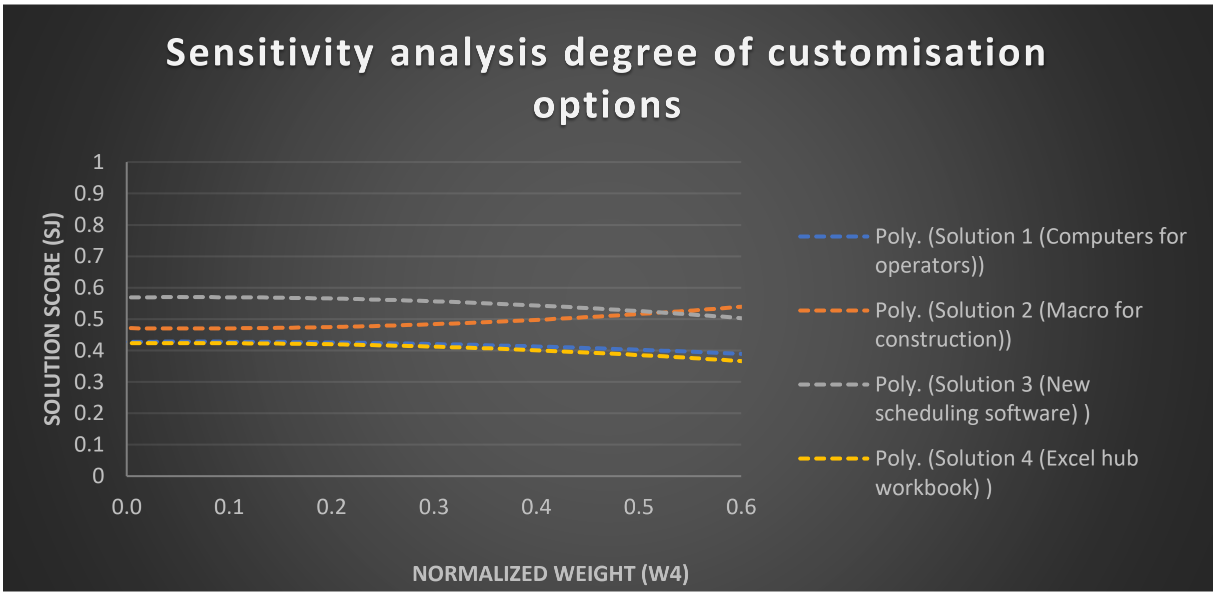

Figure 20: Sensitivity analysis degree of customisation options

	Initial assessment	Sensitivity C4 (+50%)	Sensitivity C4 (+90%)	Sensitivity C4 (+200%)	Sensitivity C4 (+300%)
Normalized weight C4	0,085714	0,123287671	0,151193634	0,219512195	0,272727273
Solution 1 (Computers for operators)	0,428146598	0,427639878	0,42709111	0,424941843	0,422209931
Solution 2 (Macro for construction)	0,470337778	0,471259831	0,472255553	0,476127411	0,480986729
Solution 3 (New scheduling software)	0,569817925	0,568930316	0,567971343	0,564237998	0,559542682
Solution 4 (Excel hub workbook)	0,423529021	0,422766949	0,421943597	0,418738224	0,414707234

Table 21: Performance matrix for sensitivity analysis for C4

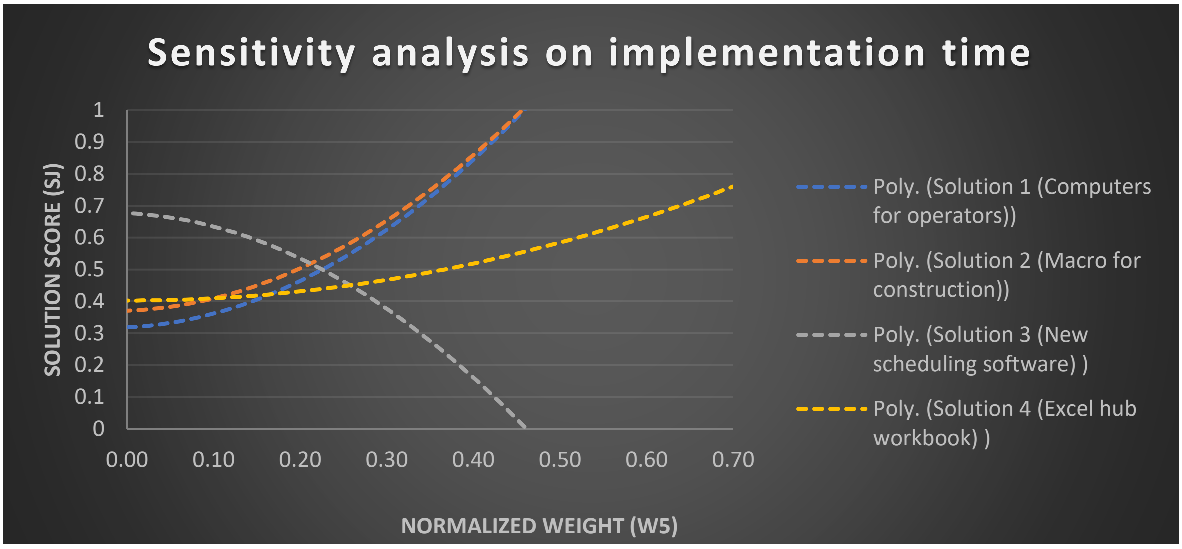

Figure 21: Sensitivity analysis on implementation time

	Initial assessment	Sensitivity C5 (-20%)	Sensitivity C5 (-40%)	Sensitivity C5 (-70%)	Sensitivity C5 (-90%)
Normalized weight C5	0,171429	0,142011834	0,110429448	0,058441558	0,02027027
Solution 1 (Computers for operators)	0,428146598	0,398620329	0,370060242	0,335190767	0,322830887
Solution 2 (Macro for construction)	0,470337778	0,442923641	0,416729322	0,385351285	0,374433273
Solution 3 (New scheduling software)	0,569817925	0,598787457	0,626685794	0,660537484	0,672468479
Solution 4 (Excel hub workbook)	0,423529021	0,41694318	0,411144258	0,40487424	0,402869498

Table 22: Performance matrix for sensitivity analysis for C5

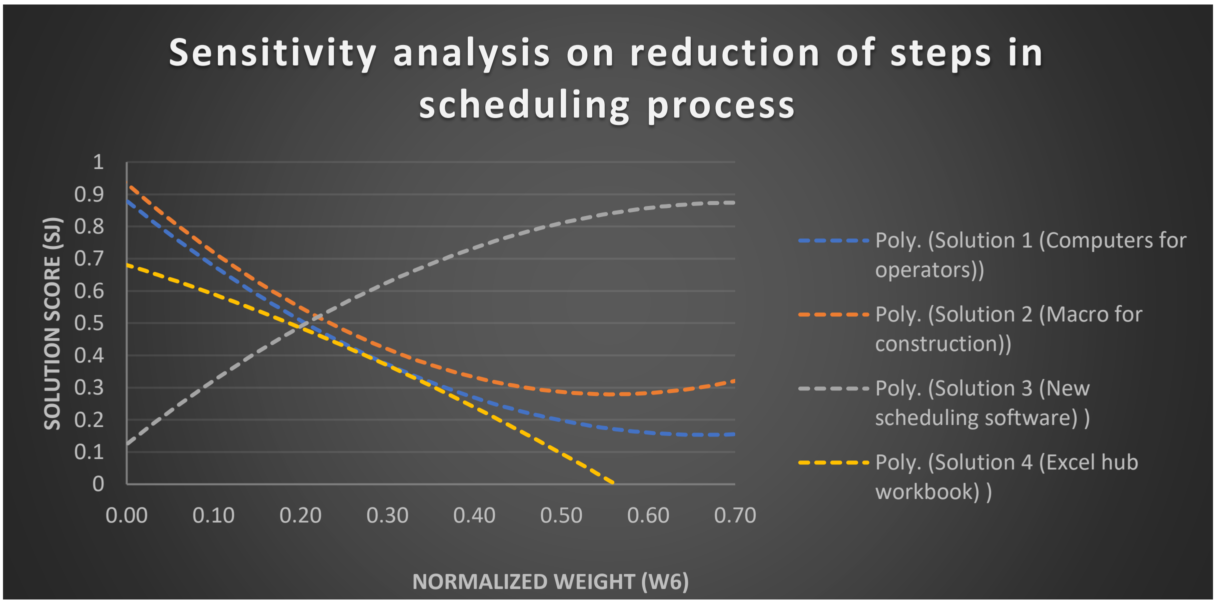

Figure 22: Sensitivity analysis on reduction of steps in scheduling process

	Initial assessment	Sensitivity C6 (-20%)	Sensitivity C6 (-40%)	Sensitivity C6 (-70%)	Sensitivity C6 (-90%)
Normalized weight C6	0,257142857	0,21686747	0,171974522	0,094076655	0,033457249
Solution 1 (Computers for operators)	0,428146598	0,481883562	0,550328095	0,69275302	0,807038711
Solution 2 (Macro for construction)	0,470337778	0,52338938	0,591098936	0,733241922	0,856149129
Solution 3 (New scheduling software)	0,569817925	0,51615482	0,447961112	0,306901981	0,195508863
Solution 4 (Excel hub workbook)	0,423529021	0,463452346	0,513044321	0,601746271	0,64892015

Table 23: Performance matrix for sensitivity analysis for C6

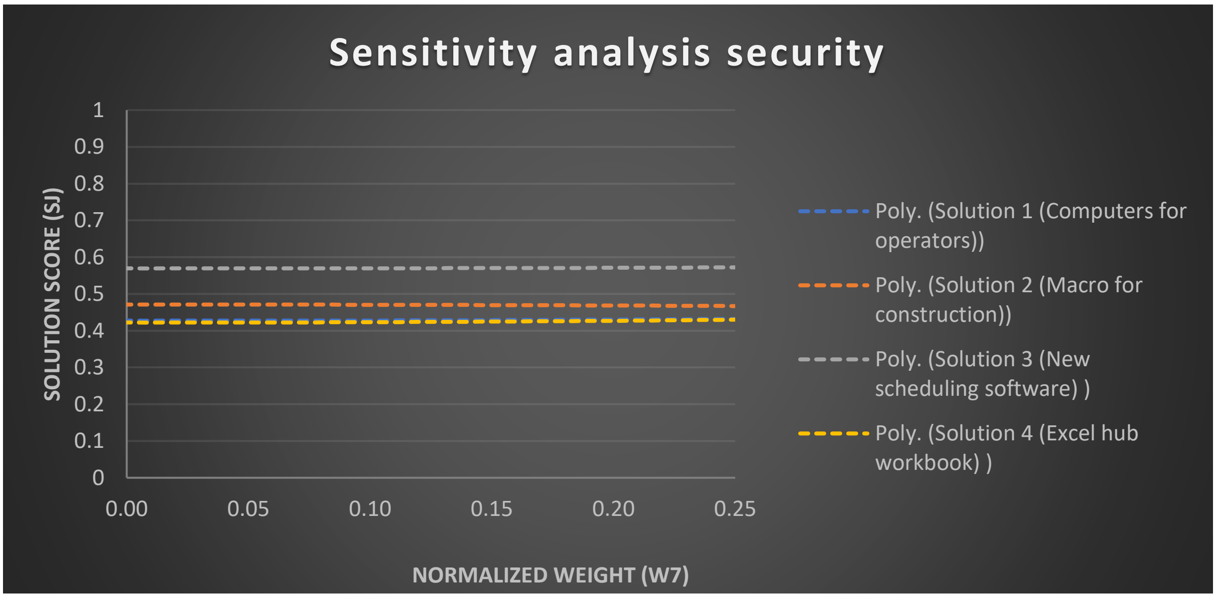

Figure 23: Sensitivity analysis of the security

	Initial assessment	Sensitivity C7 (-20%)	Sensitivity C7 (-40%)	Sensitivity C7 (-70%)	Sensitivity C7 (-90%)
Normalized weight C7	0,114285714	0,093567251	0,071856287	0,037267081	0,012738854
Solution 1 (Computers for operators)	0,428146598	0,427796204	0,42752303	0,427259076	0,427180766
Solution 2 (Macro for construction)	0,470337778	0,470619946	0,470839867	0,471052312	0,47111533
Solution 3 (New scheduling software)	0,569817925	0,5696217	0,569468849	0,569321262	0,569277497
Solution 4 (Excel hub workbook)	0,423529021	0,422980733	0,422552708	0,422138654	0,422015723

Table 24: Performance matrix for sensitivity analysis for C7

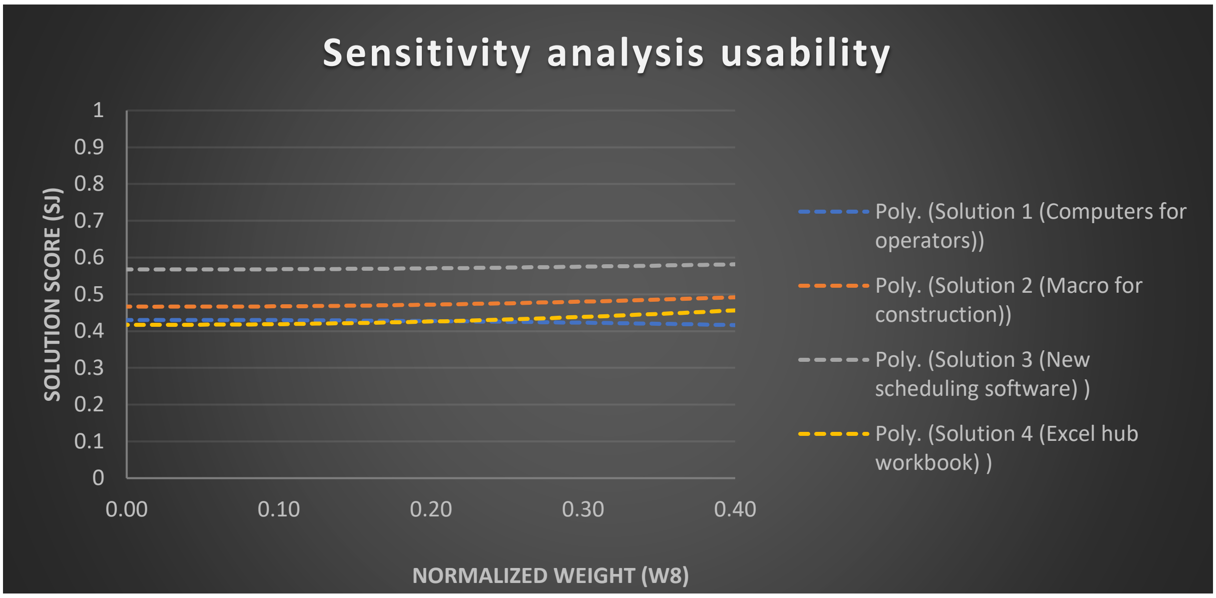

Figure 24: Sensitivity analysis usability

	Initial assessment	Sensitivity C8 (-20%)	Sensitivity C8 (-40%)	Sensitivity C8 (-70%)	Sensitivity C8 (-90%)
Normalized weight C8	0,171428571	0,142011834	0,110429448	0,058441558	0,02027027
Solution 1 (Computers for operators)	0,428146598	0,428960999	0,429598457	0,430216529	0,430400304
Solution 2 (Macro for construction)	0,470337778	0,468850512	0,467681731	0,466544544	0,466205662
Solution 3 (New scheduling software)	0,569817925	0,569003936	0,568366815	0,567749081	0,567565409
Solution 4 (Excel hub workbook)	0,423529021	0,421245796	0,419442308	0,417679654	0,417152851

Table 25: Performance matrix for sensitivity analysis for C8

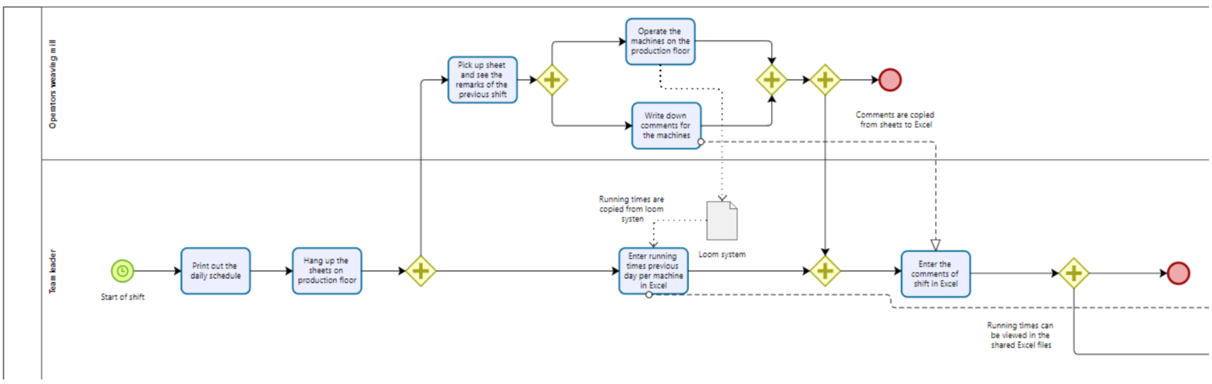

Figure 25: part of weekly planning process

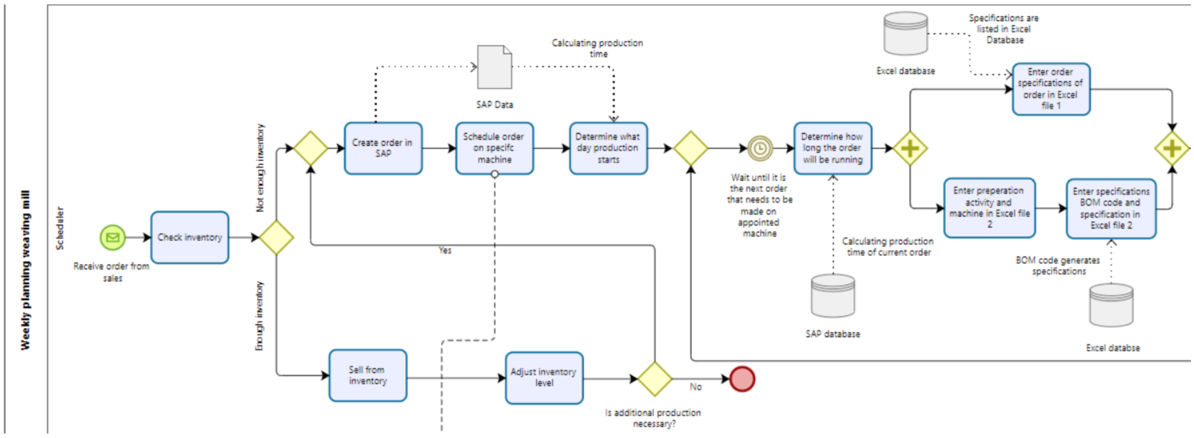

Figure 26: part 2 of weekly planning process

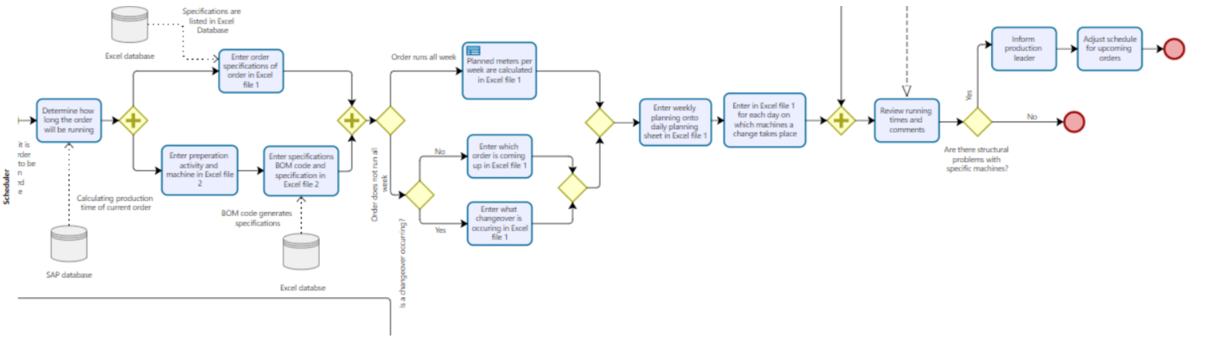

Figure 27: Part 3 of weekly planning process

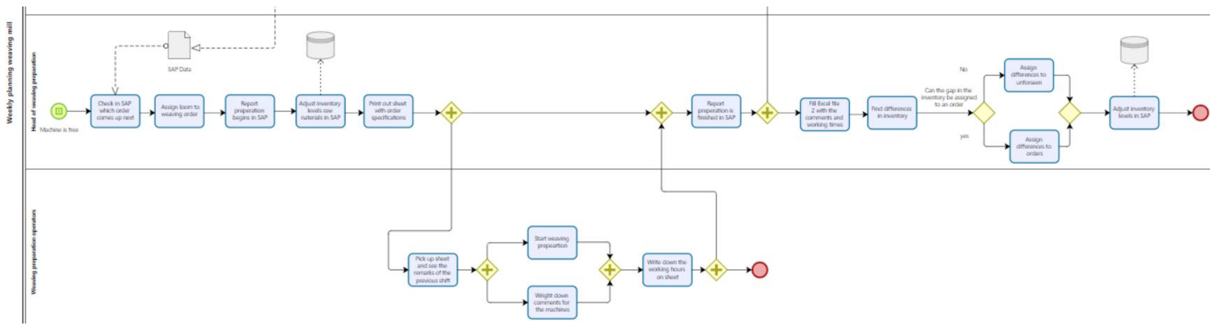

Figure 27: Part 4 of weekly planning process