

Bachelor Thesis  
Industrial Engineering and Management

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# Production Planning at Dupo Plastics

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**Eva J. P. Soontiëns**  
s1812254

**University of Twente**

Faculty of Behavioural, Management and Social Sciences

**Supervisors University of Twente**

[1] Dr. A. I. Aldea

[2] Dr. Ir. E.A. Lalla

**Supervisor Dupo Enschede B.V.**

[1] Alfred Schuiling

**UNIVERSITY  
OF TWENTE.**



## Executive Summary

Dupo Enschede B.V. is an industrial supplier of semi-finished technical parts made from plastic, metal and wood in both the Benelux and Europe. The company specializes in furniture legs, bed legs and armrests but offers a wide range of small injection moulded products. Custom made products are manufactured by Dupo Plastics, a plastic injection moulding company which was added to the trading firm.

Currently, the production planning at Dupo is made manually, using a paper schedule. Orders are often scheduled in the sequence in which they arrive at the factory, which leads to a production schedule that is found to be inefficient. But why does this problem occur now? The production planning has always been done by hand, but recently Dupo purchased a twelfth injection-moulding machine. This machine adds an extra component to the planning. Also, the available capacity has become smaller compared to the demand. Together this results in an overall more complex production planning, which cannot effectively be scheduled manually anymore.

In order to solve this problem, the main goal of this research is *to design a tool that automates the production planning process at Dupo*. To make the solving of this problem easier, it is divided into smaller research questions. One of them is to analyse the current situation at Dupo. The suitability of a production scheduling method depends on the characteristic of the planning environment. In this thesis, a framework by Jonsson & Mattson (2003) is used to analyse this planning environment. The current situation is defined as a *configure to order products* environment. The operations in this environment can be classified as assemble-to-order or make-to-order production. Based on these findings, the scheduling method is constructed.

Another important question related to the main research goal is how to select key performance indicators that should be present on the dashboard of the production scheduling tool. After conducting research, a method is constructed based on a method proposed by Shahin & Mahbod (2007), combining the analytical hierarchy process with the five generic performance objectives. This method has been successfully applied to the selection process of the indicators.

The result of this thesis is a tool that, among other things, schedules the production for the twelve machines of Dupo and a report discussing the development and construction of this tool. It provides a critical analysis of the production planning environment at Dupo, using a relatively unknown framework. It also introduces a new combination of methods in order to make a selection of alternatives, based on the relation to the processes and goals of the company.

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## Reader's Guide

In this reader's guide is stated which subjects will be covered in this thesis and which chapters relate to them. Refer to the table of contents for a more detailed description of the sections of this report. This project plan contains five chapters which cover the following four main subjects: the research plan, an analysis of the current situation, the development of the production scheduling tool, and the conclusion and evaluation.

The first subject, the research plan, is covered in the first two chapters of this thesis. Chapter 1 gives an introduction to Dupo Enschede and explains more about the problem and the desired situation. The goal of this research and the methodology used in this are discussed. Based on this the research model is constructed. Chapter 2 contains the theoretical framework, answering the knowledge questions using literature research.

The analysis of the current situation is made in Chapter 3. This chapter used theory explained in Chapter 2, to accurately describe the current production planning environment, including a business process diagram and UML class diagram.

Chapter 4 concerns the development of the production scheduling tool. It discusses the selection process of the key performance indicators, the design of the dashboard related to principles of user-friendly interface design, and the production scheduling method.

The concluding chapter of this thesis is Chapter 5. In this chapter, the dashboard design is evaluated and the answers to the research questions are summarized. It also provides recommendations to the company for future actions, recommendations for future research, and a discussion about the contribution to practice of this thesis.

## List of Abbreviations

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<b>AHP</b>	Analytical Hierarchy Process
<b>ANP</b>	Analytic Network Process
<b>APP</b>	Aggregate Production Planning
<b>ATO</b>	Assemble-To-Order
<b>BOM</b>	Bill of Materials
<b>BPD</b>	Business Process Diagram
<b>BPMN</b>	Business Process Modelling Notation
<b>CI</b>	Consistency Index
<b>CODP</b>	Customer Order Decoupling Point
<b>CR</b>	Consistency Ratio
<b>DS</b>	Design Science
<b>DSRM</b>	Design Science Research Methodology
<b>EKCIT</b>	European Knowledge Centre for Information Technology
<b>EPC</b>	Event-Driven Process Chain
<b>ETO</b>	Engineer-To-Order
<b>KPI</b>	Key Performance Indicator
<b>MAUT</b>	Multi-Attribute Utility Theory
<b>MACBETH</b>	Measuring Attractiveness by a Categorical Based Evaluation Technique
<b>MCDA</b>	Multiple-Criteria Decision Analysis
<b>MPSM</b>	Managerial Problem-Solving Method
<b>MTO</b>	Make-To-Order
<b>MTS</b>	Make-To-Stock
<b>OMT</b>	Object Modelling Technique
<b>OOA</b>	Object-Oriented Analysis and Design
<b>OOSE</b>	Object-Oriented Software Engineering
<b>PPC</b>	Production Planning and Control
<b>RI</b>	Random Consistency Index
<b>SMART</b>	Simple Multi-Attribute Rating Technique
<b>SMART</b>	Specific Measurable Attainable Relevant Timely
<b>UML</b>	Unified Modelling Language
<b>VBA</b>	Visual Basic for Applications

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## Chapter 1. Introduction

### 1.1 Introduction to Dupo Enschede

Dupo Enschede B.V.<sup>1</sup> was founded in 1972 by Mr. A.W. Duijn. Over the years the company developed into an industrial supplier of semi-finished technical parts made from plastic, metal and wood in both the Benelux and Europe. Dupo sells products cross-industry, focused on the (office) furniture industry, but also in many other sectors, such as retail, displays, contract and school furniture, machine-building and metal constructions.



The company specializes in furniture legs, bed legs and armrests, but offers a wide range of small injection moulded products for various applications, such as adjusting, stacking, connecting, moving, sliding, protecting, clamping, locking, spacing etc. There is the possibility to order “custom made” products entirely adjusted to the style and wishes of the customer. These products are manufactured by Dupo Plastics, a plastic injection moulding company which was added to the trading firm in 2002.

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<sup>1</sup> Dupo Enschede B.V. is referred to by using Dupo from this point onward.

## 1.2 Problem Identification

The assignment Dupo proposed for this bachelor thesis was *to create a dashboard or tool which automizes the planning process of their production schedule*.

Currently, the production planning at Dupo is made manually, using a paper schedule. Orders are often scheduled in the sequence in which they arrive at the factory, which is not always the optimal policy. Based on an interview with two actors of Dupo we identified the action problem, which is that the production planning is found to be inefficient (5).

The production planning has always been done by hand, so why does this problem occur now? Recently Dupo purchased a twelfth injection-moulding machine, adding an extra component to the planning. Also, the available capacity has

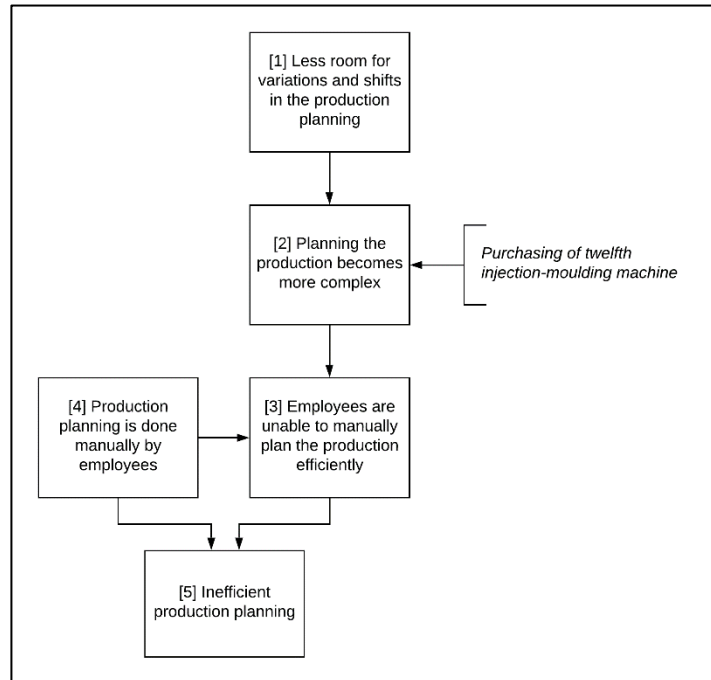


Figure 1. Problem Cluster

relatively become smaller compared to the demand. This leaves less room for variations and shifts in the production schedule (1). These two elements combined result in (2) an overall more complex production planning, which cannot (effectively) be scheduled manually anymore (3).

There are four rules of thumb which can help us to identify the core problem, as described by Heerkens, Van Winden, & Tjoitink in *Solving Managerial Problems Systematically* (2017):

1. The problem cluster shows all problems you identified as such. You are convinced that there is a relationship with other problems.
2. Follow the chain of problems back to these problems which have no direct cause themselves.
3. If you cannot influence something, then it cannot become a core problem.
4. If after applying rule 1, 2 and 3 more than one problem in the cluster remains, you should choose to fix the most important problem. The most important problem is whichever one whose solution would have the greatest impact effect at the lowest cost.

According to rule 2, problem 2, 3 and 5 cannot be core problems since they are directly caused by other problems in the chain. This leaves us with problem 1 and 4 as possible core problems. Less room for variations and shifts in the production planning can only be solved by increasing the available capacity by increasing the overall capacity (purchasing more machines) or decreasing the demand. This way there will be more leeway for the



employees when planning the production. However, this would imply that Dupo does not make optimal use of the available capacity. Besides that, purchasing new machines is very cost-intensive.

The remaining problem is the fact that the production planning is done manually by employees (4). This problem is a direct cause of the action problem but has no direct cause itself. A solution to this problem could be the initial assignment Dupo proposed; creating a dashboard or tool which automizes the planning process of their production schedule. This would solve the problem because the employees do not have to think about production scheduling anymore. Instead, they give the system the input values of an order, and it will schedule the production for them. We can create such a tool ourselves, making this solution very cost-efficient, since no investment seems to be needed. Therefore, our most important problem, and thus our core problem is that the production planning is done manually by employees (4).

Addressing problem 4 by creating a custom tool can also solve problem 3. Employees are unable to manually plan the production. If they do not have to do the planning manually, this problem will not exist anymore.

### 1.3 Relevance

Currently, the production planning is made by employees, which often schedule the production of orders in order of their arrival. The company feels that this is not the most efficient way to plan their production. By automizing the production planning process at Dupo, the planning no longer has to be made manually by the employees. In the ideal situation, the tool plans all the production at Dupo and only needs the input of new orders. With a more efficient production planning, Dupo could make better use of its capacity. Developing a tool for the company could have a significant impact on the efficiency of the production. It also could mean that employees working in the factory will be able to pay more attention to other parts of the production process since they do not have to spend time on the production schedule anymore.

According to the company, it is often the case that their products are not delivered in time or that the lead time between the placement of an order and delivery is longer than they would like it to be. A more efficient production planning system could possibly assist the company in solving these problems. Lastly, Dupo has some regular customers who order standard products. If it is possible they would like to produce these products in advance, to have them in stock. In the current production planning this is not included, but a new system could offer the possibility to include these repeating orders.

This research has a practical focus, which means that it is not its primary goal to contribute to academic literature. Because it is a case study for Dupo, the findings and outcome may not be applicable to other companies.

In the next sections, we further explain the research methodology we use during this bachelor thesis (Section 1.4). After this, we formulate our research goal (Section 1.5). Lastly, we construct the research design (Section 1.6) which includes the research questions and research design we will use to solve the main research problem we formulated in Section 1.5.

## 1.4 Research Methodology

In this section, we explain more about the research methodology of design science and how it will apply to this bachelor thesis. We also justify why we chose to use design science instead of the managerial problem-solving method.

Wieringa (2014) describes Design Science (DS) as “the design and investigation of artefacts in context”. He states that in order to fully understand a design problem, the context in which the improvement has to be made must be understood. This view on design science is illustrated in Appendix A. The difference between natural and social sciences and design science is that design science attempts to create things that serve humans, where natural and social sciences try to understand reality (Simon, 1969, as cited in Peffers et al., 2007). Design science is more solution-oriented, where natural and social sciences focus on understanding the problem.

Because DS is important when creating successful artefacts, Peffers, Tuunanen, Rothenberger, & Chatterjee (2007) proposed and developed the Design Science Research Methodology (DSRM) [Figure 2] which “...incorporates principles, practices, and procedures required to carry out such research and meets three objectives: it is consistent with prior literature, it provides a nominal process model for doing DS research, and it provides a mental model for presenting and evaluating DS research in IS [Information Systems].” (Peffers et al., 2007). The DS process consists of the following six activities:

1. *Problem identification and motivation*
2. *Define the objectives of a solution*
3. *Design and development*
4. *Demonstration*
5. *Evaluation*
6. *Communication*

The Managerial Problem-Solving Method (MPSM) could also be a suitable methodology for this type of research in a bachelor thesis and is often recommended at the University of Twente. It is an adaptive framework divided into seven phases:

1. *Defining the problem*
2. *Formulating the approach*
3. *Analysing the problem*
4. *Formulating (alternative) solutions*
5. *Choosing a solution*
6. *Implementing the solution*
7. *Evaluating the solution*

The first three phases of the MPSM are similar to the first two steps in the DS methodology. Both methodologies start by identifying and defining the core problem and research approach. Next, the MPSM focusses on formulating possible solutions for the core problem and choosing the most suitable one. This in contrast to the

DS methodology, which formulates the design objectives of a solution and develops a (single) artefact suitable for the situation. The DSRM will be more appropriate since it includes all the steps of the designing process in order to create a not yet existing artefact. Because our aim is to create a custom system for Dupo it is not relevant to think of other solutions for our core problem. Instead, the DSRM lets you create a tailored solution based on objectives. These objectives follow from the problem identification and motivation. Both the DSRM and the MPSM include the implementation (demonstration) and evaluation of the solution (artefact), so this is not a distinguishing element of the methodologies.

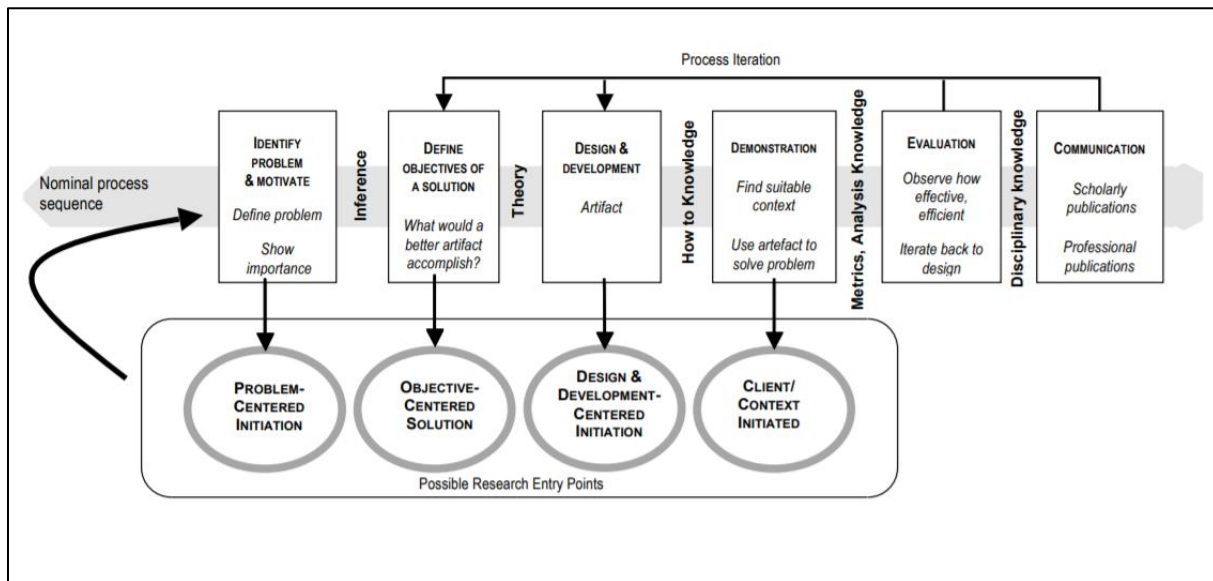


Figure 2. *Design Science Research Methodology (DSRM) Process Model*. Reprinted from “A Design Science Research Methodology” by Peffers et al. (2007), *Journal of Management Information Systems*, 24(3), pp. 45–78.

The research entry point used in this theses will be a problem-centred initiation. We use the problem-centred approach since our research resulted from the problem given by Dupo. This approach is the basis of the nominal process sequence. This means that we started with activity one of the DSRM and work towards activity six. We still have the possibility of going back to a previous activity when needed, since there is no need to always proceed in sequential order (Peffers et al., 2007).

The first activity in the DSRM is the problem identification and motivation. In this phase, the problems are researched in the context and the core problem is defined. We discuss this phase in Section 1.2 and 1.3. First, the core problem is identified in Section 1.2, then we discuss the relevance of the problem and value of solving it in Section 1.3. Now we have a clear idea of the problems we are facing, the next activity is defining the objectives of a solution. These objectives should rationally follow from the problem identification and motivation phase. They are set to trace out what is possible and desirable. In Section 1.7 we state the objectives of our solution. These are then delimited by the scope and limitations in Section 1.8. The ‘theory’ element between activity 2 and 3 of the DSRM is treated in Chapter 2. In this chapter, we answer some of the questions asked in Section 1.6. The knowledge gained from this will be useful before starting on the next activities.

After we completed activity 1 and 2 we will get started on activity 3, the design and development of the dashboard. In this phase, the artefact is created by first determining the functionality and its framework and then creating the actual tool. To test and demonstrate the working of the tool it is important to use it with actual orders the company receives. This will be done during activity 4 of the DSRM, the demonstration phase. The evaluation activity includes observing and measuring how well the tool performs when using it for the actual production planning of Dupo. This cannot be done over a longer period of time since the study only continues for ten weeks. However, we can see if the system plans the orders correctly and if there are any issues occurring when implementing it. The final activity of the DSRM, activity 6, is to communicate the importance of this research. This will be done by showing Dupo the performance of the tool when implementing it and by presenting the on during the public defense.

In the following sections, we will further construct our research model. We will describe the research strategy, work out our knowledge questions and plan on how to answer them.

## 1.5 Research Goal

In Section 1.2 we concluded that the production planning at Dupo is inefficient because the planning is made manually by the employees. Our main goal is to solve this problem by developing a tool that assists Dupo in planning the production. Other deliverables, stated in Section 1.10, are based on/in support of this tool. Using a template proposed by Wieringa (2014) for defining technical research problems in design science, we formulated the following main research question:

*“How to design a tool that automates and optimizes the production planning of Dupo?”*

If we want to express this research question in terms of norm and reality we would state that the current situation is that the production planning is not optimized and that the norm, or desired situation, is that the production planning is optimized by the tool.

## 1.6 Research Design

To find the answer to our main research question we need to divide it into smaller problems. Then we plan on how to solve these smaller problems by formulating a research method for each one. We categorized the questions according to the deliverables, stated in Section 1.10.

### *Analysing the Current Situation*

#### *1. What is the current situation at Dupo regarding the production planning process?*

In order to describe the current situation at Dupo, we need to gain a better understanding of the aspects and variables a production planning process includes. We will learn about the different aspects of production scheduling, and about the variables which it includes. This information will help us to describe the current situation systematically. Combining this with information specific to the production process at Dupo, we will gain a good understanding of the current situation. We will perform a literature review to find a systematic way to describe the situation.

## *2. What methods are available for the selection of KPIs?*

By answering question 2, we will get to know which methods are available for the selection of key performance indicators (KPIs). We will propose a method for selecting KPIs based on a literature review and apply this method later on in this thesis.

## *3. What KPIs can be used to measure the production (planning) process?*

The answer to question 3 will provide a list of frequently mentioned KPIs in relation to production planning and scheduling. We will select suitable KPIs from this list using the method that was chosen from the answer of question 2. Including these measures in the tool, will allow us to measure the situation regarding the production planning at Dupo.

### *Developing the Tool*

## *4. What literature is available regarding the development of a production planning system?*

Executing a systematic literature review to answer question 4 will give us more insight into the development of a production planning tool. We will shortly discuss and compare studies that are relevant to this thesis.

## *5. What information is needed from the company to develop a production planning tool?*

Before we can build the actual system it is important to get an accurate idea of which information about the production process is needed, and what information is available. If there is a difference between these two, this information needs to be gathered first.

## *6. How can we develop a user-friendly tool?*

The tool we are going to develop will be operated by the factory workers at Dupo. Therefore, it is important that it is user-friendly and adjusted to their preferences and needs. We will use systematic literature research to answer question 6. Next to this, we will interview the employees about their preferences and thought regarding the dashboard.

### *Writing the Manual*

## *7. To what extent are the employees acquainted with production planning methods and Microsoft Excel?*

To develop a manual which is understandable for its users, it is important to know to what extent they have knowledge of the subject. In this case, we would like to know their level of knowledge from production planning methods and Microsoft Excel. We can gain this understanding by talking to the employees that will possibly operate the tool in the future, and listening to the questions they might have about the tool.

## 1.7 Objectives of the Solution

In this section, we will define the objectives for a solution and answer the question: *“What would a better artefact accomplish?”*. We will start with the requirements that drove the research effort in the first place. Next, we shall address the function and features which Dupo would like to see in the end product. Lastly, we define objectives based on some practical matters, such as the resources that are available.

The main objective is to construct a tool for Dupo that automates the production planning process in order to make it more efficient. The main requirements of the tool have been set by Dupo and were part of the assignment description. Dupo set the following requirements of functions and features:

1. *The tool must include the production planning for the twelve injection-moulding machines.*
2. *The tool must provide insight into the remaining capacity that is available, in order to be able to give customers a more accurate indication of the expected delivery time of their orders.*

Dupo does not make a lot of demands concerning the features of the tool. They do not ask for precise planning which comes down to minutes, but they would like to have a general idea of when they have to start production. We also define the following objectives:

3. *The tool has to be easy to operate by the factory workers. They need to gain a good understanding of how to use the tool to plan the production in an efficient way.*
4. *The tool needs to run on a regular desktop computer.*

## 1.8 Scope and Limitations

The main focus of this thesis is the design of the tool for production planning at Dupo. This study focusses on the production planning process at Dupo specifically. In the perfect situation, the system fully automates the production planning for all orders for the twelve machines. Given that the time to conduct this research is limited, it is important to clearly define the limitations of the research in advance. If it appears not to be achievable in the given time, we will limit the tool to the planning of the most frequently produced products, omitting the special orders. Dupo pointed out that in this case, they will be able to further develop the tool in a later stage.

It will not be possible to evaluate the performance of the tool over a large time span since the research does not continue over a long enough period of time. This study does not propose a plan for Dupo on how they need to evaluate the performance of the tool, but the company can form their own method for evaluation over a longer period of time.

The fact that the company did not use a production planning system previously can be seen as a limitation. They do not have any prior knowledge or experience with such a system. This way of working will be completely new to the employees. This may lead to a more difficult implementation phase, than if the company would be acquainted with a tool like this.

The company does not want to invest in a bigger production scheduling system. This means there are no resources available to purchase an already existing tool. A more complete tool may connect better to other departments and systems the company currently uses. Allowing the company to create an all-over picture of their business. The tool created as the outcome of this study will only focus on the production scheduling element of their operations.

Lastly, the tool is developed using Microsoft Excel VBA. This platform has the disadvantage that it does not work well in a collaborative environment, it does not communicate with other the software that is being used by the company. In the case of Dupo, this is a consequence of the fact that they do not wish to invest in a bigger, more complete, system.

### 1.9 Validity and Reliability

Heerkens provides a clear explanation in his microlecture about validity<sup>2</sup>: “Validity means: are you actually measuring, what you think you are measuring?”. In other words, does it reflect the reality it needs to represent? Validity can be divided into internal and external validity. Internal validity relates to the correctness of your research design. It determines how well your research is done and if it avoids confounding. External validity involves the generalizability of your research. Would your results also be valid for another research population?

The biggest threats to internal validity occur in the selection process of the KPIs. A variation of the AHP method is used to select the KPIs that should be included in the tool. Firstly, it is important that the scale on which KPIs are assessed is legible to the person who needs to compare the KPIs. The scale that is used in this thesis is the nine-point scale first introduced by Saaty (1977). This ‘fundamental scale of absolute numbers’ is derived mathematically from stimulus-response theory (Ozdemir, 2005), and allows the user to make comparisons in an accessible and understandable manner.

The internal validity will also be threatened when measurements are inconsistent. To improve this validity redundancy of informed judgements is needed. The AHP method uses paired comparisons which make this redundancy possible. The user does not only need to rate A in comparison to B, and B in comparisons to C, but also A in comparison to C. The relation of A to C could also be retrieved from the first two judgements, but they are compared again to increase check the judgement. This increased redundancy gives rise to inconsistency (Ozdemir, 2005). To check if the judgements are consistent, the consistency of each used matrix is measured using a method from *Practical Decision Making* by Mu & Pereyra-Rojas (2017) will be used.

The tool developed in this bachelor thesis is fully adapted to the conditions and preferences of Dupo. Because of this, the result will not be directly generalizable to other companies. When another company would want to develop a similar system, they could use the thesis as a guideline. However, the objectives of the solution, preferences and limitations may differ from company to company. Also, the production process is set up differently in every business. This will result in a different end product every time. By carefully documenting

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<sup>2</sup> Retrieved October 17, 2019, from <https://vimeo.com/showcase/2938606/video/117885780>.

every step that is taken during this research, external validity can be increased. The report of this research can then be used by other researchers to apply to other companies.

Reliability is the extent to which research is repeatable. Will another researcher get the same results if he or she repeats the research? In this case, the reliability is threatened by the fact that one of the data sources of this research is self-reported data. This type of data is limited by the fact that it cannot be independently verified. Self-reported data is data which is obtained from for example interviews or questionnaires. When interviewing an employee or conducting a survey, information is obtained about the subject from the employees perspective, which is not always objective.

Furthermore, there is only one researcher working on this project. Which means that there is only one person that makes the decisions, without being checked by a co-researcher. When a different person repeats the research, he or she may make different decisions when selecting literature, interpreting data obtained from interviews or setting up the framework for the tool.

### 1.10 Deliverables

This report will deliver:

- A tool which automizes the production planning process for the twelve injection-moulding machines of Dupo Plastics.
- A manual for the factory workers which describes how to use the tool.
- An analysis of the current situation at Dupo concerning the production planning process.
- A report discussing the design and development process of the tool.



## Chapter 2. Theoretical Framework

After constructing our research approach we now find ourselves between step 2 and 3 of the DSRM, at the 'theory' component. In this chapter, we will answer the knowledge questions proposed in Section 1.6.

### 2.1 Describing the Current Situation

*What is the current situation at Dupo regarding the production planning process?*

#### 2.1.1 Planning Environment

According to Jonsson & Mattsson (2003) "the suitability of various planning and control methods depends on the demand, products and manufacturing characteristics". They propose a framework for defining planning methods and planning environments. The first aspect which is addressed is planning methods. The study focusses on detailed material planning, shop floor control and capacity planning levels. The second element of the framework, the planning environment, is divided into three groups, variables related to the product, the demand, and the manufacturing process. Jonsson & Mattsson (2003) define planning environments based on the following seven variables:

- **Product (BOM) complexity** – The number of levels in the bill of materials and the number of items on each level. Choosing from: *1-2 levels in the bill-of-material and few included items, 1-2 levels in the bill of materials and several included items, 3-5 levels in the bill of materials, more than 5 levels in the bill of materials.*
- **Degree of value-added at order entry** – The extent to which customer-specific items are added to the delivered product. Choosing from: *make-to-stock and deliver from stock, assembly-to-order or plan, manufacturing-to-order, engineer-to-order.*
- **Volume/frequency** – The annual manufactured volume and the number of times per year that products are manufactured. Choosing from: *few large customer orders per year, several customer orders with large quantities per year, large number of customer orders with medium quantities every year, frequent call-offs based on delivery schedules.*
- **Production process** – The type of production system that is used, e.g. one-off, batch, mass or continuous production. Choosing from: *continuous process production, continuous mass production, frequent batch production (more frequent than monthly), batch production, one-off or infrequent batch production.*
- **Shop floor layout** – Functional (process), cellular (flow) or line layout.
- **Batch sizes** – The typical manufacturing order quantity. Choosing from: *equivalent to customer order quantities/call-of quantities, small (one week of demand), medium (a few weeks of demand), large (a month's demand or more).*
- **Through-put times in manufacturing** – The typical manufacturing through-put times. Choosing from: *short through-put times (a week or less), medium through-put times (a few weeks), long through-put times (several weeks).*

Based on these variables, four main types of planning environments are differentiated to be able to compare companies with different environments. In our research, we not necessarily need to compare our company to other companies, because the solution will be tailored to the environment of Dupo. However, the four types of planning environments are also used by Jonsson & Mattsson (2003) to evaluate the most appropriate planning method for each environment. For this reason, we will classify Dupo in this framework.

The final step in the framework for defining planning methods and planning environments is the matching of planning environments and planning methods. Jonsson & Mattsson (2003) made an assessment of how well various planning methods are expected to perform in the four planning environment, based on a conceptual analysis of the characteristic of planning methods. This matrix, shown in Appendix C, needs to be seen as a hypothesis of the user satisfaction and usability of the planning methods in the different environments.

### 2.1.2 Process Modelling

To further map out the current situation at Dupo we need to model the business process. This can be done using the Business Process Modelling Notation (BPMN). The primary goal of this notation is to provide a notation that is understandable by all users. The BPMN “creates a standardized bridge for the gap between the business process design and process implementation” (Weske, 2012). Mapping the process by using the BPMN will give us more insight into the process and make it easier to understand for anyone who is reading the report.

The four basic categories of elements of any Business Process Diagram (BPD) are flow objects, connecting objects, swimlanes, and artefacts. The flow objects are the core elements of the BPD. The set consists of three recognizable shapes for events, activities and gateways, making them easy to remember. The connecting objects are there to connect the flow objects. The connectors are represented by different styles of lines, separating three different types of flows: sequence flow, message flow, and association.

Many process modelling methodologies use swimlanes as a mechanism to organize activities into separate categories in order to indicate different functional responsibilities (White, 2004). The BPMN includes two types of swimlanes: pools and lanes. Pools are used to separate two entities or participants and are physically separated in the BPD, while lanes often separate specific function within a company. Artefacts are used to include additional information about the process that is not essential for the sequence or message flow.

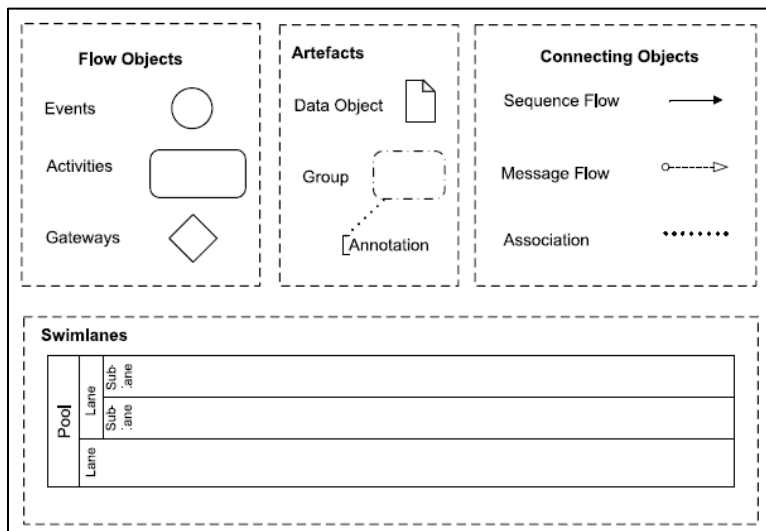


Figure 3. BPMN: categories of elements.

Reprinted from “Business Process Management: Concepts, Languages, Architectures” (2nd ed.) by Weske (2012), p. 209.

Another view on business process modelling is the Event-Driven Process Chain (EPC). Similar to the BPMN, the EPCs are targeted to be easily understood and used by its users (Korherr & List, 2006). In order to make them less complex, the EPC divides processes into three separate views: data view, function view, and organisation view. The EPC consists of the following elements: functions, events, logical operators, organisation units, information objects, and deliverables.

Despite the fact that the EPC is widely-used for business process modelling, the BPMN will be used in this bachelor thesis. This is because the EPC involves a larger number of less recognizable operators, which may make the diagram harder to interpret by persons unfamiliar with this kind of diagrams. Also, the separation into different views will make the situation more complex, instead of easier to comprehend, because the distinction between these views is not necessarily needed. Altogether, the BPMN will deliver a clearer picture of the current situation at Dupo, because the operators seem to be more intuitive and widely used.

### 2.1.3 Data Modelling with UML

Modelling is the designing of software applications before coding (Object Management Group Inc.<sup>3</sup>). Unified Modelling Language (UML) is a modelling language that provides a standard way to visualize the design of a system. UML has many types of diagrams, which can be categorized into structural UML diagrams and behavioural UML diagrams. To create a data model of the situation at Dupo, a UML class diagram will be used. A class diagram is a structural UML diagram, which means that the diagram represents the structure of the information. Structural diagrams are often used when developing software systems.

The data present at Dupo will be visualized in a UML class diagram. A class diagram is a type of structural UML diagram that is used to model the static structure of a system, it describes the elements of the system and the relationships between them. A class diagram consists of a set of classes and a set of relationships between classes. A class is a group of objects with similar roles in the system.

<sup>3</sup> Retrieved August 12, 2019, from <https://www.uml.org/what-is-uml.htm>.

Structural features (attributes) define what objects of the class “know”, behavioural features (methods) define what objects of the class can do (Visual Paradigm<sup>4</sup>).

In a class diagram, a class is represented by a rectangle that can be subdivided into sections:

- The upper section contains the name of the class.
- The middle section contains the attributes of the class. It is used to describe the qualities of the class.
- The bottom section includes operations. The operations describe how a class interacts with data.

Every class has a different access level, depending on the visibility of a class. The visibility of attributes and operations specifies who is and who is not permitted to access them (Seidl, Scholz, Huemer, & Kappel, 2015).

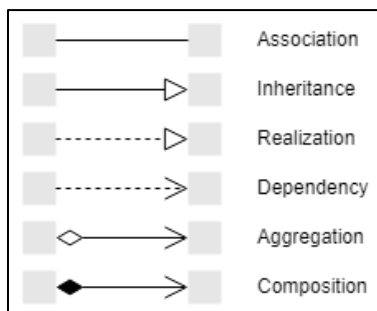


Figure 4. Relationships in UML class diagrams.

The relationships between classes are indicated using different types of arrows. The relationships can be one of the types shown in Figure 4. An association is a general relationship between classes, which shows that classes are linked to each other or combined logically or physically into some assembly. Inheritance (or generalization) implies that one class is derived from another. Generalizations can be used to highlight common characteristics between classes or to derive more specific classes from existing classes. Realization means that one class implies another. A

dependency between classes indicates that the classes depend on each other and that changing one may influence another.

Aggregation implies that one class is part of another or that one class “has” another class. This type of association is used to indicate that one class is a result of another class being built as a collection. A composition association is a stronger version of an aggregation and means that one class is entirely made of another. This results in that the parts exist and stop to exist as a whole.

To model the activities that will be performed by the tool, an activity diagram is used. An activity diagram is considered to be a behavioural diagram because it describes the dynamic behaviour of a system. The only activities these diagrams do not show are message flows from one activity to another. In this case, the activity diagram is used to show the logic of the VBA programming code.

The activity diagram displays activities using rectangles with rounded corners. Diagrams have to be read from top to bottom and have branches and forks to describe conditions of parallel activities. A fork is used when multiple activities are occurring simultaneously. Action flows illustrate the transitions from one activity to another, and are drawn using an arrowed line. After completing an activity the system flows to the next activity using the action flow. When a decision is required before moving to the next activity, a diamond with a condition is added between the two activities.

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<sup>4</sup> Retrieved August 12, 2019, from <https://www.visual-paradigm.com/guide/uml-unified-modeling-language/what-is-class-diagram/>.

The UML language can be classified under object-oriented analysis and design (OOA). Prior to the UML, several other OOA methods were developed: the Booch method by Grady Booch (1991), object-modelling technique (OMT) by Jim Rumbaugh (1991), and object-oriented software engineering (OOSE) by Ivar Jacobson (1992). In 1995 Booch, Rumbaugh and Jacobson combined their methods and created the unified modelling language. Each of these three methods can be seen as an alternative for using the UML. However, these three methods were combined in order to improve all three earlier methods and to address problems that none of the methods could handle well independently (University of Klagenfurt, 2003). Therefore, UML is the best alternative to use in this thesis.

## 2.2 KPI selection

### *What methods are available for the selection of KPIs?*

Eckerson (2009) states that KPIs are multidimensional, which means that they have a variety of characterizing features. Key performance indicators measure the performance of a company against certain targets. These targets are specified based on the strategic goals and objectives. They have performance ranges, which include being above, on or below target, measured against a baseline or benchmark (Turban, Sharda, Delen, & King, 2010). According to Turban et al. (2010), the basic principles of a good collection of KPIs are the following:

- *Measures should focus on key factors.*
- *Measures should be a mix of past, present, and future.*
- *Measures should balance the needs of all stakeholders.*
- *Measures should start at the top and flow down to the bottom.*
- *Measures need to have targets that are based on research and reality.*

Macharis & Bernardini (2015) categorized the most popular multiple-criteria decision analysis (MCDA) methods by problem type and approach based on Ishizaka & Nemery (2013). Ishizaka & Nemery (2013) explain that “MCDA methods provide stepping-stones and techniques for finding a compromise solution”. These methods have been developed to support decision making in every unique decision process. The MCDA methods can be grouped into the following three sections, according to their approach:

- Full aggregation approach (American school).
- Outranking approach (French school).
- Goal, aspiration or reference level approach.

For the purpose of selecting KPIs, the full aggregation approach is the most appropriate. This approach allows bad scores to be compensated by good scores. In the outranking approach, scores are not compensable and “the notion of incomparability is allowed” (Ishizaka & Nemery, 2013). In the case of Dupo, the KPIs are ranked according to their importance. In order to do this, each KPI alternative needs to be compared to the others, and incomparability is not allowed. Lastly, there is the goal, aspiration or reference level approach. This approach requires a goal to be defined at the beginning of the selection process, then the closest option to the goal is selected. Because the goal of this selection process is to rank the KPIs, this method will not be relevant.

After categorizing the methods according to the approach, they can be grouped into four categories based on the type of decision problem they solve. Four types of problems are considered by Ishizaka & Nemery (2013):

- Choice problems – Select the single best option or reduce the group of options to a subset.
- Ranking problems – Rank the options from best to worst.
- Sorting problems – Sort similar options into predefined groups or categories.
- Description problems – Describe options and their consequences.

As mentioned before, the goal of the selection process is to rank the KPIs from most to least important to the employees at Dupo. Therefore, the problem is classified as a ranking problem. Macharis & Bernardini (2015) constructed a table which categorizes the MCDA methods according to the approach and type of problem, shown in Table 1.

Approach	Choice Problem	Ranking Problem	Sorting Problem	Description Problem
Full Aggregation Approach	AHP/ANP MAUT/MAVT SMART/SMARTER MACBETH	AHP/ANP MAUT/MAVT SMART/SMARTER MACBETH	AHPSort UTADIS	
Outranking Approach	PROMETHEE ELECTRE I	PROMETHEE ELECTRE III	FlowSort ELECTRE-Tri	GAIA FS-Gaia
Goal, Aspiration or Reference-Level Approach	TOPSIS Goal Programming DEA	TOPSIS DEA		

Table 1 *Most popular MCDA methods, categorised by problem type and approach* (Macharis, & Bernardini, 2015).

Four types of methods, highlighted in Table 1 using the blue rectangle, remain after categorizing the MCDA.

The Analytical Hierarchy Process (AHP), developed by Thomas L. Saaty, is an approach which helps decision-makers to simplify complex problems. The AHP is often referred to as “the most powerful and widely used technique for decision making. It allows decision-makers to measure the consistency and stability of their decisions.” (Shahin & Mahbod, 2007). The method is based on three principles: decomposition, comparative judgement, and synthesis of priorities.

In their article about the prioritization of KPIs, Shahin & Mahbod (2007) propose a method which combines the AHP method with SMART (Specific, Measurable, Attainable, Relevant, and Timely) goal setting to select KPIs. When using this approach, the KPIs should be compared with respect to the organizational goals. The approach consists of the following five steps:

1. *Define and list all of the KPIs.*
2. *Build an AHP hierarchy, in which the goal is to prioritize KPI alternatives with respect to SMART criteria.*
3. *Undertake a pairwise comparison between alternatives, i.e. KPIs.*

4. *Calculate composite priority: calculate local weights and global weights.*
5. *Selection of KPIs that are more relevant to organizational goals.*

The Analytic Network Process (ANP) is a generalization of the AHP, by considering the dependence between elements of the hierarchy (Saaty, 2006). The theory uses relative measurement with absolute scales of tangible and intangible criteria. Its goal is to reduce a multidimensional problem into a one dimensional one. Both the AHP and the ANP use pairwise comparison in the selection method. However, the ANP also includes the interrelationships between the decision levels, while the AHP only considers one direction of relationships (Görener, 2012).

The Multi-Attribute Utility Theory (MAUT) proposed by Keeny and Raiffa is based on the expected utility theory. This theory reduces the criteria values into utility scores (Allah Bukhsh, Stipanovic, Hartmann, & Klanker, 2018). Where the main focus of the AHP is to derive relative importance by pairwise comparison, when using MAUT the emphasis is on the selection of the utility function and to reduce the data to utility scores (Allah Bukhsh et al., 2018).

The Simple Multi-Attribute Rating Technique (SMART) is a method developed by Edwards (Patel, Bhatt, & Vashi, 2017). It was designed to make the implementation of the origins of MAUT easier. In SMART the selection is done mathematically by the decision-maker and the ratings are assigned on the natural scale of the criteria. For example, a natural scale is a range of 100 to 200 miles per hour if you are evaluating the top speed of vehicles. Since the KPI alternatives will have different natural scales, it will not be possible to all rank them on one natural scale. Therefore, this method is not used in this thesis.

The Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) was first introduced by Bana e Costa and Vansnick. It is an interactive approach that requires only qualitative judgements about the differences between options to quantify relative attractiveness of options. The method is mostly applied by the M-MACBETH software. Since this software is not freely available, this method cannot be used in this thesis.

In order to select relevant KPIs for the dashboard, the method proposed by Shahin & Mahbod (2007) is used in this thesis. The ANP method considers a large number of relationship, which would make the system hard to evaluate with the employees of Dupo. The AHP compares the KPIs pairwise and on one level, keeping it transparent and manageable to everyone. Furthermore, the AHP method allows an easy transition from subjective information, obtained using interviews or questionnaires, to objective information which can be used for data processing and comparison. The MAUT method was found to be less accessible than the AHP (Bard, 1992) and is therefore not used in this thesis.

According to Slack, Chambers, & Johnston (2010), one of the problems when choosing performance measures is achieving a balance between having a few key measures and having many detailed measures. In the case of Dupo, a compromise can be reached by ensuring a link between the company's overall strategy and the most important KPI's. Shahin & Mahbod (2007) proposed a method that combines the analytical hierarchy process (AHP) method with SMART goal setting to select KPIs. By prioritizing KPI alternatives with respect to SMART

criteria, decisionmakers are assisted in prioritizing KPIs in terms of their relevance to the goals of the company. The combination of the AHP with SMART may not be the best in the case of Dupo.

A more accessible way for the employees to address the relevance of KPIs would be to evaluate the KPIs with respect to the five generic performance objectives proposed by Slack et al. (2010): quality, speed, dependability, flexibility, and cost. These measures are more directly related to the production process and goals from Dupo, and therefore more understandable for the employees. Also, the five objectives used by Slack et al. (2010) can be seen as the dimensions of overall performance that will satisfy the customers. Based on the above discussion, combining the AHP with a measure of performance objectives is found as the most appropriate method. The approach from Shahin & Mahbod (2007) will be adjusted, resulting in the following five steps:

1. Define and list all of the KPIs.
2. Build an AHP hierarchy, in which the goal is to prioritize KPI alternatives with respect to the five generic performance objectives.
3. Undertake a pairwise comparison between alternatives, i.e. KPIs.
4. Calculate composite priority: calculate local weights and global weights.
5. Selection of KPIs that are more relevant to organizational goals.

In addition to the calculations mentioned above, the consistency of the input should be addressed. Once the judgements from the questionnaire have been entered, it is necessary to check that they are consistent. Because the numeric values are based on subjective judgements of people, it is unavoidable that there will be inconsistencies. However, only a certain amount of inconsistency is allowed when using the AHP method. The AHP calculates a consistency ratio (CR) by comparing the consistency index of the matrix (CI) with a consistency index of a random matrix (RI).

$$CR = \frac{CI}{RI}$$

Saaty (2012) has shown that the consistency ratio should be 0.10 or less, for the analysis to be valid. If the ratio is greater than this the judgements should be revised.

In step 3 of the method proposed above, pairwise comparison is made between the KPIs and between the performance objectives. This data can be used to measure the consistency of the judgements. In the method proposed by Shahin & Mahbod (2007), the sum of the normalized rows is used to calculate the global weights. To measure the consistency of the input values, the method in *Practical Decision Making* by Mu & Pereyra-Rojas (2017) will be used. In this method, the average value of the normalized rows is used as a priority value. Then this priority is used as a factor in the table with original judgements. The results of this are weighted columns. From the weighted columns, the weighted sum can be calculated by summing each row.

After the weighted sum values have been calculated for each KPI and each performance objective, the average of the values will be calculated, this value is called  $\lambda_{max}$ . It can be obtained by dividing the elements of the weighted sum vector by the corresponding priority of each criterion.



The consistency index (CI) can be calculated using  $\lambda_{max}$  by applying the following formula:

$$CI = (\lambda_{max} - n)/(n - 1)$$

where  $n$  is the number of compared elements.

Using the CI we can then calculate the consistency ratio (CR), earlier defined as:

$$CR = \frac{CI}{RI}$$

where RI is the consistency index of a randomly generated comparison matrix. This matrix can be found in Appendix G. If  $CR \leq 0.10$  the matrix is considered consistent. If  $CR > 0.10$  the matrix is inconsistent, the input values (judgements) should then be reconsidered.

#### *What KPIs can be used to measure the production (planning) process?*

This section provides a list of commonly used KPIs when measuring production planning processes. Later on, several KPIs will be selected, using the method described in the previous section. The KPIs in Table 2 are a selection of measures for the production scheduling process, found in the studies by Hon (2005), Bauer, Lucke, Johnsson, Harjunkoski, & Schlake (2016), and Rakar, Zorzut, & Jovan (2004).

KPI alternative	Hon (2005)	Bauer et al. (2016)	Rakar et al. (2004)
Orders finished late			✓
Orders finished ahead			✓
Orders finished on time	✓		
Planned order execution time	✓	✓	
Average lead time	✓		
Planned set-up time	✓	✓	
Planned runtime per item		✓	✓
Downtime	✓		✓
Planned production time	✓	✓	
Planned machine utilization	✓	✓	✓

Table 2 *The KPI alternatives and the papers they are found in.*

## 2.3 Developing a Production Planning System

#### *What literature is available regarding the development of a production planning system?*

Systematic literature research provided insight into the available literature about the development of production planning or scheduling systems. There are two papers discussing different production planning approaches in the Make-To-Order sector. Stevenson, Hendry, & Kingsman (2005) review classical production planning and

control approaches from the point of view of the MTO industry. They consider factors such as the importance of customer enquiry stage, company size, degree of customization and shop floor configuration. Since Dupo is an MTO company for the largest part, this paper will be a good source. It provides information about the characteristics of the MTO sector in general, proposes criteria as requirements for a production planning and control (PPC) system in this sector, and reviews several production planning approaches according to these criteria. This will be helpful when selecting a production planning approach for the company. The research by Hendry & Kingsman (1989) relates to this, it assesses the applicability of different production planning systems, developed for the Make-To-Stock (MTS) industry, to the Make-To-Order sector. It discusses approaches different from Stevenson et al., making it a good addition to our research.

Alfieri, Tolio, & Urgo (2011) study production planning under uncertainty. They propose a two-stage stochastic approach for the production planning in an Engineer-To-Order/Make-To-Order (ETO/MTO) industry. This approach consists of a baseline production plan and a set of revisions of this plan to react to uncertain events. Since Dupo also has to deal with the uncertainty of their demand, it is useful to get familiar with an approach which takes this into account.

Lastly, the research about the development of the actual model is discussed. Nussbaum & Parra (1993) present a knowledge-based scheduling system for a plant with multipurpose machines. They discuss several concepts related to the development of this system including a qualitative analysis of the advantages and disadvantages. This paper is useful to this research because it discusses the development of a production planning system in detail. In their paper about aggregate production planning (APP), Techawiboonwong & Yenradee (2002) present guidelines for the development of an APP using a spreadsheet solver approach. First, an APP model is proposed based on the general requirements and constraints. Then the guidelines are used to develop a spreadsheet system. This paper may be more useful than the research of Nussbaum & Parra (1993), since it also involves the transition to the spreadsheet solver, in addition to a detailed description of the design process.

## 2.4 Developing the Dashboard

### *How can we develop a user-friendly tool?*

In this section the most frequently mentioned principles about user-friendly interfaces found in the literature are summarized. These principles provide a guideline when developing the dashboard of the tool.

#### Task Conformance

Task conformance is the degree to which the system supports the user's tasks. It can be divided into task completeness and task adequacy. Task adequacy concerns if tasks are mapped in a way that the user finds satisfying (Kristoffersen, 2008). Task completeness implies that the system needs to be complete and covers every aspect of the user's tasks sufficiently.

### Flexibility

Bhaskar, Prathap Naidu, Ravi Chandra Babu, & Govindarajulu (2011) define flexibility as “the system’s ability to respond to individual differences in people. Permit people to choose the method of interaction that is most appropriate to their situation”.

### Consistency

Consistency is important so that users should not have to wonder whether different words, situations or actions mean the same thing (Picking, Grout, McGinn, Crisp, & Grout, 2010). According to Galitz (1992), consistency can be achieved by:

- *A system should look, act and operate the same throughout. Similar components should have a similar look, similar uses and operate similarly.*
- *The same action should always yield the same result.*
- *The function of the elements should not change.*
- *The position of standard elements should not change.*

### Simplicity

Simplicity is important in order to “not overwhelm users’ cognitive abilities by over-complication of the interface”. The design should make frequently performed tasks simple and provide good and meaningful shortcuts (Picking et al., 2010). Simplicity can be provided again using principles proposed by Galitz (1992):

- *Use progressive disclosure, hiding things until they are needed. Present important and common functions prominently and hide more sophisticated and less frequently used functions.*
- *Provide defaults.*
- *Make common actions simple at the expense of uncommon actions being made harder.*

### Familiarity

The familiarity of a system concerns that it should present information in a natural and logical order. It should speak the users’ language in terms of concepts that the user is acquainted with (Picking et al., 2010). Galitz (1992) also proposes guidelines to insure familiarity to the user:

- *Employing familiar concepts and using language that is familiar to the user.*
- *Keeping the interface natural, mimicking the user’s behaviour patterns.*
- *Using real-world metaphors.*

To conclude, it is important that the dashboard presents information in a logical order, mapped in a way that the user finds satisfying. For example, tasks that are usually performed in a sequence should be placed close to each other on the dashboard. Also, the communication of information to the user needs to be consistent, to avoid unnecessary confusion. The same applies to the performing of similar activities. The action of adding a new product to the database should be in line with adding a new customer or mould. Lastly, it is of great importance to not overwhelm the user with non-essential information. Simplicity is key in not over-complicating the interface. Information should be available to the user, but do not directly confront them with all of it.

## Chapter 3. Analysing the Current Situation

In this chapter, the current situation at Dupo is analysed using the framework proposed by Jonsson & Mattson (2003). The order processing is modeled by a business process diagram and a UML class diagram is constructed to provide insight into the relations among different types of information.

### 3.1 The Business Process Diagram

In Section 2.1.2, the BPMN was introduced as a way to model business processes. In this section, the process at Dupo is modelled using a BPD, which can be found in Figure 5. Mapping the process by using the BPMN will provide more insight into the process and make it easier to understand for the reader.

Dupo Enschede B.V. consists of a trading firm and a production facility, Dupo Plastics. When a customer places an order at Dupo it is received at the main office. If the order concerns the trading firm, it will be further processed at the office. When it involves products that are produced by Dupo Plastics, the order will be sent to the factory.

When the order is received in the factory, the BOM is extracted from the product database. An employee checks if all the required materials for the production are available. If all materials are available the production will be scheduled. If materials are unavailable an order will be placed at the respective supplier. Based on the estimated delivery time of the lacking materials, the order will still be scheduled for production. Production can only start when the materials have arrived.

Employees in the factory schedule the incoming orders for production, based on their instinct. Most of the time, orders are scheduled at the first available spot in the schedule. The tool developed in this study will concern the “plan production” and “plan production (based on delivery time)” boxes in the diagram. The tool will perform this activity for the employee. Therefore, when the tool is finished and implemented at the company, the business process diagram will not look any different. The activities will just be performed in a different way.

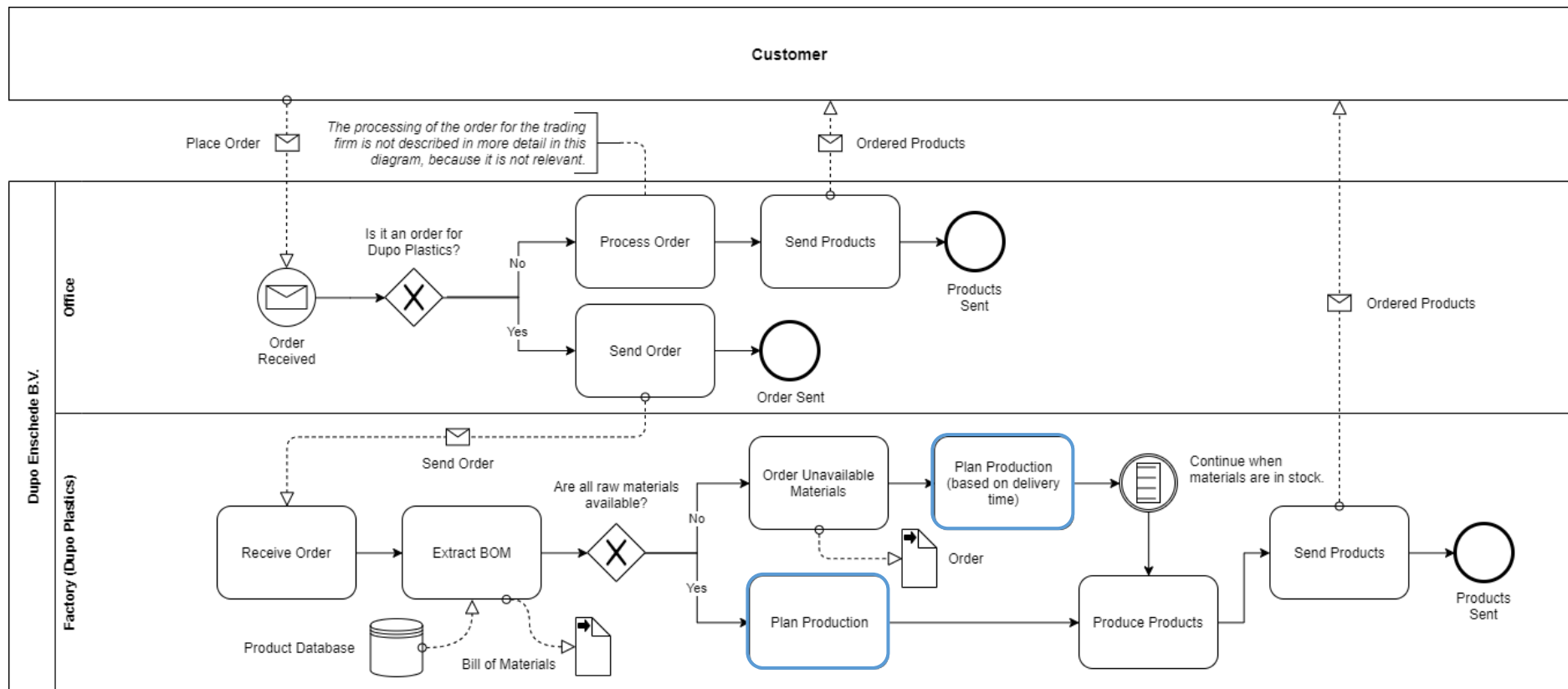


Figure 5. Business Process Diagram of the order processing at Dupo.

## 3.2 Characteristics of the Planning Environment

According to Jonsson & Mattsson (2003) “the suitability of various planning and control methods depends on the demand, products and manufacturing characteristics”. In their paper about the fit between the planning environment and planning methods, they propose a framework for defining planning methods and planning environments. Seven conceptually identified product, demand, and manufacturing process-related variables are used to describe four main types of planning environments. In Section 2.1.1 these variables were defined and further explained. In this section, the situation at Dupo will be defined using the seven variables. Then the seven variables will be used to classify the environment at Dupo as one of the four types of planning environments proposed by Jonsson & Mattsson (2003).

### 3.2.1 Characteristics of Dupo

In Section 2.1.1 seven variables were defined and explained. This section addresses the application of the variables to the planning environment of Dupo.

#### *Product (BOM) complexity*

The first variable that is considered is the complexity of the product. This is measured based on the complexity and number of levels of the bill of materials (BOM). A multi-level BOM is a bill of materials in which all the parts that are required for the production of a product are listed, including all assemblies, parts, and raw materials. BOM of Dupo’s products typically involves 1-2 levels with several included items.

#### *Degree of value-added at order entry*

This variable assesses the manufacturing strategy of the company. It differentiates the planning environments based on the position of the customer order decoupling point (CODP). The CODP is the point of customization, from where the customer triggers the production. Dupo works with a make-to-order (MTO) strategy, which means that the production begins after a customer order is received. The position of the CODP is at the beginning of the production process when using an MTO strategy.

The biggest advantage of the MTO strategy is that a surplus of supply almost never occurs. Also, this production method allows more flexible customization by the customer compared to a make-to-stock (MTS) process. Being able to give the customer tailor-made products can give a company a competitive advantage in the marketplace. A disadvantage of the MTO strategy can be that customers experience a longer lead time due to additional wait time (European Knowledge Center for Information Technology (EKCIT), 2018).

#### *Volume/frequency*

Dupo has a rather large number of customers that place smaller orders, compared to other injection-moulding companies. Order quantities can be as small as tens of thousands, where other injection-moulding companies do not produce for less than a hundred thousand or even a million pieces. The volume/frequency variable can then be defined as “large number of customer order with medium quantities every year” or “frequent call-offs based on delivery schedules”. The latter one is not an appropriate description of the environment at Dupo, because it suggests an MTS strategy.

### *Production process*

Jonsson & Mattson (2003) define five types of production processes: continuous process production, continuous mass production, frequent batch production, batch production, and one-off production. The process at Dupo corresponds best to the batch production process. Products are produced in batches several times each year, responding to customer demand. Frequent batch production would imply that batches are produced more frequent than monthly, which is not the case at Dupo.

### *Shop floor layout*

Production facilities can have different kinds of shop floor layouts, in the framework of Jonsson & Mattson they are categorized as: flow layout, line layout, or a functional layout. In a flow layout, or cell layout, resources move to one cell in which all the transforming resources the product needs are located. In a line layout, resources flow along a predetermined route (line) of processes according to their product needs.

The shop floor layout at Dupo is a functional (process) layout. In this layout, similar resources or processes are located together. This implies that when a product flows through the operation, the route is determined by the steps that must be taken to complete it. Different products have different needs and will, therefore, have a different flow (Slack et al., 2010). The general flow of products at Dupo starts at the injection-moulding machines, after this, products are assembled, packaged and sent to the customer. Because of this, the functional layout is more appropriate than a flow or line layout.

### *Batch sizes*

The batch sizes in which the products are produced at Dupo are equivalent to the customer order quantities. When an order is placed, the quantity the customer desires will be produced. Sometimes frequently ordered products are produced as stock when there is free time, but that is not often the case.

### *Through-put times in manufacturing*

The through-put time is the average time it takes for inputs to move through the process and become outputs (Slack et al., 2010). The time it takes for an order to be processed and manufactured at Dupo is approximately four to five weeks, depending on the available capacity of the injection-moulding machines. This can be classified as a medium through-put time in manufacturing.

### *3.2.2 Classifying the Planning Environment*

Now all the variables are defined, they can be used to classify the total planning environment at Dupo. This can be done using the table created by Jonsson & Mattson (2003), which is enclosed in Appendix B. Table 3 shows the characteristics of the planning environment at Dupo and the points which are assigned to each type of planning environment that has been defined by Jonsson & Mattson (2003). When the scores are calculated, it shows that the planning environment at Dupo is the most similar to the type 2 planning environment: configure to order products.

	Type 1	Type 2	Type 3	Type 4
<i>Product (BOM) complexity</i>				
1-2 levels in the bill-of-material and several included items	0	2	1	2
<i>Degree of value-added at order entry</i>				
Manufacturing-to-order	0	3	0	0
<i>Volume/frequency</i>				
Large number of customer orders, medium quantities every year	0	2	2	1
<i>Production process</i>				
Batch production (less frequent than monthly)	0	0	1	0
<i>Shop floor layout</i>				
Functional layout (process layout)	2	0	0	0
<i>Batch sizes</i>				
Equivalent to customer order quantities/call-of quantities	2	2	0	0
<i>Through-put times in manufacturing</i>				
Medium through-put times, a few weeks	1	0	2	0
<b>Total</b>	5	9	6	3

Table 3. Classification of planning environment.

The type 2 environment consists of less complex products that are assembled in small batches. The operations can be classified as assemble-to-order (ATO) or MTO. The number of orders is large and the delivery lead-times are less than for environments with more complex order types. Through-put times are relatively short. Flow and line layouts are more frequently used than functional layouts.

The situation at Dupo has a lot of similarities to the type 2 planning environment. However, the shop floor layout of the factory is more functional than a flow or line layout, which would normally appear in a type 2 environment. In this case, the shop floor layout is not relevant because there are just a few steps involved in the production of most products.

Despite the fact that we cannot directly relate the planning environment to a specific planning method because the model proposed by Jonsson & Mattsson (2003) is only conceptual. Assessing and classifying the planning environment on different levels provided more insight into the current situation at Dupo. It creates a basis from which we can search for the appropriate planning method. Section 4.4 further elaborates on the MTO environment and the appropriate planning method for Dupo.



### 3.3 Data Model

In Section 2.1.3 the UML class diagrams were introduced and explained. In this section, this knowledge will be used to create a diagram that describes the information present at Dupo (Figure 6) and the relationship among different types of information.

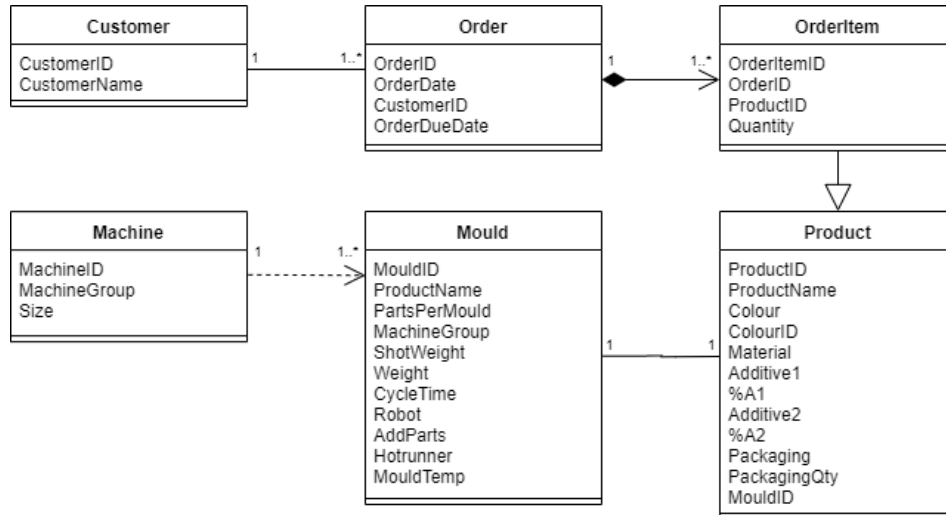


Figure 6. UML class diagram.

A customer can place multiple orders at Dupo. These orders exist out of one or more items, of which a certain quantity is ordered by the customer. These items are products, each having their own name, colour, material, and packaging. Every product will be produced using a mould. A mould can be configured in different ways so that different products can be produced using one mould. For example, products with a different colour or material can be produced in the same mould. The moulds are used by an injection moulding machine to produce products. A machine fits multiple moulds, depending on the size of the mould and the machine. Machines are categorized in different machine groups, according to the size of the moulds which it can utilize.

The customer ID connects the customer to its orders. The order ID connects the order to its items. The items are specified using a product ID. The products are connected to their moulds by using a mould ID. This ID is linked to a specific machine group. In this way, the employees know which machines can produce a certain product.

## Chapter 4. Tool Design and Implementation

In this chapter, the actual development of the production scheduling tool is explained. In Section 4.1 the KPI are selected using a combination of the AHP and the five generic performance objectives. After this, the design of the dashboard and the planning method are discussed.

### 4.1 Selection of KPIs

In Section 2.2 a method for the selection of KPIs has been introduced. In this section, a combination of AHP with the five generic performance objectives from Slack et al. (2010) will be used to make a selection of KPIs for the dashboard. The method consist of the following steps:

1. Define and list all of the KPIs.
2. Build an AHP hierarchy, in which the goal is to prioritize KPI alternatives with respect to the five generic performance objectives.
3. Undertake a pairwise comparison between alternatives, i.e. KPIs.
4. Calculate composite priority: calculate local weights and global weights.
5. Selection of KPIs that are more relevant to organizational goals.

As mentioned in Section 2.2, the following KPIs are a selection of measures for the production scheduling process, proposed by Hon (2005), Bauer, Lucke, Johnsson, Harjunkoski, & Schlake (2016), and Rakar, Zorzut, & Jovan (2004).

- |                                |                               |
|--------------------------------|-------------------------------|
| ▪ Orders finished late         | ▪ Planned setup time          |
| ▪ Orders finished ahead        | ▪ Planned runtime per item    |
| ▪ Orders finished on time      | ▪ Downtime                    |
| ▪ Planned order execution time | ▪ Planned production time     |
| ▪ Average lead time            | ▪ Planned machine utilization |

The AHP hierarchy structure for this research can be found in Figure 7 below. The overall objective is the selection of KPIs (level 1 of the diagram). The performance objectives in the second level are used as criteria to compare the KPI alternatives. These KPI alternatives are the third level of the diagram, they form the pool from which the final KPIs will be selected.

The comparison between the KPI alternatives is based on the opinion of the employees. Since they will be the users of the dashboard it is important to know which information they find useful. The employees are consulted using a survey, from which the details can be found in Appendix D. Employees from different levels of the organization were consulted, including the managing director, technical manager and production employees.

During the survey, the employees are asked to rank and score the generic performance objectives according to their importance to the company. After this, they are asked to rank the KPI alternatives according to their contribution to each performance objective. The opinions of the employees are combined into final scores for the 5 generic objectives and each KPI with respect to the generic objectives. The results of this can be found in Appendix E. The final scores are then used to determine the relative importance of the KPIs, using the nine-point scale for AHP analysis, shown in Table 4.

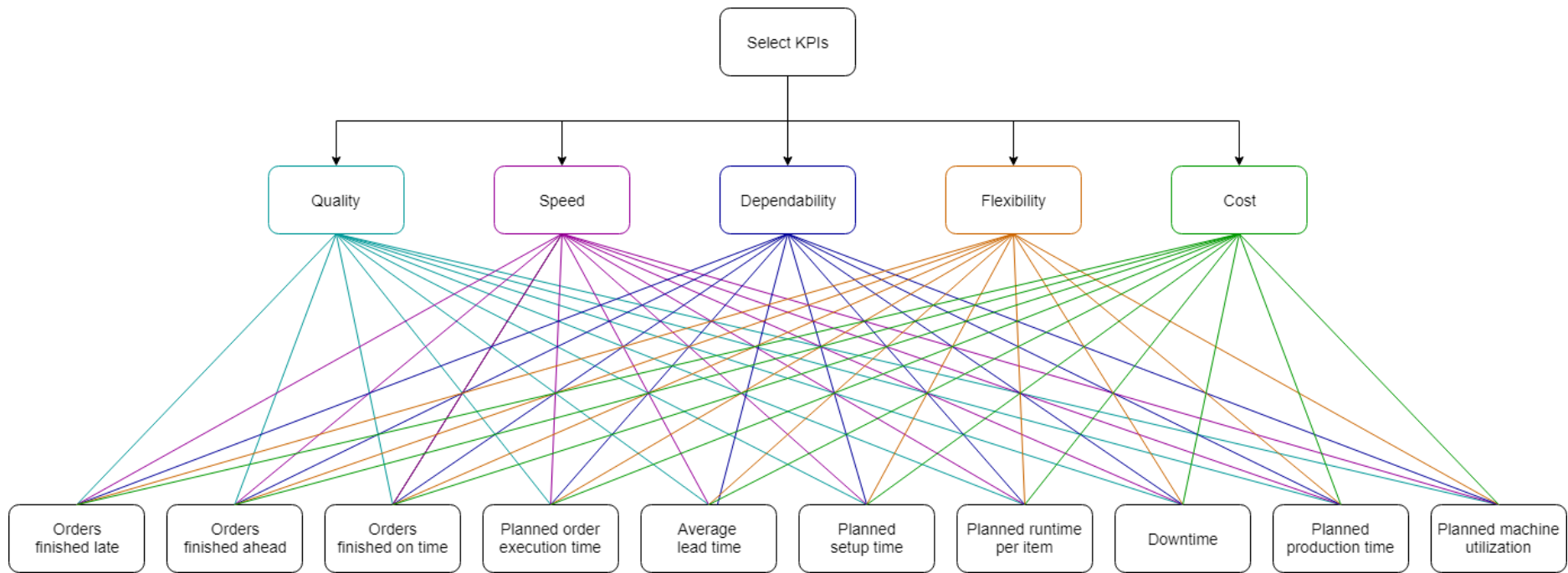


Figure 7. AHP hierarchy of KPI alternatives and the five generic performance objectives.

Ratings	Definition	Intensity of importance
1	Equal importance	<i>Two criteria/alternatives contribute equally to the objective.</i>
2	Weak	<i>Experience and judgement slightly favour one criterion/alternative over another.</i>
3	Moderate importance	
4	Moderate plus	<i>Experience and judgement strongly favour one criterion/alternative over another.</i>
5	Strong importance	
6	Strong plus	<i>A criterion/alternative is favoured very strong over another.</i>
7	Very strong importance	
8	Very, very strong	<i>The evidence favouring one criterion/alternative over another is of the highest possible order of affirmation.</i>
9	Extreme importance	

Table 4. *Saaty's nine-point scale for AHP analysis*. Reprinted from "Prioritization of Key Performance Indicators" (p. 233) by Shahin, A., & Mahbod, M.A. (2007), International Journal of Productivity and Performance Management, 56(3).

An Excel spreadsheet has been created to simplify the process of calculating local and global weights. The input of the calculations is the scoring of the comparison of the relative importance of alternatives. The spreadsheet then calculates the normalized weights and the global weights of the KPI alternatives. This allows the user to rate the KPIs based on their global weight and decide whether to include them in the dashboard or not. Additional information about the Excel spreadsheet can be found in Appendix F.

Rank	KPI alternative	Global weight
1	Orders finished on time	12,23
2	Planned order execution time	7,09
3	Planned production time	6,22
4	Planned runtime per item	5,60
5	Planned setup time	5,50
6	Downtime	5,02
7	Average lead time	3,71
8	Planned machine utilization	1,62
9	Orders finished late	1,62
10	Orders finished ahead	1,39

Table 5. *The final ranking of KPI alternatives*.

Before the results can be used, they need to be checked for consistency. This is done on two separate sheets in the spreadsheet, one for the KPI tables and one for the generic performance objective table. In these sheets the consistency of the matrices is calculated as described in Section 2.2, these calculations are documented in Appendix F (Table 14 – 17). All matrices turned out to be consistent enough, so the data can be used to select KPIs.

The final ranking of KPI alternatives after calculations are shown in Table 5. In order not to overwhelm the user with information, a select number of KPIs will be displayed on the dashboard. The first six KPIs on the list (with a score > 5) will be included in the dashboard because the employees find them the most useful. When looking at the list, the difference between number 6 and 7 is relatively large. This is why the line of including KPIs is drawn between them. The planned machine utilization will also be measured because it is related to the performance of the tool. To again not overwhelm the user, the KPIs will be categorized and placed under three tabs: production, machines, and delivery. This way, the information can easily be requested by the user but is not always displayed.

Production	Machines	Delivery
Planned order execution time	Planned machine utilization	Orders finished on time
Planned runtime per item	Downtime	
Planned setup time	Planned production time	

Table 6. *Distribution of KPIs on the dashboard.*

## 4.2 Measuring KPIs

In this section, the measurement of the selected KPIs will be further explained.

### Production

The production sheet will provide insight into the portion of the total production time that is spent on certain activities. The user of the tool can select the order of which they would like to see these statistics. The tool will then display the total production time of this order, the runtime per item, and which part of the total production time is set-up time.

- Planned order execution time – The time between StartProduction and EndProduction.
- Planned runtime per item – The CycleTime of the mould divided by the PartsPerMould.
- Planned setup time – The proportion of the time that is needed for set-up.

### Machines

The machine sheet shows the performance of the tool and the occupation of the machines. The planned machine utilization time and the planned production time are calculated over the planning horizon of the schedule. The downtime is based on historical data.

- Planned machine utilization – The planned proportion of time during which machines are utilized (including set-up time) over the planning horizon of the schedule.
- Planned production time – The planned proportion of time machines that is scheduled to produce over the planning horizon of the schedule.
- Downtime – The percentage of total production time during which machines were not available for production. This can be due to defects or alterations to the production settings. Since the tool is unable to communicate with the machines in any way, the downtime has to be entered manually using the 'Edit Order' option.

### Delivery

The delivery sheet provides information about the lateness of orders.

- Orders finished on time – The percentage of historic orders for which production was finished before or on the OrderDueDate, for which the lateness was equal to zero. This information will be displayed in a pie chart, to show the late orders in proportion to the orders that were finished on time.

## 4.3 Dashboard Design

### The Dashboard

In Section 2.4 the research question *'how can we develop a user-friendly tool?'* has been answered, by using multiple principles about user-friendly interfaces. These principles provide a guideline when developing the dashboard of the tool. The following list summarizes the criteria for the dashboard design:

1. The dashboard should present information in a logical order.
2. The communication of information to the user needs to be consistent.
3. Comparable activities should be performed in a similar way.
4. The dashboard should not overwhelm the user with non-essential information.

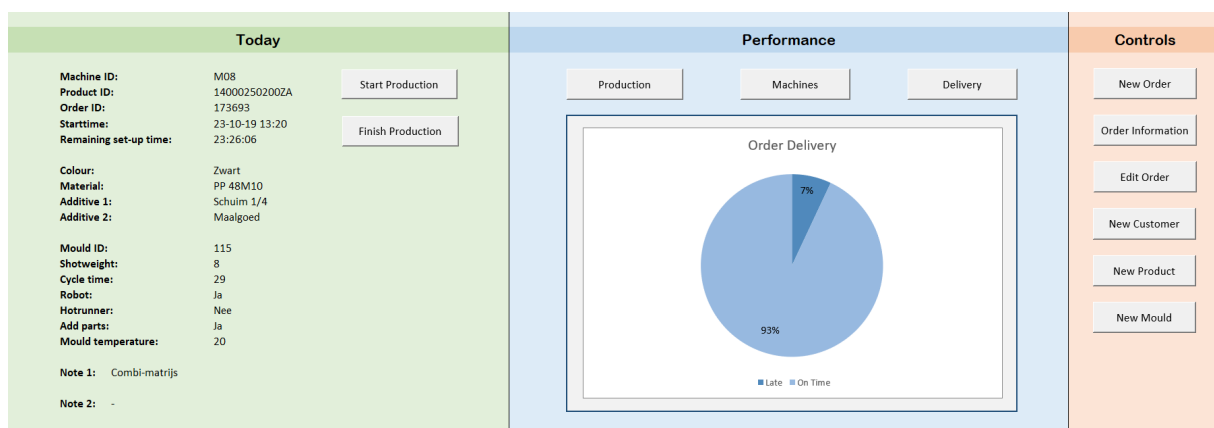


Figure 8 Overview of the dashboard.

Figure 8 shows an overview of the dashboard of the tool, which includes three sections: *today*, *performance*, and *controls*. By categorizing information and controls in different sections, the information is presented in a logical order (criteria 1). Information and actions regarding similar activities or subjects are grouped in one section.

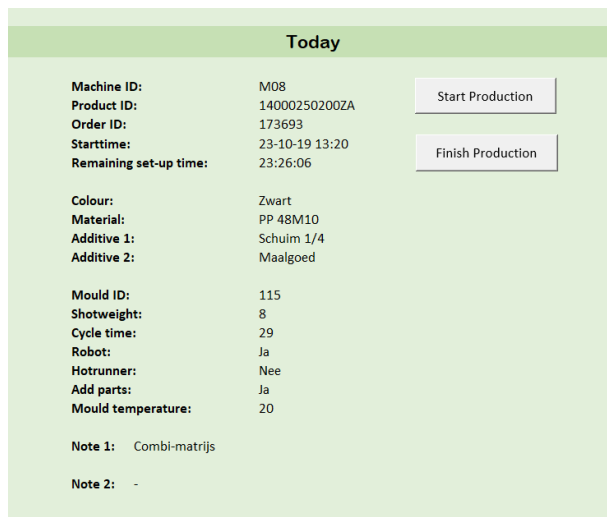


Figure 9 The 'today' section of the dashboard.

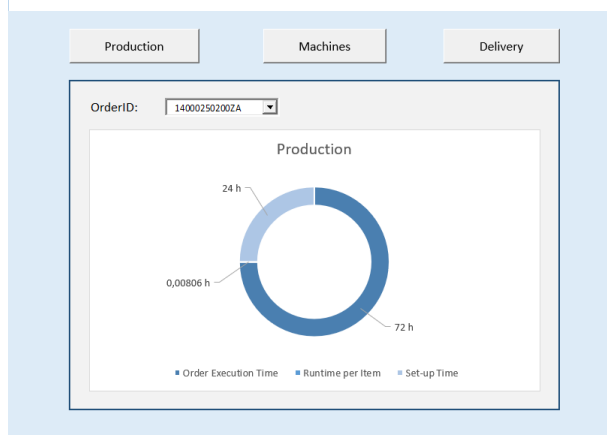


Figure 10 Production related statistics in the 'performance' section of the dashboard.



Figure 11 Machine related statistics in the 'performance' section of the dashboard.

The today section (Figure 9) of the dashboard contains information about the orders that need to be produced next. It shows the user when the next order should be produced, on which machine it will be produced, which materials are needed, and information about the configuration of the machine.

This section also includes two buttons: *start production* and *finish production*. These buttons can be used to set the actual start and end time of the production. This way the system can use these times instead of the planned times to calculate future production schedules.

The performance section (Figure 10 – 12) shows the user statistics about the production process, the machines, and the delivery of orders. By grouping the information into three sections, the user can decide which information is displayed on the dashboard (by using the buttons at the top). This way, the user is not overwhelmed with information he does not necessarily need at that moment (criterion 4). The sections have the same look and colour, which adds to the consistency of the dashboard (criterion 2).

The production statistics (Figure 10) show the portion of the total production time that is used for set-up time, actual production of products, and the time needed to produce one part. The statistics related to the performance of the machines (Figure 11) include the downtime and machine utilization and production time related to the total time that is scheduled. The delivery statistics (Figure 12) are the proportion of orders delivered late and on time. Together these statistics include all KPIs selected in Section 4.1, and give the user insight into the performance of the production process and the planning tool.

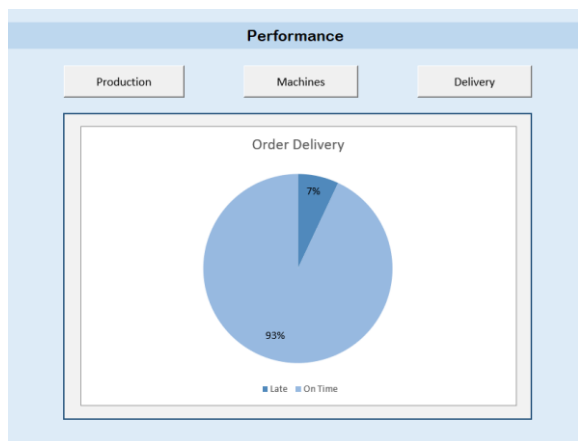


Figure 12 *Delivery related statistics in the 'performance' section of the dashboard.*

Lastly, there is the controls section of the dashboard. This section includes all controls related to all user actions. The 'new order', 'new customer', 'new product', and 'new mould' controls allow the user to add information to the different databases. These buttons are linked to UserForms (shown in Appendix I). Because these actions are closely related they must be performed in similar ways (criterium 3). Every UserForm is constructed in the same way, the user enters the information into the corresponding fields and clicks the 'save' button to transfer the information to the database.



Figure 13 *The 'controls' section of the dashboard.*

The remaining two controls are 'order information' and 'edit order' these controls do not have controls that perform the same type of action. The order information button allows the user to search for an order based on the customer or the order ID. When selecting a customer, the tool returns every order that has been placed by this customer, and the corresponding order information. When selecting an order ID, the system returns every item of which the order exists and the corresponding order information.

The edit order button allows the user to adjust the due date of an order item or the duration of its production. The due date might need to be adjusted if the agreements with the customer change. The duration of the production can be manually adjusted using the edit order button. This is a request from the employees at Dupo. It may occur that they estimate the duration of the production differently than the tool, based on past experiences.

### *The User Manual*

To support the user of the dashboard, a User Manual has been created for the tool. It includes information about the working of the tool and guides the user when performing everyday activities. The User Manual has been included in Appendix I. This section will explain more about the structure of the manual.

The manual consists of three sections: *the dashboard*, *adding information*, and *using the tool*. Each section includes information about a different functionality of the dashboard and tool. The manual starts with explaining which information can be found on the dashboard, and how to read the different sections of the dashboard. The second section 'adding information' describes how to use the buttons and UserForms to insert data into the databases of the tool. Lastly, there is a 'using the tool' section. This part of the manual assists the user when performing daily activities.

When writing the user manual, criterium 1 and 2 have been taken into account. Because the user manual should also present information in a logical order and ensure consistent communication of information to the user.



## 4.4 Planning Method

In Section 3.2 the planning environment at Dupo was classified using the model proposed by Jonsson & Mattsson (2003). The environment is most similar to a type 2 planning environment: configure to order products. The operations at Dupo can be classified as make-to-order (MTO).

Production systems can be characterized as a push or pull system. A pull system starts production as a reaction to the current demand, wherein a push system production is initiated in anticipation of future demand. In an MTO environment, production is initiated to meet actual customer orders. Therefore, the environment can be seen as a push system, the production follows demand (Liberopoulos, 2013).

The difficulties of production scheduling in an MTO environment include that these companies cannot accurately forecast demand. In addition, the production requirements may vastly differ from job to job which adds a lot of variety (Stevenson et al., 2005). According to Stevenson et al. (2005), the ability of a production planning system in the MTO sector must assist in the calculation of competitively short and realistic delivery dates. It must also be able to provide planning when shop floor routings are variable.

As mentioned in Section 1.3, it is often the case that products are not delivered in time or that the lead time between the placement of an order and delivery is longer than the company would like it to be. This is why the main objective of the scheduling method is to find the schedule in which the least orders will be delivered after the agreed order due date, to minimize the sum of the lateness of all orders. As Stevenson et al. (2005) pointed out, it is important for the planning system to assist in the calculation of the delivery dates. Therefore, the objective is not only to minimize the lateness, but also to give the user insight into the expected delivery dates of the orders. Dupo can use this to give their customers an accurate estimation of the lead time.

The main parameters that are used by the tool to determine the schedule are the due date for delivery and the duration of the production. The due date is determined by the customer and will be manually entered into the tool by an employee, using a UserForm. The duration is calculated based on the type of product that will be produced, the quantity that will be produced, the cycle time of the required mould, and the number of parts produced per mould.

The schedule is subject to several constraints, concerning production times, capacity, and available resources:

- Production cannot start before 09:00 or after 16:00 on Monday through Thursday.
- Production cannot start before 09:00 or after 12:00 on Friday.
- Production may not end after 15:00 on Friday since machines will be turned off then.
- There is no production during the weekend and vacation since machines are then turned off.
- The schedule must be filled for no more than 80%.
- The twelve machines each have a capacity of about 100 hours per week.
- Each mould fits machines of a specific machine group or larger.
- There are one hot runner<sup>5</sup>, one robot and one other convertible part available for production.

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<sup>5</sup> A system of parts that are heated such that they can be more effectively used to transfer molten plastic from a machine into the mould cavities.

Most of the constraints listed above are self-explanatory. We will elaborate further on the constraints concerning the machine groups. Dupo owns twelve injection-moulding machines, these can be categorized into seven machine groups according to their size, as shown in Table 7. A mould is connected to a certain machine group and can be placed on machines of this machine group or larger. For example, a mould for machine group 4 can be placed on machines M07 to M12, machine group 4 to 7.

Machine Group	Machine ID	Size
1	M01	25 tons
2	M02	40 tons
2	M03	40 tons
3	M04	50 tons
3	M05	50 tons
3	M06	50 tons
4	M07	100 tons
4	M08	100 tons
4	M09	100 tons
5	M10	150 tons
6	M11	200 tons
7	M12	vertical inlay

Table 7 *Machines and their machine groups.*

Before the system architecture or VBA code can be developed, a framework for should be constructed which serves as a guideline when programming the tool's activities. This is why the following heuristic has been designed. A heuristic is a numerical procedure created to systematically solve optimization problems. In this case, the heuristic is a step-by-step plan run by the tool for generating a feasible solution, which aims to minimizes the sum of the lateness of all orders. The step-by-step plan does not include information about calculations, it only includes the actual scheduling part. The heuristic consist of the following steps:

1. Find the first row in the production schedule to which no machine is allocated.
2. Look up the mould ID in the product database.
3. Look up the machine group in the mould database.
4. Select the machine with the next lowest machine number from the allowed machine groups.
5. Allocate the machine to the selected machine group.
6. If the new total lateness is smaller than the previous total lateness, save new total lateness.
7. If the selected machine number is lower than M12, go back to number 4.
8. Allocate the production to the machine with the lowest total lateness.

The heuristic that is developed to be used by the tool will allocate an order to the smallest possible machine, the machine with the lowest allowable machine group. This is to anticipate future orders because small moulds can fit on larger machines, but it does not work the other way around. When the system would allocate relatively small moulds to the larger machines, less capacity would be left for future orders involving large moulds.

The objective of the scheduling code is to minimize total lateness. Each order will be assigned to the smallest machine for which the lateness is equal to zero. If for none of the machines the lateness will be zero, the order is assigned to the machine with the lowest possible lateness. If two or more machines have the lowest possible lateness (not equal to zero), the order is assigned to the machine with the smallest machine identifier.

Although there are no penalties for orders that are late, it is still important to deliver orders in time. This is because the due date of an order is set in agreement with the customer. If orders are late, the appointment with the customer cannot be met. When an order is scheduled and the lateness is greater than zero, the tool will display a warning. This way, the company can give an accurate estimation of the delivery date of the products, and inform the customer in advance if the delivery date will be after the agreed due date.

## 4.5 System Architecture

Figure 12 shows the activity diagram of the scheduling functionality of the tool. It has two events that trigger the initialization of the activities; adding a new order and changing order information. If the flow starts with adding a new order, the system goes through a number of loops to ensure that all order items have been scheduled for production and all allowable machines are being considered.

When the flow is triggered by the user changing the order information of an existing order, two things can have happened: the user changed the agreement with the client about the due date of the order or production is not running as planned, and will take shorter or longer than the scheduled duration. In both cases, the system finds the order that has been changed. It then recalculates the schedule for the concerning machine from the changed order and further. This is needed to allow the company to provide up to date information about the delivery dates to their customers. The VBA code that enables the tool to perform these activities is included in Appendix K.

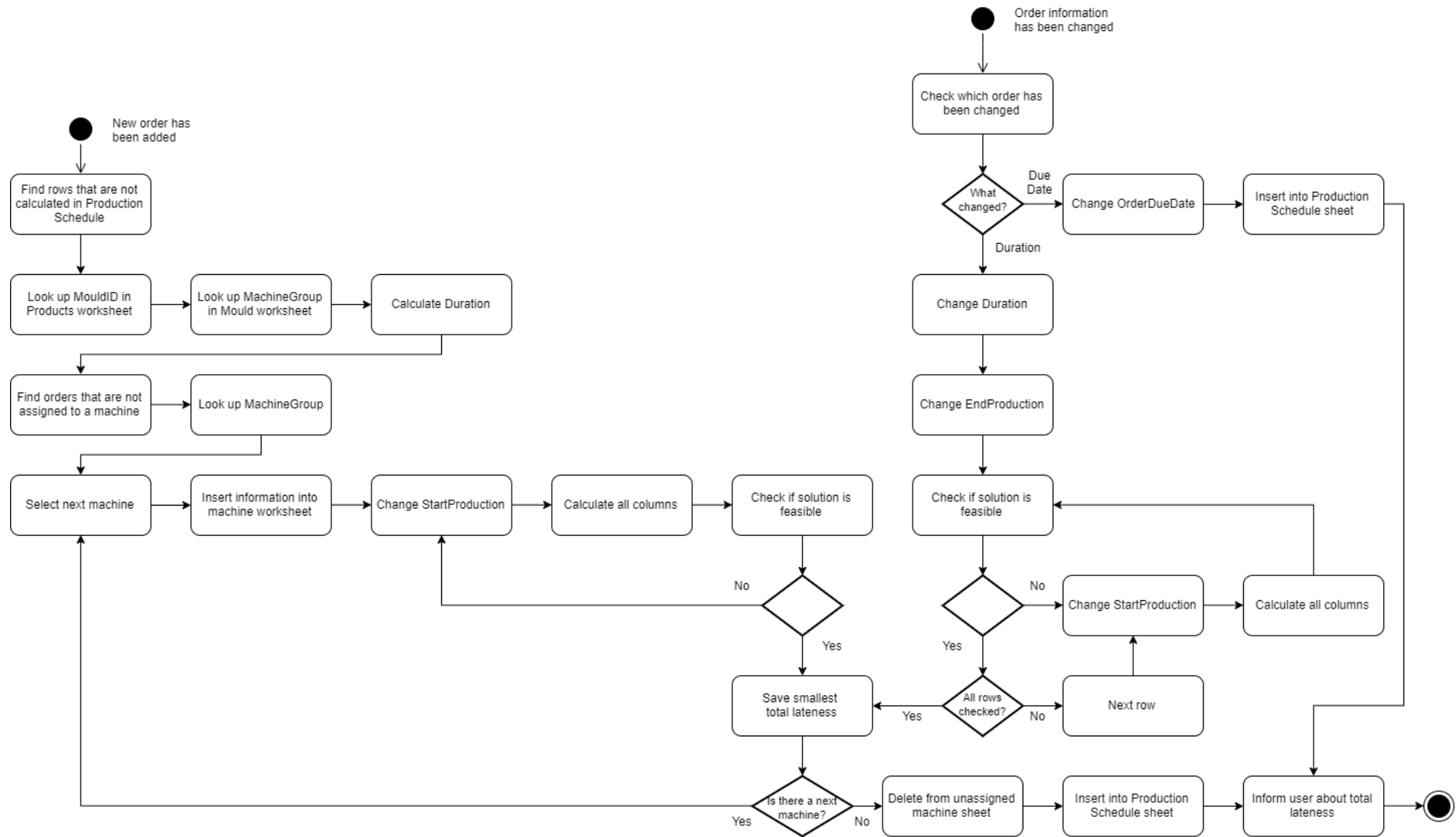


Figure 12 Activity diagram of the tool.

## Chapter 5. Conclusion

### 5.1 Evaluation

The design and functionality of the dashboard have been evaluated using an evaluation form. This section presents the results of the evaluation form, which has been filled in by the employees working in the factory at Dupo. The questions asked in this form are based on the criteria set in Section 2.4. The complete evaluation form is appended in Appendix H.

The evaluation consists of two sections: *functionality* and *usability*. The functionality section includes questions concerning the communication of information. The usability section covers topics as cohesion and consistency throughout the dashboard. Both sections include several rating questions, in which the respondent had to rate the statements on a scale from 'disagree' to 'agree'. Table 8 provides the results of these questions.

Nr.	Question	Disagree	Agree
1	The dashboard contains redundant information.	<input type="radio"/> <input checked="" type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>	
2	Important information is missing from the dashboard.	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input checked="" type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>	
3	I know what the given information is about.	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input checked="" type="radio"/> <input type="radio"/>	
7	Information is presented in a logical order.	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input checked="" type="radio"/> <input type="radio"/>	
8	The information is coherent.	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input checked="" type="radio"/> <input type="radio"/>	
9	Matching activities are performed in a similar way.	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input checked="" type="radio"/>	
10	My knowledge of Microsoft Excel is good.	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input checked="" type="radio"/> <input type="radio"/>	
11	My knowledge about VBA code is good.	<input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input checked="" type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/> <input type="radio"/>	

Table 8 Results of the dashboard evaluation form.

Section 4.3 provides a list of four criteria for the design of the dashboard. Each of these criteria has been evaluated in the dashboard evaluation form. According to the respondents of this form, each of the four criteria has been met in the dashboard design.

- The dashboard presents information in a logical order (Table 8, Nr. 7).
- The communication of information is consistent (Table 8, Nr. 8).
- Comparable activities can be performed in a similar way (Table 8, Nr. 9).
- The dashboard does not overwhelm the user with non-essential information (Table 8, Nr. 1).

Besides the rating questions, the evaluation form also includes three open questions. These questions are a follow up to question 1 – 3, and ask the respondent to elaborate further on their answer. From the answers to questions 1 and 3 can be concluded that there is no redundant or vague information on the dashboard. However, according to the respondents, there is information missing from the dashboard. There are several features which are not included in the dashboard yet, but would add to its functionality:

- Manually adjusting the machine number using the 'Edit Order' button.
- Overview of the upcoming production for more than one order.
- Overview of the products currently being produced.
- Showing the product name as well as the product ID in the 'Today' section.
- 'Edit' buttons for the customers, products, and moulds.
- A database with all the available materials.

The features listed above are not essential for the working of the tool. However, they would increase the user experience. The functions could be added in a future research project, but are not included in this thesis.

## 5.2 Research Questions

In Section 1.6 seven research questions were formulated to answer the main research question *“how to design a tool that automates and optimizes the production planning at Dupo?”*. These seven questions have been answered in Chapter 2 based on literature research, then the theory was applied in Chapter 3 and 4. This section provides a brief overview and explanation of the research questions.

### 1. What is the current situation at Dupo regarding the production planning process?

The current situation of Dupo is described in Chapter 3 using a business process diagram and UML class diagram. The planning environment has been analyzed using the framework propped by Jonsson & Mattson (2003). The environment was classified as a type 2 environment: configure to order products. Characteristics of this environment are less complex products that are assembled in small batches. The operations are classified as ATO or MTO. The number of orders is relatively large and lead times are less than for environments with more complex order types. The shop floor layout at Dupo is a functional layout.

In Section 4.4 the characteristics of the planning environment have been used to determine the planning method.

### 2. What methods are available for the selection of KPIs?

In Section 2.2 several methods are considered for the selection of KPIs, including AHP, MAUT, SMART, and MACBETH. The conclusion of this section was that AHP is the most appropriate method for this study. Therefore, a variation of the method proposed by Shahin & Mahbod (2007) has been used, combining the AHP with the five generic performance objectives from Slack et al. (2010). This method was applied in Section 4.1.

### 3. What KPIs can be used to measure the production (planning) process?

Section 2.2 also provides a table with KPI alternatives found in the studies by Hon (2005), Bauer, Lucke, Johnsson, Harjunkoski, & Schlake (2016), and Rakar, Zorzut, & Jovan (2004). The following ten KPI alternatives were considered using the method proposed in Section 2.2.

- |                                |                               |
|--------------------------------|-------------------------------|
| ▪ Orders finished late         | ▪ Planned setup time          |
| ▪ Orders finished ahead        | ▪ Planned runtime per item    |
| ▪ Orders finished on time      | ▪ Downtime                    |
| ▪ Planned order execution time | ▪ Planned production time     |
| ▪ Average lead time            | ▪ Planned machine utilization |

#### 4. What literature is available regarding the development of a production planning system?

A literature review provided insight into the available literature about the development of production scheduling systems. This section summarizes the papers discussed in Section 2.3 and the insights extracted from them.

##### Production planning in the MTO sector

*A Review of Production Planning and Control: The Applicability of Key Concepts to the Make-To-Order Industry* by Stevenson et al. (2005) provides information about the characteristics of the MTO sector in general, proposes criteria as requirements for a production planning and control (PPC) system in this sector, and reviews several production planning approaches according to these criteria.

*Production Planning Systems and their Applicability to Make-To-Order Companies* by Hendry & Kingsman (1989) assesses the applicability of different production planning systems, developed for the Make-To-Stock industry, to the MTO sector.

##### Production planning under uncertainty

*A Two-Stage Stochastic Programming Project Scheduling Approach to Production Planning* by Alfieri et al. (2011) proposes a two-stage stochastic approach for the production planning in an Engineer-To-Order/Make-To-Order (ETO/MTO) industry.

##### Development of production planning models

*A Production Scheduling System* by Nussbaum & Parra (1993) presents a knowledge-based scheduling system for a plant with multipurpose machines. It discusses several concepts related to the development of this system including a qualitative analysis of the advantages and disadvantages.

*Aggregate Production Planning Using Spreadsheet Solver: Model and Case Study* by Techawiboonwong & Yenradee (2002) presents guidelines for the development of an APP using a spreadsheet solver approach.

The studies listed above are a result of a literature review based on production planning in general. When answering the other research questions, more sources were used, related to other aspects of the developing process. These sources are not mentioned in this section.

#### 5. What information is needed from the company to develop a production planning tool?

This research question has not been answered using literature research. The information that has been used from the company is their objectives of the solution, information about the production processes and the input data for the scheduling tool. Two objectives of the solution were set by Dupo:

1. *The tool must include the production planning for the twelve injection-moulding machines.*
2. *The tool must provide insight into the remaining capacity that is available, in order to be able to give customers a more accurate indication of the expected delivery time of their orders.*

Information about the production process at Dupo has been used to construct the BPD in Section 3.1. This includes the process from the moment that the order is received until the products are sent to the customer.

Then there is the information about the production times, available capacity, moulds, and machine groups, which resulted in the constraints mentioned in Section 4.4.

The input data for the scheduling tool has also been provided by Dupo. To create a clear overview of the available data, a UML class diagram has been created in Section 3.3. The production data provided by Dupo has not been listed in this report. However, the databases within the production scheduling tool contain information about all the products, moulds, and machines present at Dupo. This information is critical for the working of the tool.

#### *6. How can we develop a user-friendly tool?*

A large part of creating the tool was developing a user-friendly dashboard. In Section 2.4, frequently mentioned principles about user-friendly interfaces were explained. These principles provided a guideline when developing the dashboard. The principles include task conformance, flexibility, consistency, simplicity, and familiarity. In Section 4.3 four criteria were established based on the principles:

1. The dashboard should present information in a logical order.
2. The communication of information to the user needs to be consistent.
3. Comparable activities should be performed in a similar way.
4. The dashboard should not overwhelm the user with non-essential information.

When these criteria have been met, the dashboard can be considered to be user-friendly. In Section 5.1 the dashboard evaluation form has been used to conclude if the dashboard meets these four criteria, and can, therefore, be considered as user-friendly.

#### *7. To what extent are the employees acquainted with production planning methods and Microsoft Excel?*

The dashboard evaluation form included two questions about the extent of knowledge employees think to have about Microsoft Excel and VBA. The conclusion following from their answers is that all employees, that will be working with the tool, have good knowledge about Microsoft Excel. The level of knowledge about the VBA coding language differs among employees. The employees do not necessarily have to be acquainted with VBA to be able to use the tool for production planning. If the company would want to add new features to the tool or expand existing features, knowledge of VBA is necessary.

The employees at Dupo do not have any experience with production planning systems or methods. Because of this lack of experience, it is not assumed that they are acquainted with production planning methods. For the working of the tool, it is not necessary that the user possesses knowledge about production planning methods because the tool applies these methods for them. However, experience with other production planning systems would lead to an easier implementation phase of the tool, since the employee would already be used to not planning the production manually.



### 5.3 Recommendations

The main requirement of the tool, scheduling the production for the twelve machines, has been met. However, the scheduling heuristic is not optimal yet. This section includes recommendations for the improvement and further development of the production scheduling tool. Section 5.1 includes a list of functionalities that can be added to the tool in order to improve the functionality and user-friendliness. The recommendation is to add these features to the tool, in order to make the scheduling of production more accessible and pleasant for the employees.

Furthermore, there are some recommendations of features that need to be added in order to further optimize the scheduling process. The first is to add the possibility of adjustable set-up times. The standard set-up time for production is set to 24 hours. This is an approximation made by the company since they do not have information about the set-up times. If a table would be created containing set-up times from mould to mould, or even a guideline with which moulds or materials require a longer set-up time, the production schedule would be more realistic. Secondly, at this moment is not possible yet to spread the production of one batch of products over more than one week. Due to this limitation, orders with a duration above 100 hours cannot be scheduled using the tool. Lastly, a part of the information that should be in the product and mould databases is missing. When the system then requests this information about for example a mould, it will return an error. The company needs to complete the databases first before the system can be implemented.

### 5.4 Contribution to Practice

This section will discuss the contribution to practice of this thesis. Because the tool developed in this thesis is fully adapted to the conditions and preferences of Dupo, the results will not be directly generalizable to other companies or environments. However, this thesis could be used as a guideline for other companies when they would want to develop a similar system. Also, two methods have been applied while conducting this study, which could be a contribution to practice.

Firstly, the method proposed by Shahin & Mahbod (2007) has been adjusted to create a method combining the AHP with the five generic performance objectives. This method has not been used before in similar types of research. In this thesis, this method was successfully applied to make a selection of the KPI alternatives that are the most relevant for the employees at Dupo. The method allows an easy transition from subjective information, obtained from interviews or questionnaires, to objective information that can be used for data processing and comparison. This makes the method suited for environments in which the participant is not acquainted with the method since data can be subtracted from questionnaires.

Adding the component of the generic performance objectives to the AHP method makes the decision making more accessible for the employees working at the company. Because they can more directly relate the KPIs to the production processes and goals of Dupo. Also, the measuring of the consistency of the input has been added to the method proposed by Shahin & Mahbod (2007). This measurement is often done when conducting the AHP method, in order to ensure consistency in the judgement of a participant. Adding this measurement increases the internal validity of the research method.

Secondly, the method proposed by Jonsson & Mattson (2003) was successfully used to analyze and classify the planning environment. In their paper, the four different planning environments are conceptually matched to planning methods. The framework for classifying the planning environment is explained, but not applied to practice. This thesis provides a step by step application of the framework for defining the planning environment, which can be used as a case study for classifying planning environments using the method from Jonsson & Mattson (2003).

## 5.5 Future Research

While developing this tool and learning about the production environment and way of working at Dupo, I have come to the view that a tool like the one developed in this study will not be sufficient in the long term. To allow the company to grow it is important that they gain insight into more performance objectives than this tool provides. While there are no penalties as a result of late deliveries, it is important to fulfil the agreements that have been made with customers. Also at this point, Dupo has no historic order or delivery data, making it hard to measure the added value of the tool and monitor operations performance in general. Therefore, future research should be conducted on the possibility of purchasing and implementing an ERP system at Dupo.

One of the benefits of an ERP system is that it is an integrated software system, combining all of the workflow data in one place. It is an effective way of centralizing information by using data management. Because data does not have to be transferred between systems, the risk of duplicated or wrong data decreases significantly. With the tool that is designed in this thesis, a lot of data has to be manually inserted into the system. This way of working is prone to errors since a typing error can already cause problems.

Another benefit of an ERP system is that it not only schedules the production but also connects to other departments within the company. The inventory and purchasing of raw materials depend on the production activities of a company. The production then, in the case of Dupo, depends on incoming customer orders. Integrating the information stream in these departments allows for more effective operational management.

Overall it is a more complete system that one could ever program in an Excel file. Implementing an ERP system is a long process, which includes decisions about vendors, training, change management, and process engineering. Therefore, further research should be done about the impact of implementing ERP at Dupo, before any steps are taken.

As mentioned in Section 2.1.1 and 3.2, the matching of planning environments and methods by Jonsson & Mattson (2003) shown in Appendix C, is only conceptual. For this reason, this table has not been used to select a planning method for the production planning tool. A recommendation for future research is to conduct a follow-up study about the matching of the proposed planning environments to production planning methods. This way the framework can be used to classify the environment as well as selecting an appropriate method.

The method used for the selection of KPIs is a variation of the method proposed by Shahin & Mahbod (2007). This method has been successfully applied to the selection process of KPIs. Research could be conducted to the applicability of this method in other environments and selection processes.

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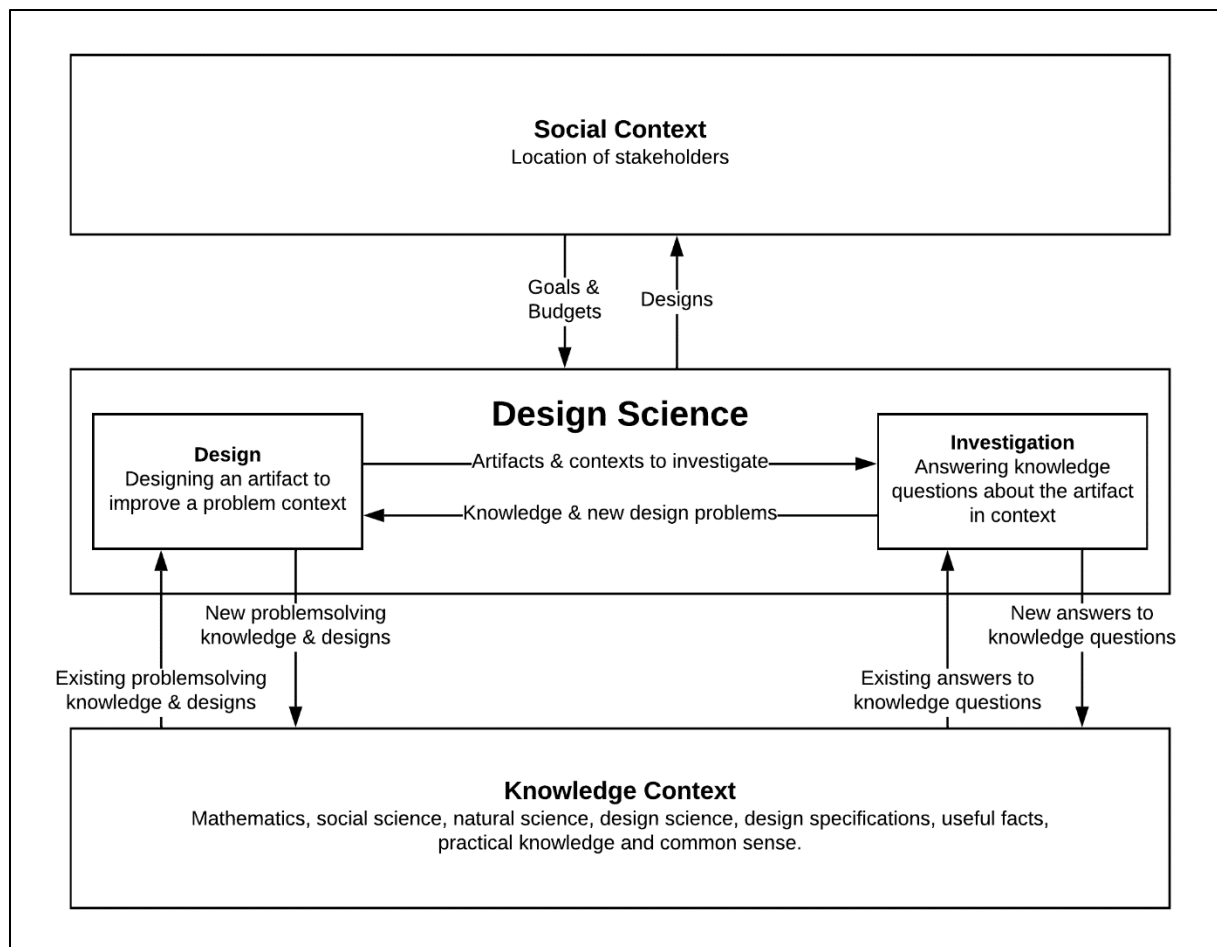
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## Appendix

### A. Framework for Design Science by Wieringa (2014)



Reprinted from "Design Science Methodology for Information Systems and Software Engineering" (p. 7) by Wieringa, R. J. (2014), Germany, Heidelberg: Springer-Verlag.

## B. Classification of Planning Environments

	Type 1	Type 2	Type 3	Type 4
<i>Product (BOM) complexity</i>				
1-2 levels in the bill-of-material and few included items	0	0	0	2
1-2 levels in the bill-of-material and several included items	0	2	1	2
3-5 levels in the bill-of-material	1	1	2	0
More that 5 levels in the bill-of-material	2	0	0	0
<i>Degree of value added at order entry</i>				
Make-to-stock and deliver from stock	0	0	3	2
Assembly-to-order or plan	0	3	0	2
Manufacturing-to-order	0	3	0	0
Engineer-to-order	3	0	0	0
<i>Volume/frequency</i>				
Few large customer orders per year	2	0	0	0
Several customer orders with large quantities per year	0	0	2	0
Large number of customer orders with medium quantities every year	0	2	2	1
Frequent call-offs based on delivery schedules	0	0	0	3
<i>Production process</i>				
Continuous process production	0	0	0	2
Continuous mass production	0	0	0	2
Frequent batch production (more frequent than monthly)	0	0	2	0
Batch production (less frequent than monthly)	0	0	1	0
One-off or infrequent batch production	2	0	0	0
<i>Shop floor layout</i>				
Functional layout (process layout)	2	0	0	0
Cellular layout (flow layout)	0	2	0	0
Continuous line layout	0	2	0	2
<i>Batch sizes</i>				
Equivalent to customer order quantities/call-off quantities	2	2	0	0
Small, equivalent to one week of demand	0	0	0	0
Medium, equivalent to a few weeks of demand	0	0	2	0
Large, equivalent to a months demand or more	0	0	2	0
<i>Through-put times in manufacturing</i>				
Short through-put times, a week or less	0	2	0	2
Medium through-put times, a few weeks	1	0	2	0
Long through-put times, several weeks	2	0	0	0

Reprinted from "The implications of fit between planning environments and manufacturing planning and control methods" (p. 900) by Jonsson, P., & Mattsson, S. (2003), International Journal of Operations & Production Management, 23(8).

### C. Matching of Planning Environments and Methods by Jonsson & Mattsson (2003)

Planning method	Type 1	Planning environment Type 2	Type 3	Type 4
<i>Detailed materials planning</i>				
Re-order point system		+	++	+
Runout-time planning		+	++	+
Material requirements planning	+	++	++	+
Kanban	-	+	+	++
Order-based planning	++	+		-
<i>Capacity planning</i>				
Overall factors	-		-	++
Capacity bills		+	+	+
Resource profiles	++	+	+	+
Capacity requirements planning	+	+	++	+
<i>Scheduling</i>				
Infinite capacity scheduling				++
Finite capacity scheduling	+		++	
Input/output control		++	+	++
<i>Sequencing</i>				
Sequencing by foremen	+			-
Priority rules		+		+
Dispatch lists	++	++	++	+
<b>Note:</b> ++ Strong match, + Poor match, - Mismatch				

Reprinted from "The Implications of Fit between Planning Environments and Manufacturing Planning and Control Methods" (p. 879) by Jonsson, P., & Mattsson, S. (2003), International Journal of Operations & Production Management, 23(8).



## D. Survey Questions for KPI Selection

The dashboard created for Dupo will include several KPIs that allow the employees to measure the performance of the production scheduling process. In order to identify which KPIs are the most appropriate, employees from different parts of the organization are consulted using a survey. This appendix includes the questions and results of the survey.

To be able to calculate the global weights of the KPIs, the five generic performance objectives need to be ranked according to their importance. After this, the contribution of each KPI to the performance objectives are considered and also ranked according to their importance.

*The survey has been conducted in Dutch in order to make it more accessible for the employees. Questions have been translated for the purpose of this report.*

### Informed Consent

We are interested in your opinion about the production planning dashboard. You will be asked to answer some questions about the functions and performance indicators that you would like to see on the dashboard. Please be assured that your responses will be processed anonymously.

The study consists of 7 questions and should take you around 15 minutes to complete. Your participation in this research is voluntary. You have the right to withdraw at any point during the study, for any reason, and without any prejudice.

By clicking the button below, you acknowledge that your participation in the study is voluntary, you are 18 years of age, and that you are aware that you may choose to terminate your participation in the study at any time and for any reason.

Please note that this survey will be best displayed on a laptop or desktop computer. Some features may be less compatible for use on a mobile device.

- ☐ I agree, start the survey
- ☐ I do not agree

### Ranking the Objectives

#### Information

In the first part of this survey, several questions will be asked regarding performance objectives, in order to better understand which objectives are central to the company. The questions will relate to the following five performance objectives:

**Quality** – The extent to which the product meets specifications and expectations of the customer, but also the reliability and durability of the product.

**Speed** – The speed at which the company can manufacture and deliver products to its customers,

**Dependability** – How reliable the company is when it comes to on-time delivery of products, in accordance with the agreed prices and costs.

**Flexibility** – The degree to which the process is adaptable. It concerns the adaptability of internal and external changes, changing what the process does, how it does it, or when it does something.

**Cost** – To reduce the production costs, so that the price of products can be reduced.

**Question 1.** Rank the objectives from most to least significant, with 1 being the most significant and 5 being the least significant objective.

Quality	<input type="checkbox"/>
Speed	<input type="checkbox"/>
Dependability	<input type="checkbox"/>
Flexibility	<input type="checkbox"/>
Cost	<input type="checkbox"/>

**Question 2.** How important are these performance objectives? Value them from 1 to 10, with 1 being 'very insignificant' and 10 being 'very significant'.

	1	2	3	4	5	6	7	8	9	10
Quality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Speed	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Dependability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Flexibility	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

## Ranking the KPIs

### Information

The production planning dashboard will contain different performance indicators. The indicators, so-called KPIs (key performance indicators), provide insight into the situation regarding the planning and performance of the tool. To find out what indicators the employees of Dupo find most useful, some questions will be asked about them in the next part of the survey. The following key performance indicators will be addressed:

**Orders finished late** – Percentage of production orders finished after the due date.

**Orders finished ahead** – Percentage of production orders finished well before the due date.

**Orders finished on time** – Percentage of production orders finished on time.

**Planned order execution time** – The planned time for executing an order.

**Average lead time** – Mean waiting time between the initiation (order placement) and completion of the production process.

**Planned setup time** – The planned time for the setup of an order.

**Planned runtime per item** – The planned time for producing one quantity unit.

**Downtime** – The percentage of time during which the machines are not functional.

**Planned production time** – The total time the machines are scheduled to produce.

**Planned machine utilization** – The planned percentage of used machine capacity.

**Question 3.** We would like to evaluate the contribution of the KPIs to the performance objectives. In order to do this, we ask you to rank the KPIs from 1 to 10 according to their contribution to the **Quality** objective.

Orders finished late	<input type="checkbox"/>
Orders finished ahead	<input type="checkbox"/>
Orders finished on time	<input type="checkbox"/>
Planned order execution time	<input type="checkbox"/>
Average lead time	<input type="checkbox"/>
Planned setup time	<input type="checkbox"/>
Planned runtime per item	<input type="checkbox"/>
Downtime	<input type="checkbox"/>
Planned production time	<input type="checkbox"/>
Planned machine utilization	<input type="checkbox"/>

**Question 4.** We would like to evaluate the contribution of the KPIs to the performance objectives. In order to do this, we ask you to rank the KPIs from 1 to 10 according to their contribution to the **Speed** objective.

Orders finished late	<input type="checkbox"/>
Orders finished ahead	<input type="checkbox"/>
Orders finished on time	<input type="checkbox"/>
Planned order execution time	<input type="checkbox"/>
Average lead time	<input type="checkbox"/>
Planned setup time	<input type="checkbox"/>
Planned runtime per item	<input type="checkbox"/>
Downtime	<input type="checkbox"/>
Planned production time	<input type="checkbox"/>
Planned machine utilization	<input type="checkbox"/>

**Question 5.** We would like to evaluate the contribution of the KPIs to the performance objectives. In order to do this, we ask you to rank the KPIs from 1 to 10 according to their contribution to the **Dependability** objective.

Orders finished late	<input type="checkbox"/>
Orders finished ahead	<input type="checkbox"/>

Orders finished on time	<input type="checkbox"/>
Planned order execution time	<input type="checkbox"/>
Average lead time	<input type="checkbox"/>
Planned setup time	<input type="checkbox"/>
Planned runtime per item	<input type="checkbox"/>
Downtime	<input type="checkbox"/>
Planned production time	<input type="checkbox"/>
Planned machine utilization	<input type="checkbox"/>

**Question 6.** We would like to evaluate the contribution of the KPIs to the performance objectives. In order to do this, we ask you to rank the KPIs from 1 to 10 according to their contribution to the **Flexibility** objective.

Orders finished late	<input type="checkbox"/>
Orders finished ahead	<input type="checkbox"/>
Orders finished on time	<input type="checkbox"/>
Planned order execution time	<input type="checkbox"/>
Average lead time	<input type="checkbox"/>
Planned setup time	<input type="checkbox"/>
Planned runtime per item	<input type="checkbox"/>
Downtime	<input type="checkbox"/>
Planned production time	<input type="checkbox"/>
Planned machine utilization	<input type="checkbox"/>

**Question 7.** We would like to evaluate the contribution of the KPIs to the performance objectives. In order to do this, we ask you to rank the KPIs from 1 to 10 according to their contribution to the **Cost** objective.

Orders finished late	<input type="checkbox"/>
Orders finished ahead	<input type="checkbox"/>
Orders finished on time	<input type="checkbox"/>
Planned order execution time	<input type="checkbox"/>
Average lead time	<input type="checkbox"/>
Planned setup time	<input type="checkbox"/>
Planned runtime per item	<input type="checkbox"/>
Downtime	<input type="checkbox"/>
Planned production time	<input type="checkbox"/>
Planned machine utilization	<input type="checkbox"/>

## E. Survey Results

Scores have been assigned to KPI's and generic performance objectives according to the position they have been ranked. For example: In Question 3 'orders finished on time' has been ranked as most important (1<sup>st</sup> place) by all three respondents. If a KPI is ranked as most important it earns 10 points. The total score of 'orders finished on time' thus totals to, three times ten, 30 points. Since in Question 3 the KPIs are ranked according to their contribution to the Quality objective, the following questions repeat this for the other generic performance objectives.

	Q12	Q2	Rank		Q5	Score	Rank
Quality	15	29	1		Planned production time	29	1
Dependability	11	27	2		Orders finished on time	25	2
Flexibility	8	24	3		Planned runtime per item	20	3
Costs	6	20	4		Downtime	20	3
Speed	1	17	5		Planned order execution time	18	4
					Planned setup time	16	5
<b>Q3</b>	<b>Score</b>	<b>Rank</b>			Average lead time	14	6
Orders finished on time	30	1			Orders finished late	10	7
Planned setup time	23	2			Orders finished ahead	8	8
Planned order execution time	23	2			Planned machine utilization	5	9
Planned runtime per item	21	3					
Planned production time	18	4			<b>Q6</b>	<b>Score</b>	<b>Rank</b>
Downtime	16	5			Orders finished on time	28	1
Average lead time	15	6			Planned order execution time	26	2
Planned machine utilization	9	7			Average lead time	24	3
Orders finished late	6	8			Planned setup time	20	4
Orders finished ahead	4	9			Orders finished ahead	17	5
					Planned runtime per item	16	6
<b>Q4</b>	<b>Score</b>	<b>Rank</b>			Downtime	13	7
Orders finished on time	27	1			Planned production time	11	8
Planned order execution time	24	2			Planned machine utilization	8	9
Planned setup time	19	3			Orders finished late	5	10
Planned runtime per item	15	4					
Planned production time	15	4			<b>Q7</b>	<b>Score</b>	<b>Rank</b>
Downtime	15	4			Downtime	26	1
Average lead time	14	5			Average lead time	21	2
Planned machine utilization	12	6			Planned runtime per item	21	2
Orders finished late	12	6			Planned order execution time	19	3
Orders finished ahead	12	6			Planned machine utilization	17	4
					Orders finished late	16	5
					Planned production time	14	6
					Planned setup time	13	7
					Orders finished on time	12	8
					Orders finished ahead	6	9

## F. Spreadsheet for KPI selection

	Quality	Speed	Dependability	Flexibility	Cost
Quality	1,00	7,00	2,00	4,00	5,00
Speed	0,14	1,00	0,17	0,25	0,33
Dependability	0,50	6,00	1,00	2,00	5,00
Flexibility	0,25	4,00	0,50	1,00	2,00
Cost	0,20	3,00	0,20	0,50	1,00
<b>Total</b>	<b>2,09</b>	<b>21,00</b>	<b>3,87</b>	<b>7,75</b>	<b>13,33</b>

Table 9. Pair-wise comparison of the 5 generic performance objectives.

	Orders finished late	Orders finished ahead	Orders finished on time	Planned order execution time	Average lead time	Planned setup time	Planned runtime per item	Downtime	Planned production time	Planned machine utilization
<b>Quality</b>										
Orders finished late	1,00	2,00	0,14	0,17	0,33	0,17	0,20	0,25	0,25	0,50
Orders finished ahead	0,50	1,00	0,14	0,17	0,25	0,17	0,17	0,20	0,20	0,33
Orders finished on time	7,00	7,00	1,00	3,00	6,00	3,00	4,00	6,00	5,00	7,00
Planned order execution time	6,00	6,00	0,33	1,00	4,00	1,00	2,00	4,00	3,00	5,00
Average lead time	3,00	4,00	0,17	0,25	1,00	0,25	0,33	0,50	0,50	2,00
Planned setup time	6,00	6,00	0,33	1,00	4,00	1,00	2,00	4,00	3,00	5,00
Planned runtime per item	5,00	6,00	0,25	0,50	3,00	0,50	1,00	3,00	2,00	4,00
Downtime	4,00	5,00	0,17	0,25	2,00	0,25	0,33	1,00	0,50	3,00
Planned production time	4,00	5,00	0,20	0,33	2,00	0,33	0,50	2,00	1,00	3,00
Planned machine utilization	2,00	3,00	0,14	0,20	0,50	0,20	0,25	0,33	0,33	1,00
<b>Total</b>	<b>38,50</b>	<b>45,00</b>	<b>2,88</b>	<b>6,87</b>	<b>23,08</b>	<b>6,87</b>	<b>10,78</b>	<b>21,28</b>	<b>15,78</b>	<b>30,83</b>
<b>Speed</b>										
Orders finished late	1,00	1,00	0,17	0,20	0,50	0,25	0,33	0,33	0,33	1,00
Orders finished ahead	1,00	1,00	0,17	0,20	0,50	0,25	0,33	0,33	0,33	1,00
Orders finished on time	6,00	6,00	1,00	2,00	5,00	3,00	4,00	4,00	4,00	6,00
Planned order execution time	5,00	5,00	0,50	1,00	4,00	2,00	3,00	3,00	3,00	5,00
Average lead time	2,00	2,00	0,20	0,25	1,00	0,33	0,50	0,50	0,50	2,00
Planned setup time	4,00	4,00	0,33	0,50	3,00	1,00	2,00	2,00	2,00	4,00
Planned runtime per item	3,00	3,00	0,25	0,33	2,00	0,50	1,00	1,00	1,00	3,00
Downtime	3,00	3,00	0,25	0,33	2,00	0,50	1,00	1,00	1,00	3,00
Planned production time	3,00	3,00	0,25	0,33	2,00	0,50	1,00	1,00	1,00	3,00
Planned machine utilization	1,00	1,00	0,17	0,20	0,50	0,25	0,33	0,33	0,33	1,00
<b>Total</b>	<b>29,00</b>	<b>29,00</b>	<b>3,28</b>	<b>5,35</b>	<b>20,50</b>	<b>8,58</b>	<b>13,50</b>	<b>13,50</b>	<b>13,50</b>	<b>29,00</b>
<b>Dependability</b>										
Orders finished late	1,00	2,00	0,20	0,33	0,50	0,50	0,25	0,25	0,17	3,00
Orders finished ahead	0,50	1,00	0,17	0,25	0,33	0,33	0,20	0,20	0,14	0,50
Orders finished on time	5,00	6,00	1,00	3,00	4,00	4,00	2,00	2,00	0,50	7,00
Planned order execution time	3,00	4,00	0,33	1,00	2,00	2,00	0,50	0,50	0,25	5,00
Average lead time	2,00	3,00	0,25	0,50	1,00	1,00	0,33	0,33	0,20	4,00
Planned setup time	2,00	3,00	0,25	0,50	1,00	1,00	0,33	0,33	0,20	4,00
Planned runtime per item	4,00	5,00	0,50	2,00	3,00	3,00	1,00	1,00	0,33	6,00
Downtime	4,00	5,00	0,50	2,00	3,00	3,00	1,00	1,00	0,33	6,00
Planned production time	6,00	7,00	2,00	4,00	5,00	5,00	3,00	3,00	1,00	8,00
Planned machine utilization	0,33	2,00	0,14	0,20	0,25	0,25	0,17	0,17	0,13	1,00
<b>Total</b>	<b>27,83</b>	<b>38,00</b>	<b>5,34</b>	<b>13,78</b>	<b>20,08</b>	<b>20,08</b>	<b>8,78</b>	<b>8,78</b>	<b>3,25</b>	<b>44,50</b>
<b>Flexibility</b>										
Orders finished late	1,00	0,33	0,14	0,17	0,20	0,25	0,33	0,50	0,50	1,00
Orders finished ahead	3,00	1,00	0,20	0,25	0,33	0,50	1,00	2,00	2,00	3,00
Orders finished on time	7,00	5,00	1,00	2,00	3,00	4,00	5,00	6,00	6,00	7,00
Planned order execution time	6,00	4,00	0,50	1,00	2,00	3,00	4,00	5,00	5,00	6,00
Average lead time	5,00	3,00	0,33	0,50	1,00	2,00	3,00	4,00	4,00	5,00
Planned setup time	4,00	2,00	0,25	0,33	0,50	1,00	2,00	3,00	3,00	4,00
Planned runtime per item	3,00	1,00	0,20	0,25	0,33	0,50	1,00	2,00	2,00	3,00
Downtime	2,00	0,50	0,17	0,20	0,25	0,33	0,50	1,00	1,00	2,00
Planned production time	2,00	0,50	0,17	0,20	0,25	0,33	0,50	1,00	1,00	2,00
Planned machine utilization	1,00	0,33	0,14	0,17	0,20	0,25	0,33	0,50	0,50	1,00
<b>Total</b>	<b>34,00</b>	<b>17,67</b>	<b>3,10</b>	<b>5,07</b>	<b>8,07</b>	<b>12,17</b>	<b>17,67</b>	<b>25,00</b>	<b>25,00</b>	<b>34,00</b>
<b>Cost</b>										
Orders finished late	1,00	3,00	2,00	0,50	0,33	2,00	0,33	0,20	2,00	1,00
Orders finished ahead	0,33	1,00	0,50	0,25	0,20	0,50	0,20	0,14	0,50	0,33
Orders finished on time	0,50	2,00	1,00	0,33	0,25	1,00	0,25	0,17	1,00	0,50
Planned order execution time	2,00	4,00	3,00	1,00	0,50	3,00	0,50	0,25	3,00	2,00
Average lead time	3,00	5,00	4,00	2,00	1,00	4,00	1,00	0,33	4,00	3,00
Planned setup time	0,50	2,00	1,00	0,33	0,25	1,00	0,25	0,17	1,00	0,50
Planned runtime per item	3,00	5,00	4,00	2,00	1,00	4,00	1,00	0,33	4,00	3,00
Downtime	5,00	7,00	6,00	4,00	3,00	6,00	3,00	1,00	6,00	5,00
Planned production time	0,50	2,00	1,00	0,33	0,25	1,00	0,25	0,17	1,00	0,50
Planned machine utilization	1,00	3,00	2,00	0,50	0,33	2,00	0,33	0,20	2,00	1,00
<b>Total</b>	<b>16,83</b>	<b>34,00</b>	<b>24,50</b>	<b>11,25</b>	<b>7,12</b>	<b>24,50</b>	<b>7,12</b>	<b>2,96</b>	<b>24,50</b>	<b>16,83</b>

Table 10. Pair-wise comparison of the KPI alternatives.

	Quality	Speed	Dependability	Flexibility	Cost	Total
Quality	0,48	0,33	0,52	0,52	0,38	2,22
Speed	0,07	0,05	0,04	0,03	0,03	0,22
Dependability	0,24	0,29	0,26	0,26	0,38	1,42
Flexibility	0,12	0,19	0,13	0,13	0,15	0,72
Cost	0,10	0,14	0,05	0,06	0,08	0,43

Table 11. Normalized comparison of the 5 generic performance objectives.

	Orders finished late	Orders finished ahead	Orders finished on time	Planned order execution time	Average lead time	Planned setup time	Planned runtime per item	Downtime	Planned production time	Planned machine utilization	Total
<b>Quality</b>											
Orders finished late	0,03	0,04	0,05	0,02	0,01	0,02	0,02	0,01	0,02	0,02	0,25
Orders finished ahead	0,01	0,02	0,05	0,02	0,01	0,02	0,02	0,01	0,01	0,01	0,19
Orders finished on time	0,18	0,16	0,35	0,44	0,26	0,44	0,37	0,28	0,32	0,23	3,02
Planned order execution time	0,16	0,13	0,12	0,15	0,17	0,15	0,19	0,19	0,19	0,16	1,60
Average lead time	0,08	0,09	0,06	0,04	0,04	0,04	0,03	0,02	0,03	0,06	0,49
Planned setup time	0,16	0,13	0,12	0,15	0,17	0,15	0,19	0,19	0,19	0,16	1,60
Planned runtime per item	0,13	0,13	0,09	0,07	0,13	0,07	0,09	0,14	0,13	0,13	1,12
Downtime	0,10	0,11	0,06	0,04	0,09	0,04	0,03	0,05	0,03	0,10	0,64
Planned production time	0,10	0,11	0,07	0,05	0,09	0,05	0,05	0,09	0,06	0,10	0,77
Planned machine utilization	0,05	0,07	0,05	0,03	0,02	0,03	0,02	0,02	0,02	0,03	0,34
<b>Speed</b>											
Orders finished late	0,03	0,03	0,05	0,04	0,02	0,03	0,02	0,02	0,02	0,03	0,32
Orders finished ahead	0,03	0,03	0,05	0,04	0,02	0,03	0,02	0,02	0,02	0,03	0,32
Orders finished on time	0,21	0,21	0,30	0,37	0,24	0,35	0,30	0,30	0,30	0,21	2,78
Planned order execution time	0,17	0,17	0,15	0,19	0,20	0,23	0,22	0,22	0,22	0,17	1,95
Average lead time	0,07	0,07	0,06	0,05	0,05	0,04	0,04	0,04	0,04	0,07	0,51
Planned setup time	0,14	0,14	0,10	0,09	0,15	0,12	0,15	0,15	0,15	0,14	1,32
Planned runtime per item	0,10	0,10	0,08	0,06	0,10	0,06	0,07	0,07	0,07	0,10	0,83
Downtime	0,10	0,10	0,08	0,06	0,10	0,06	0,07	0,07	0,07	0,10	0,83
Planned production time	0,10	0,10	0,08	0,06	0,10	0,06	0,07	0,07	0,07	0,10	0,83
Planned machine utilization	0,03	0,03	0,05	0,04	0,02	0,03	0,02	0,02	0,02	0,03	0,32
<b>Dependability</b>											
Orders finished late	0,04	0,05	0,04	0,02	0,02	0,02	0,03	0,03	0,05	0,07	0,38
Orders finished ahead	0,02	0,03	0,03	0,02	0,02	0,02	0,02	0,02	0,04	0,01	0,23
Orders finished on time	0,18	0,16	0,19	0,22	0,20	0,20	0,23	0,23	0,15	0,16	1,91
Planned order execution time	0,11	0,11	0,06	0,07	0,10	0,10	0,06	0,06	0,08	0,11	0,85
Average lead time	0,07	0,08	0,05	0,04	0,05	0,05	0,04	0,04	0,06	0,09	0,56
Planned setup time	0,07	0,08	0,05	0,04	0,05	0,05	0,04	0,04	0,06	0,09	0,56
Planned runtime per item	0,14	0,13	0,09	0,15	0,15	0,15	0,11	0,11	0,10	0,13	1,28
Downtime	0,14	0,13	0,09	0,15	0,15	0,15	0,11	0,11	0,10	0,13	1,28
Planned production time	0,22	0,18	0,37	0,29	0,25	0,25	0,34	0,34	0,31	0,18	2,73
Planned machine utilization	0,01	0,05	0,03	0,01	0,01	0,01	0,02	0,02	0,04	0,02	0,23
<b>Flexibility</b>											
Orders finished late	0,03	0,02	0,05	0,03	0,02	0,02	0,02	0,02	0,02	0,03	0,26
Orders finished ahead	0,09	0,06	0,06	0,05	0,04	0,04	0,06	0,08	0,08	0,09	0,65
Orders finished on time	0,21	0,28	0,32	0,39	0,37	0,33	0,28	0,24	0,24	0,21	2,88
Planned order execution time	0,18	0,23	0,16	0,20	0,25	0,25	0,23	0,20	0,20	0,18	2,06
Average lead time	0,15	0,17	0,11	0,10	0,12	0,16	0,17	0,16	0,16	0,15	1,45
Planned setup time	0,12	0,11	0,08	0,07	0,06	0,08	0,11	0,12	0,12	0,12	0,99
Planned runtime per item	0,09	0,06	0,06	0,05	0,04	0,04	0,06	0,08	0,08	0,09	0,65
Downtime	0,06	0,03	0,05	0,04	0,03	0,03	0,03	0,04	0,04	0,06	0,41
Planned production time	0,06	0,03	0,05	0,04	0,03	0,03	0,03	0,04	0,04	0,06	0,41
Planned machine utilization	0,03	0,02	0,05	0,03	0,02	0,02	0,02	0,02	0,02	0,03	0,26
<b>Cost</b>											
Orders finished late	0,06	0,09	0,08	0,04	0,05	0,08	0,05	0,07	0,08	0,06	0,66
Orders finished ahead	0,02	0,03	0,02	0,02	0,03	0,02	0,03	0,05	0,02	0,02	0,26
Orders finished on time	0,03	0,06	0,04	0,03	0,04	0,04	0,04	0,06	0,04	0,03	0,40
Planned order execution time	0,12	0,12	0,12	0,09	0,07	0,12	0,07	0,08	0,12	0,12	1,04
Average lead time	0,18	0,15	0,16	0,18	0,14	0,16	0,14	0,11	0,16	0,18	1,56
Planned setup time	0,03	0,06	0,04	0,03	0,04	0,04	0,04	0,06	0,04	0,03	0,40
Planned runtime per item	0,18	0,15	0,16	0,18	0,14	0,16	0,14	0,11	0,16	0,18	1,56
Downtime	0,30	0,21	0,24	0,36	0,42	0,24	0,42	0,34	0,24	0,30	3,07
Planned production time	0,03	0,06	0,04	0,03	0,04	0,04	0,04	0,06	0,04	0,03	0,40
Planned machine utilization	0,06	0,09	0,08	0,04	0,05	0,08	0,05	0,07	0,08	0,06	0,66

Table 12. Normalized comparison of the KPI alternatives.

	Quality	Speed	Dependability	Flexibility	Cost	Global weight	Ranking
Orders finished late	0,54	0,07	0,53	0,19	0,28	1,615	9
Orders finished ahead	0,43	0,07	0,32	0,46	0,11	1,393	10
Orders finished on time	6,69	0,60	2,70	2,07	0,17	12,231	1
Planned order execution time	3,54	0,42	1,20	1,48	0,45	7,091	2
Average lead time	1,09	0,11	0,79	1,04	0,67	3,709	7
Planned setup time	3,54	0,28	0,79	0,71	0,17	5,503	5
Planned runtime per item	2,48	0,18	1,81	0,46	0,67	5,601	4
Downtime	1,42	0,18	1,81	0,29	1,32	5,018	6
Planned production time	1,71	0,18	3,87	0,29	0,17	6,218	3
Planned machine utilization	0,76	0,07	0,33	0,19	0,28	1,620	8

Table 13. Calculation of the global weights.

	Quality	Speed	Dependability	Flexibility	Cost	Average			
Quality	0,48	0,33	0,52	0,52	0,38	0,44			
Speed	0,07	0,05	0,04	0,03	0,03	0,04			
Dependability	0,24	0,29	0,26	0,26	0,38	0,28			
Flexibility	0,12	0,19	0,13	0,13	0,15	0,14			
Cost	0,10	0,14	0,05	0,06	0,08	0,09			
	Quality	Speed	Dependability	Flexibility	Cost	Weighted Sum			
Priority	0,44	0,04	0,28	0,14	0,09				
Quality	0,44	0,28	0,56	0,56	0,45	2,29			
Speed	0,06	0,04	0,05	0,04	0,03	0,21			
Dependability	0,22	0,24	0,28	0,28	0,45	1,47			
Flexibility	0,11	0,16	0,14	0,14	0,18	0,73			
Cost	0,09	0,12	0,06	0,07	0,09	0,42			
Calculation of $\lambda_{\max}$						Calculation of CR			
<u>Weighted Sum</u>	<u>Priority</u>					$CI = (\lambda_{\max} - n)/(n - 1)$			
2,29	0,44	5,20	divide weighted sum by priority			$n = 5$ (number of compared elements)			
0,21	0,04	5,25				$CI = 0,029$			
1,47	0,28	5,25				$CR = CI/RI$			
0,73	0,14	5,21				$RI = 1,12$ (for a 5th order matrix)			
0,42	0,09	4,67				$CR = 0,026$			
	<b>Total</b>	25,59				$CR < 0,10 \rightarrow$ consistent matrix			
	<b><math>\lambda_{\max}</math></b>	5,12	divide total by 5						

Table 14. Calculating the consistency of the performance objectives matrix.



	Orders finished late	Orders finished ahead	Orders finished on time	Planned order execution time	Average lead time	Planned setup time	Planned runtime per item	Downtime	Planned production time	Planned machine utilization	Average
<b>Quality</b>											
Orders finished late	0,03	0,04	0,05	0,02	0,01	0,02	0,02	0,01	0,02	0,02	0,02
Orders finished ahead	0,01	0,02	0,05	0,02	0,01	0,02	0,02	0,01	0,01	0,01	0,02
Orders finished on time	0,18	0,16	0,35	0,44	0,26	0,44	0,37	0,28	0,32	0,23	0,30
Planned order execution time	0,16	0,13	0,12	0,15	0,17	0,15	0,19	0,19	0,19	0,16	0,16
Average lead time	0,08	0,09	0,06	0,04	0,04	0,04	0,03	0,02	0,03	0,06	0,05
Planned setup time	0,16	0,13	0,12	0,15	0,17	0,15	0,19	0,19	0,19	0,16	0,16
Planned runtime per item	0,13	0,13	0,09	0,07	0,13	0,07	0,09	0,14	0,13	0,13	0,11
Downtime	0,10	0,11	0,06	0,04	0,09	0,04	0,03	0,05	0,03	0,10	0,06
Planned production time	0,10	0,11	0,07	0,05	0,09	0,05	0,05	0,09	0,06	0,10	0,08
Planned machine utilization	0,05	0,07	0,05	0,03	0,02	0,03	0,02	0,02	0,02	0,03	0,03
<b>Speed</b>											
Orders finished late	0,03	0,03	0,05	0,04	0,02	0,03	0,02	0,02	0,02	0,03	0,03
Orders finished ahead	0,03	0,03	0,05	0,04	0,02	0,03	0,02	0,02	0,02	0,03	0,03
Orders finished on time	0,21	0,21	0,30	0,37	0,24	0,35	0,30	0,30	0,30	0,21	0,28
Planned order execution time	0,17	0,17	0,15	0,19	0,20	0,23	0,22	0,22	0,22	0,17	0,20
Average lead time	0,07	0,07	0,06	0,05	0,05	0,04	0,04	0,04	0,04	0,07	0,05
Planned setup time	0,14	0,14	0,10	0,09	0,15	0,12	0,15	0,15	0,15	0,14	0,13
Planned runtime per item	0,10	0,10	0,08	0,06	0,10	0,06	0,07	0,07	0,07	0,10	0,08
Downtime	0,10	0,10	0,08	0,06	0,10	0,06	0,07	0,07	0,07	0,10	0,08
Planned production time	0,10	0,10	0,08	0,06	0,10	0,06	0,07	0,07	0,07	0,10	0,08
Planned machine utilization	0,03	0,03	0,05	0,04	0,02	0,03	0,02	0,02	0,02	0,03	0,03
<b>Dependability</b>											
Orders finished late	0,04	0,05	0,04	0,02	0,02	0,02	0,03	0,03	0,05	0,07	0,04
Orders finished ahead	0,02	0,03	0,03	0,02	0,02	0,02	0,02	0,02	0,04	0,01	0,02
Orders finished on time	0,18	0,16	0,19	0,22	0,20	0,20	0,23	0,23	0,15	0,16	0,19
Planned order execution time	0,11	0,11	0,06	0,07	0,10	0,10	0,06	0,06	0,08	0,11	0,09
Average lead time	0,07	0,08	0,05	0,04	0,05	0,05	0,04	0,04	0,06	0,09	0,06
Planned setup time	0,07	0,08	0,05	0,04	0,05	0,05	0,04	0,04	0,06	0,09	0,06
Planned runtime per item	0,14	0,13	0,09	0,15	0,15	0,15	0,11	0,11	0,10	0,13	0,13
Downtime	0,14	0,13	0,09	0,15	0,15	0,15	0,11	0,11	0,10	0,13	0,13
Planned production time	0,22	0,18	0,37	0,29	0,25	0,25	0,34	0,34	0,31	0,18	0,27
Planned machine utilization	0,01	0,05	0,03	0,01	0,01	0,01	0,02	0,02	0,04	0,02	0,02
<b>Flexibility</b>											
Orders finished late	0,03	0,02	0,05	0,03	0,02	0,02	0,02	0,02	0,02	0,03	0,03
Orders finished ahead	0,09	0,06	0,06	0,05	0,04	0,04	0,06	0,08	0,08	0,09	0,06
Orders finished on time	0,21	0,28	0,32	0,39	0,37	0,33	0,28	0,24	0,24	0,21	0,29
Planned order execution time	0,18	0,23	0,16	0,20	0,25	0,25	0,23	0,20	0,20	0,18	0,21
Average lead time	0,15	0,17	0,11	0,10	0,12	0,16	0,17	0,16	0,16	0,15	0,14
Planned setup time	0,12	0,11	0,08	0,07	0,06	0,08	0,11	0,12	0,12	0,12	0,10
Planned runtime per item	0,09	0,06	0,06	0,05	0,04	0,04	0,06	0,08	0,08	0,09	0,06
Downtime	0,06	0,03	0,05	0,04	0,03	0,03	0,03	0,04	0,04	0,06	0,04
Planned production time	0,06	0,03	0,05	0,04	0,03	0,03	0,03	0,04	0,04	0,06	0,04
Planned machine utilization	0,03	0,02	0,05	0,03	0,02	0,02	0,02	0,02	0,02	0,03	0,03
<b>Cost</b>											
Orders finished late	0,06	0,09	0,08	0,04	0,05	0,08	0,05	0,07	0,08	0,06	0,07
Orders finished ahead	0,02	0,03	0,02	0,02	0,03	0,02	0,03	0,05	0,02	0,02	0,03
Orders finished on time	0,03	0,06	0,04	0,03	0,04	0,04	0,04	0,06	0,04	0,03	0,04
Planned order execution time	0,12	0,12	0,12	0,09	0,07	0,12	0,07	0,08	0,12	0,12	0,10
Average lead time	0,18	0,15	0,16	0,18	0,14	0,16	0,14	0,11	0,16	0,18	0,16
Planned setup time	0,03	0,06	0,04	0,03	0,04	0,04	0,04	0,06	0,04	0,03	0,04
Planned runtime per item	0,18	0,15	0,16	0,18	0,14	0,16	0,14	0,11	0,16	0,18	0,16
Downtime	0,30	0,21	0,24	0,36	0,42	0,24	0,42	0,34	0,24	0,30	0,31
Planned production time	0,03	0,06	0,04	0,03	0,04	0,04	0,04	0,06	0,04	0,03	0,04
Planned machine utilization	0,06	0,09	0,08	0,04	0,05	0,08	0,05	0,07	0,08	0,06	0,07

Table 15. Calculating the consistency of the KPI alternatives matrix.

	Orders finished late	Orders finished ahead	Orders finished on time	Planned order execution time	Average lead time	Planned setup time	Planned runtime per item	Downtime	Planned production time	Planned machine utilization	Weighted Sum
<b>Quality</b>											
Priority	0,02	0,02	0,30	0,16	0,05	0,16	0,11	0,06	0,08	0,03	
Orders finished late	0,02	0,04	0,04	0,03	0,02	0,03	0,02	0,02	0,02	0,02	0,25
Orders finished ahead	0,01	0,02	0,04	0,03	0,01	0,03	0,02	0,01	0,02	0,01	0,20
Orders finished on time	0,17	0,13	0,30	0,48	0,30	0,48	0,45	0,38	0,38	0,24	3,31
Planned order execution time	0,15	0,12	0,10	0,16	0,20	0,16	0,22	0,26	0,23	0,17	1,76
Average lead time	0,07	0,08	0,05	0,04	0,05	0,04	0,04	0,03	0,04	0,07	0,51
Planned setup time	0,15	0,12	0,10	0,16	0,20	0,16	0,22	0,26	0,23	0,17	1,76
Planned runtime per item	0,12	0,12	0,08	0,08	0,15	0,08	0,11	0,19	0,15	0,14	1,21
Downtime	0,10	0,10	0,05	0,04	0,10	0,04	0,04	0,06	0,04	0,10	0,66
Planned production time	0,10	0,10	0,06	0,05	0,10	0,05	0,06	0,13	0,08	0,10	0,82
Planned machine utilization	0,05	0,06	0,04	0,03	0,02	0,03	0,03	0,02	0,03	0,03	0,35
<b>Speed</b>											
Priority	0,03	0,03	0,28	0,20	0,05	0,13	0,08	0,08	0,08	0,03	
Orders finished late	0,03	0,03	0,05	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,32
Orders finished ahead	0,03	0,03	0,05	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,32
Orders finished on time	0,19	0,19	0,28	0,39	0,26	0,39	0,33	0,33	0,33	0,19	2,89
Planned order execution time	0,16	0,16	0,14	0,20	0,21	0,26	0,25	0,25	0,25	0,16	2,03
Average lead time	0,06	0,06	0,06	0,05	0,05	0,04	0,04	0,04	0,04	0,06	0,52
Planned setup time	0,13	0,13	0,09	0,10	0,15	0,13	0,17	0,17	0,17	0,13	1,35
Planned runtime per item	0,10	0,10	0,07	0,07	0,10	0,07	0,08	0,08	0,08	0,10	0,84
Downtime	0,10	0,10	0,07	0,07	0,10	0,07	0,08	0,08	0,08	0,10	0,84
Planned production time	0,10	0,10	0,07	0,07	0,10	0,07	0,08	0,08	0,08	0,10	0,84
Planned machine utilization	0,03	0,03	0,05	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,32
<b>Dependability</b>											
Priority	0,04	0,02	0,19	0,09	0,06	0,06	0,13	0,13	0,27	0,02	
Orders finished late	0,04	0,05	0,04	0,03	0,03	0,03	0,03	0,03	0,05	0,07	0,38
Orders finished ahead	0,02	0,02	0,03	0,02	0,02	0,02	0,03	0,03	0,04	0,01	0,23
Orders finished on time	0,19	0,14	0,19	0,26	0,22	0,22	0,26	0,26	0,14	0,16	2,03
Planned order execution time	0,11	0,09	0,06	0,09	0,11	0,11	0,06	0,06	0,07	0,11	0,89
Average lead time	0,08	0,07	0,05	0,04	0,06	0,06	0,04	0,04	0,05	0,09	0,58
Planned setup time	0,08	0,07	0,05	0,04	0,06	0,06	0,04	0,04	0,05	0,09	0,58
Planned runtime per item	0,15	0,11	0,10	0,17	0,17	0,17	0,13	0,13	0,09	0,14	1,35
Downtime	0,15	0,11	0,10	0,17	0,17	0,17	0,13	0,13	0,09	0,14	1,35
Planned production time	0,23	0,16	0,38	0,34	0,28	0,28	0,38	0,38	0,27	0,18	2,89
Planned machine utilization	0,01	0,05	0,03	0,02	0,01	0,01	0,02	0,02	0,03	0,02	0,23
<b>Flexibility</b>											
Priority	0,03	0,06	0,29	0,21	0,14	0,10	0,06	0,04	0,04	0,03	
Orders finished late	0,03	0,02	0,04	0,03	0,03	0,02	0,02	0,02	0,02	0,03	0,26
Orders finished ahead	0,08	0,06	0,06	0,05	0,05	0,05	0,06	0,08	0,08	0,08	0,65
Orders finished on time	0,18	0,32	0,29	0,41	0,43	0,40	0,32	0,24	0,24	0,18	3,03
Planned order execution time	0,16	0,26	0,14	0,21	0,29	0,30	0,26	0,20	0,20	0,16	2,17
Average lead time	0,13	0,19	0,10	0,10	0,14	0,20	0,19	0,16	0,16	0,13	1,52
Planned setup time	0,10	0,13	0,07	0,07	0,07	0,10	0,13	0,12	0,12	0,10	1,02
Planned runtime per item	0,08	0,06	0,06	0,05	0,05	0,05	0,06	0,08	0,08	0,08	0,65
Downtime	0,05	0,03	0,05	0,04	0,04	0,03	0,03	0,04	0,04	0,05	0,41
Planned production time	0,05	0,03	0,05	0,04	0,04	0,03	0,03	0,04	0,04	0,05	0,41
Planned machine utilization	0,03	0,02	0,04	0,03	0,03	0,02	0,02	0,02	0,02	0,03	0,26
<b>Cost</b>											
Priority	0,07	0,03	0,04	0,10	0,16	0,04	0,16	0,31	0,04	0,07	
Orders finished late	0,07	0,08	0,08	0,05	0,05	0,08	0,05	0,06	0,08	0,07	0,66
Orders finished ahead	0,02	0,03	0,02	0,03	0,03	0,02	0,03	0,04	0,02	0,02	0,26
Orders finished on time	0,03	0,05	0,04	0,03	0,04	0,04	0,04	0,05	0,04	0,03	0,40
Planned order execution time	0,13	0,10	0,12	0,10	0,08	0,12	0,08	0,08	0,12	0,13	1,06
Average lead time	0,20	0,13	0,16	0,21	0,16	0,16	0,16	0,10	0,16	0,20	1,62
Planned setup time	0,03	0,05	0,04	0,03	0,04	0,04	0,04	0,05	0,04	0,03	0,40
Planned runtime per item	0,20	0,13	0,16	0,21	0,16	0,16	0,16	0,10	0,16	0,20	1,62
Downtime	0,33	0,18	0,24	0,41	0,47	0,24	0,47	0,31	0,24	0,33	3,21
Planned production time	0,03	0,05	0,04	0,03	0,04	0,04	0,04	0,05	0,04	0,03	0,40
Planned machine utilization	0,07	0,08	0,08	0,05	0,05	0,08	0,05	0,06	0,08	0,07	0,66

Table 16. Calculating the consistency of the KPI alternatives matrix.

<b>Calculation of <math>\lambda_{\max}</math> (quality)</b>				<b>Calculation of CR (quality)</b>			
<u>Weighted Sum</u>	<u>Priority</u>			$CI = (\lambda_{\max} - n)/(n - 1)$			
0,32	0,02	13,14	divide weighted sum by priority	$n = 10$ (number of compared elements)			
0,32	0,02	16,74		<b>CI = 0,067</b>			
2,89	0,30	9,57					
2,03	0,16	12,70		$CR = CI/RI$			
0,52	0,05	10,47		$RI = 1,49$ (for a 10th order matrix)			
1,35	0,16	8,49		<b>CR = 0,045</b>			
0,84	0,11	7,51		$CR < 0,10$	→ consistent matrix		
0,84	0,06	13,11					
0,84	0,08	10,90					
0,32	0,03	9,47					
	<b>Total</b>	112,12					
	<b><math>\lambda_{\max}</math></b>	11,21	divide total by 10				
<b>Calculation of <math>\lambda_{\max}</math> (speed)</b>				<b>Calculation of CR (speed)</b>			
<u>Weighted Sum</u>	<u>Priority</u>			$CI = (\lambda_{\max} - n)/(n - 1)$			
0,25	0,03	7,84	divide weighted sum by priority	$n = 10$ (number of compared elements)			
0,20	0,03	6,21		<b>CI = 0,019</b>			
3,31	0,28	11,91					
1,76	0,20	9,01		$CR = CI/RI$			
0,51	0,05	9,85		$RI = 1,49$ (for a 10th order matrix)			
1,76	0,13	13,36		<b>CR = 0,013</b>			
1,21	0,08	14,68		$CR < 0,10$	→ consistent matrix		
0,66	0,08	8,04					
0,82	0,08	9,94					
0,35	0,03	10,88					
	<b>Total</b>	101,73					
	<b><math>\lambda_{\max}</math></b>	10,17	divide total by 10				
<b>Calculation of <math>\lambda_{\max}</math> (dependability)</b>				<b>Calculation of CR (dependability)</b>			
<u>Weighted Sum</u>	<u>Priority</u>			$CI = (\lambda_{\max} - n)/(n - 1)$			
0,38	0,04	10,22	divide weighted sum by priority	$n = 10$ (number of compared elements)			
0,23	0,02	10,27		<b>CI = 0,043</b>			
2,03	0,19	10,63					
0,89	0,09	10,44		$CR = CI/RI$			
0,58	0,06	10,30		$RI = 1,49$ (for a 10th order matrix)			
0,58	0,06	10,30		<b>CR = 0,029</b>			
1,35	0,13	10,57		$CR < 0,10$	→ consistent matrix		
1,35	0,13	10,57					
2,89	0,27	10,58					
0,23	0,02	10,02					
	<b>Total</b>	103,88					
	<b><math>\lambda_{\max}</math></b>	10,39	divide total by 10				
<b>Calculation of <math>\lambda_{\max}</math> (flexibility)</b>				<b>Calculation of CR (flexibility)</b>			
<u>Weighted Sum</u>	<u>Priority</u>			$CI = (\lambda_{\max} - n)/(n - 1)$			
0,26	0,03	10,16	divide weighted sum by priority	$n = 10$ (number of compared elements)			
0,65	0,06	10,14		<b>CI = 0,029</b>			
3,03	0,29	10,53					
2,17	0,21	10,55		$CR = CI/RI$			
1,52	0,14	10,46		$RI = 1,49$ (for a 10th order matrix)			
1,02	0,10	10,31		<b>CR = 0,019</b>			
0,65	0,06	10,14		$CR < 0,10$	→ consistent matrix		
0,41	0,04	10,07					
0,41	0,04	10,07					
0,26	0,03	10,16					
	<b>Total</b>	102,58					
	<b><math>\lambda_{\max}</math></b>	10,26	divide total by 10				
<b>Calculation of <math>\lambda_{\max}</math> (cost)</b>				<b>Calculation of CR (cost)</b>			
<u>Weighted Sum</u>	<u>Priority</u>			$CI = (\lambda_{\max} - n)/(n - 1)$			
0,66	0,07	10,10	divide weighted sum by priority	$n = 10$ (number of compared elements)			
0,26	0,03	10,18		<b>CI = 0,023</b>			
0,40	0,04	10,08					
1,06	0,10	10,23		$CR = CI/RI$			
1,62	0,16	10,37		$RI = 1,49$ (for a 10th order matrix)			
0,40	0,04	10,08		<b>CR = 0,015</b>			
1,62	0,16	10,37		$CR < 0,10$	→ consistent matrix		
3,21	0,31	10,46					
0,40	0,04	10,08					
0,66	0,07	10,10					
	<b>Total</b>	102,05					
	<b><math>\lambda_{\max}</math></b>	10,20	divide total by 10				

Table 17. Calculating the consistency of the KPI alternatives matrix.

## G. The Consistency Indices of Randomly Generated Matrices

Order of the Matrix	RI Values	Order of the Matrix	RI Values
1, 2	0	9	1.45
3	0.58	10	1.49
4	0.90	11	1.51
5	1.12	12	1.48
6	1.24	13	1.56
7	1.32	14	1.57
8	1.41	15	1.59

Reprinted from “*Application of TOPSIS Method to the Selection of a Production Drilling Rig*” (p. 6) by Stephen, C. (2018), Eskişehir Osmangazi University, Institute of Applied Sciences.

## H. Dashboard Evaluation Form

*The survey has been conducted in Dutch in order to make it more accessible for the employees. Questions have been translated for the purpose of this report.*

I am interested in your opinion about the production planning dashboard. You will be asked to answer some questions about the design and functions of the dashboard. Please be assured that your responses will be processed anonymously. The evaluation consists of 11 questions divided over two subjects. Your participation in this evaluation is voluntary. You have the right to withdraw at any point during the study, for any reason, and without any prejudice.

☐ I acknowledge that my participation in the study is voluntary, I am 18 years of age, and I am aware that I may choose to terminate my participation in the study at any time and for any reason.

### Functionality

- |   |                 |                       |                       |                       |                       |                       |              |
|---|-----------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|--------------|
| 1. The dashboard contains redundant information.        | <i>Disagree</i> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <i>Agree</i> |
| 2. Important information is missing from the dashboard. | <i>Disagree</i> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <i>Agree</i> |
| 3. I know what the given information is about.          | <i>Disagree</i> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <i>Agree</i> |

4. Which information is redundant in your opinion?

5. Which information is missing from the dashboard in your opinion?

6. Which information do you find unclear?

### Usability

- |  |                 |                       |                       |                       |                       |                       |              |
|--|-----------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|--------------|
| 7. Information is presented in a logical order.        | <i>Disagree</i> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <i>Agree</i> |
| 8. The information is coherent.                        | <i>Disagree</i> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <i>Agree</i> |
| 9. Matching activities are performed in a similar way. | <i>Disagree</i> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <i>Agree</i> |
| 10. My knowledge of Microsoft Excel is good.           | <i>Disagree</i> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <i>Agree</i> |
| 11. My knowledge about VBA code is good.               | <i>Disagree</i> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <i>Agree</i> |

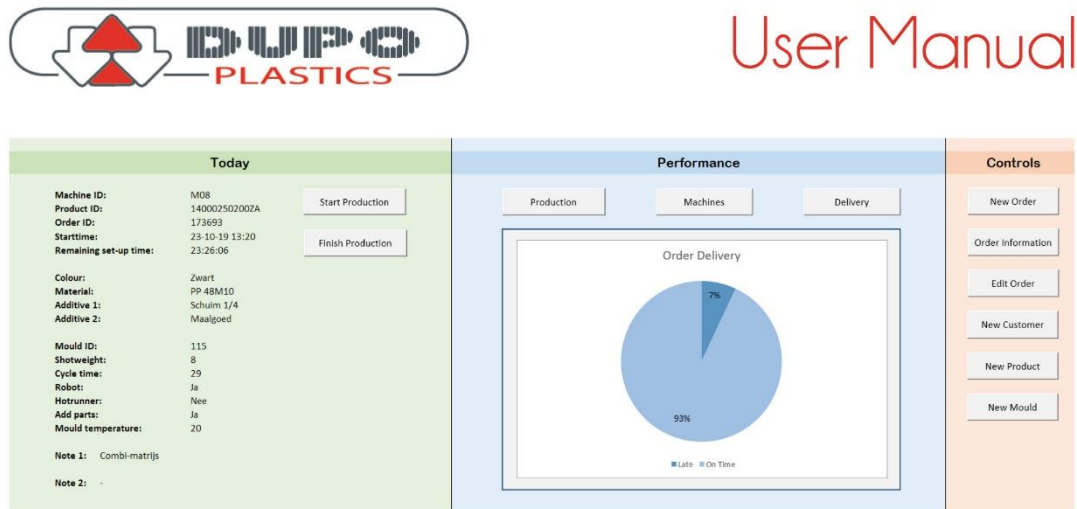


Figure 1. The dashboard.

## 01. The Dashboard

### 1.1 Today

This section of the dashboard includes information about upcoming production orders. It shows which order needs to be produced next, and how much time is left for setting up the corresponding machine. This section also provides information about the configuration of the machine and required materials.

### 1.2 Performance

The performance section shows relevant statistics regarding the production planning and process. Using the three buttons 'production', 'machines', and 'delivery' you can easily switch between the windows. The production window includes measures for proportion of set-up and production time. The machines window shows information about the machine utilization and downtime. In the delivery window, the proportion of orders which has been delivered on time is calculated.

### 1.3 Controls

This section consists of controls related to user actions. They can be used to insert data into the tool, request order information, or adjust previously entered data.

## 02. Adding Information

Adding information to the database of the tool becomes easy when using the controls on the dashboard.

The controls 'new order', 'new customer', 'new product', and 'new mould' in the control section can be used to insert information into the corresponding database.

Each of the above mentioned buttons will call a UserForm. Insert the information into the form and click the save button to transfer the information to the database. Click the cancel button if you do not wish to save the information and want to clear the form.

Figure 2. New Order UserForm



# User Manual

A screenshot of the 'New Customer' user form. It features a title bar with a close button. The form contains a 'Customer Name' text field, a 'Notes' text area, and 'Save' and 'Cancel' buttons at the bottom.

Figure 3. New Customer UserForm

A screenshot of the 'New Product' user form. It includes fields for 'Product Name\*', 'Product ID\*', 'Colour\*', 'Colour ID', 'Material\*', 'Additive 1' (with a percentage field), 'Additive 2' (with a percentage field), 'Packaging\*', 'Amount\*' (with a percentage field), 'Mould ID\*', and a 'Note' text area. 'Save' and 'Cancel' buttons are at the bottom.

Figure 4. New Product UserForm

Figure 2 - 5 show the UserForms that can be used to insert information into a database. Most of the fields need to be filled manually, however CustomerIDs, ProductIDs and MachineGroups can be selected from a drop down menu.

The note sections of the forms can be used to provide additional information about the order, customer, product or mould. This information is not used by the tool to make calculations.

A screenshot of the 'New Mould' user form. It contains fields for 'Mould ID', 'Product Name', 'Parts Per Mould', 'Machine Group' (a dropdown menu), 'Shot Weight', 'Weight', 'Cycle Time', 'Robot' (Yes/No checkboxes), 'Add Parts' (Yes/No checkboxes), 'Hotrunner' (Yes/No checkboxes), 'Mould Temperature', 'Note 1', and 'Note 2'. 'Save' and 'Cancel' buttons are at the bottom.

Figure 5. New Mould UserForm

## 03. Using the Tool

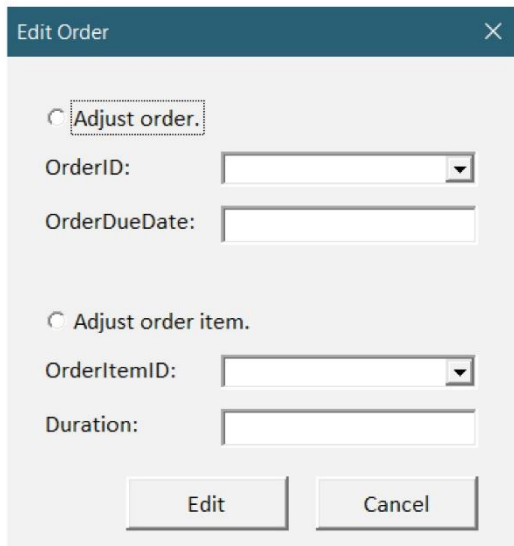
### 3.1 Starting Production

The today section of the dashboard shows which order is next up and how much set-up time is left before the production is planned to start. It also shows the machine settings and needed materials.

When the machines are ready for production, the actual start time of the production can be inserted using the 'start production' button and UserForm (Figure 6).

A screenshot of the 'Start Production' user form. It features a 'MachineID' dropdown menu and 'Start' and 'Cancel' buttons.

Figure 6. Start Production UserForm



**Edit Order**

☐ Adjust order.

OrderID:

OrderDueDate:

☐ Adjust order item.

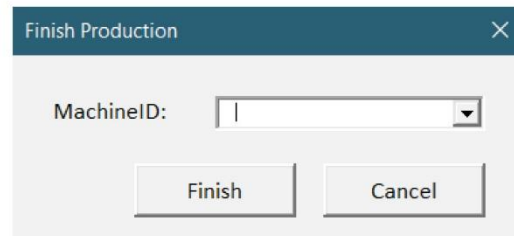
OrderItemID:

Duration:

Figure 7. Edit Order UserForm

### 3.2 Making Adjustments

If the production process is not going as planned, it might occur that the actual production time is longer than the planned duration. In this case the duration (in hours) can be manually inserted using the 'edit order' button (Figure 7). When agreement about the due date of the delivery of the order changes, this can also be adjusted using the 'edit order' button in the controls section (Figure 7).



**Finish Production**

MachineID:

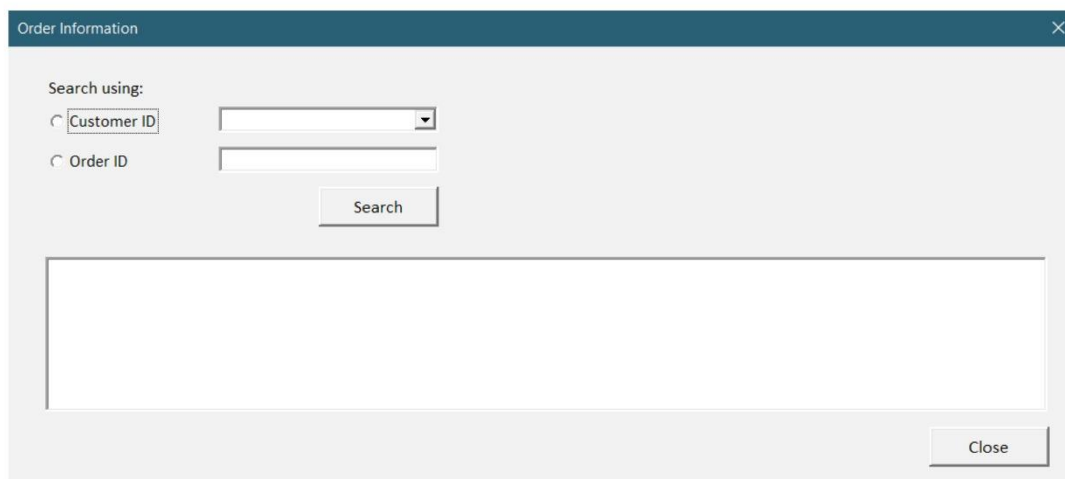
Figure 8. Finish Production UserForm

### 3.3 Finish Production

When the machines are finished producing an order item, the actual end time of the production can be inserted using the 'finish production' button and UserForm (Figure 8).

### 3.4 Request Information

Information about orders can be easily found using the 'order information' button and UserForm (Figure 9). You can search by customer ID (the form returns all orders placed by the customer) or by order ID (the form returns all order items included in the order).



**Order Information**

Search using:

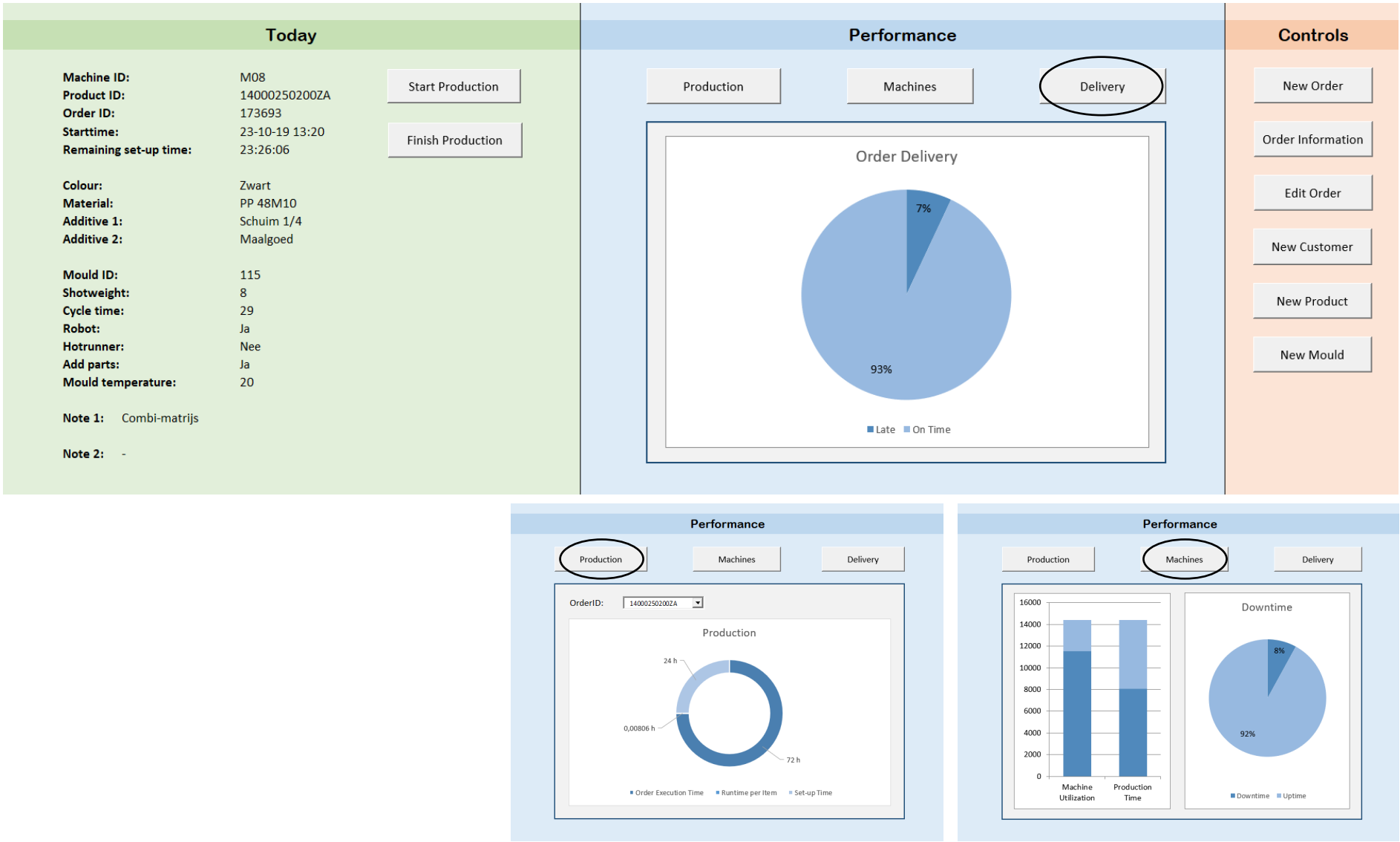
☐ Customer ID

☐ Order ID

Figure 9. Order Information UserForm



J. Screenshots of the Dashboard



## K. Microsoft Excel VBA code

### *New Customer UserForm*

Option Explicit

Private Sub CancelButton\_Click()

    Unload Me

End Sub

Private Sub SaveButton\_Click()

Dim LastRow, EmptyRow As Integer

Dim CustomerID, CustomerName, Notes As Long

*'link text to column number*

CustomerID = 1

CustomerName = 2

Notes = 3

*'insert new customer into Customers sheet*

*'ensuring that the CustomerName field is not empty*

If TextBox1.Value = "" Then

    MsgBox "Insert customer name."

    GoTo Error

Else

*'check last filled row in Orders worksheet*

LastRow = ThisWorkbook.Sheets("Customers").Cells(Rows.Count, 1).End(xlUp).Row

EmptyRow = LastRow + 1

ThisWorkbook.Sheets("Customers").Cells(EmptyRow, CustomerName).Value = TextBox1.Text

ThisWorkbook.Sheets("Customers").Cells(EmptyRow, Notes).Value = TextBox2.Text

*'generate CustomerID*

ThisWorkbook.Sheets("Customers").Cells(EmptyRow, CustomerID).Value =

ThisWorkbook.Sheets("Customers").Cells(LastRow, CustomerID).Value + 1

Unload Me

Error:

End If

End Sub

### *New Mould UserForm*

```
Private Sub CancelButton_Click()
```

```
    Unload Me
```

```
End Sub
```

```
Private Sub SaveButton_Click()
```

```
    Dim LastRow, EmptyRow As Integer
```

```
    Dim MouldID, PartsPerMould, ProductName, MachineGroup, ShotWeight, Weight, CycleTime, Robot, AddParts, Hotrunner,  
    MouldTemp, Note1, Note2 As Long
```

```
'link text to column number
```

```
MouldID = 1
```

```
PartsPerMould = 2
```

```
ProductName = 3
```

```
MachineGroup = 4
```

```
ShotWeight = 5
```

```
Weight = 6
```

```
CycleTime = 7
```

```
Robot = 8
```

```
AddParts = 9
```

```
Hotrunner = 10
```

```
MouldTemp = 11
```

```
Note1 = 12
```

```
Note2 = 13
```

```
'insert product information in the next available row in the Mould worksheet
```

```
'ensuring that all required fields are filled
```

```
If TextBox1.Value = "" Or TextBox3.Value = "" Or ComboBox1.Value = "" Or TextBox4.Value = "" Or TextBox5.Value = "" Or  
TextBox6.Value = "" Or TextBox7.Value = "" Then
```

```
    MsgBox "Not all required fields are filled."
```

```
    GoTo Error
```

```
Else
```

```
'ensuring that either 'yes' or 'no' is selected
```

```
If CheckBox1.Value = True And CheckBox4.Value = True Or CheckBox2.Value = True And CheckBox5.Value = True  
Or CheckBox3.Value = True And CheckBox6.Value = True Or CheckBox1.Value = False And CheckBox4.Value =  
False Or CheckBox2.Value = False And CheckBox5.Value = False Or CheckBox3.Value = False And CheckBox6.Value  
= False Then
```

```
    MsgBox "Select either 'yes' or 'no'."
```

```
    GoTo Error
```

Else

'check last filled row in Moulds worksheet

LastRow = ThisWorkbook.Sheets("Moulds").Cells(Rows.Count, 1).End(xlUp).Row

EmptyLine = LastRow + 1

'insert mould information into the Moulds worksheet

ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, MouldID).Value = TextBox1.Text

ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, PartsPerMould).Value = TextBox3.Text

ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, ProductName).Value = TextBox2.Text

ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, MachineGroup).Value = ComboBox1.Value

ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, ShotWeight).Value = TextBox4.Value

ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, Weight).Value = TextBox5.Value

ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, CycleTime).Value = TextBox6.Value

ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, MouldTemp).Value = TextBox7.Text

ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, Note1).Value = TextBox8.Text

ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, Note2).Value = TextBox9.Text

'check if robot is needed

If CheckBox1.Value = True Then

    ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, Robot).Value = "TRUE"

    Else: ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, Robot).Value = "FALSE"

End If

'check if parts will be added

If CheckBox2.Value = True Then

    ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, AddParts).Value = "TRUE"

    Else: ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, AddParts).Value = "FALSE"

End If

'check if hotrunner is needed

If CheckBox3.Value = True Then

    ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, Hotrunner).Value = "TRUE"

    Else: ThisWorkbook.Sheets("Moulds").Cells(EmptyLine, Hotrunner).Value = "FALSE"

End If

Unload Me

Error:

End If

End If

End Sub

Private Sub UserForm\_Initialize()

'dim variables and create array

Dim MachineRows As Integer

Dim MachineArray As Variant

'define number of rows in Machines worksheet

'(-1 to remove header count, -1 because an array starts counting at 0 -> array with MachineRows - 2 rows)

MachineRows = ThisWorkbook.Sheets("Machines").Cells(Rows.Count, 1).End(xlUp).Row - 2

'dim MachineArray with correct number of rows and columns

'column count 1 -> column 0 and column 1 (total of 2 columns)

ReDim MachineArray(MachineRows, 1) As Variant

'fill MachineArray

MachineArray(0, 0) = 1

MachineArray(0, 1) = "25 ton"

MachineArray(1, 0) = 2

MachineArray(1, 1) = "40 ton"

MachineArray(2, 0) = 3

MachineArray(2, 1) = "50 ton"

MachineArray(3, 0) = 4

MachineArray(3, 1) = "100 ton"

MachineArray(4, 0) = 5

MachineArray(4, 1) = "150 ton"

MachineArray(5, 0) = 6

MachineArray(5, 1) = "200 ton"

MachineArray(6, 0) = 7

MachineArray(6, 1) = "verticaal inleg"

'fill combobox with machine groups

ComboBox1.List = MachineArray

End Sub

### *New Order UserForm*

Option Explicit

Private Sub CancelButton\_Click()

    Unload Me

End Sub

Private Sub SaveButton\_Click()

Dim LastRow, LastSched, EmptyRow, EmptySched As Integer

Dim OrderID, OrderItemID, CustomerID, OrderDate, ProductID, Quantity, OrderDueDate, Notes As Long

Dim SchedID, SchedItemID, SchedProd, SchedQty, SchedDate, SchedDueDate As Long

'link text to column number for Orders worksheet

OrderID = 1

OrderItemID = 2

CustomerID = 3

OrderDate = 4

ProductID = 5

Quantity = 6

OrderDueDate = 7

Notes = 8

'link text to column number for Production Schedule sheet

SchedID = 2

SchedItemID = 3

SchedProd = 4

SchedQty = 5

SchedDate = 6

SchedDueDate = 7

'insert order information on next available row in Orders worksheet

'(seperating different items on multiple rows)

'ensuring that at least one of the ProductID fields is filled

If ComboBox2.Value = "" Then

    MsgBox "Insert at least one product."

    GoTo Error

Else

'check last filled row in Orders worksheet

```
LastRow = ThisWorkbook.Sheets("Orders").Cells(Rows.Count, 1).End(xlUp).Row  
EmptyRow = LastRow + 1
```

'insert order information into the orders sheet

```
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, ProductID).Value = ComboBox2.Value  
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, Quantity).Value = TextBox6.Text  
  
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderID).Value = TextBox1.Text  
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, CustomerID).Value = ComboBox1.Value  
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderDate).Value = TextBox2.Value  
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderDueDate).Value = TextBox3.Value  
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, Notes).Value = TextBox4.Text
```

'generate OrderItemID

```
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderItemID).Value = TextBox1.Text + "A"
```

'write on next empty line in the Production Schedule

```
LastSched = ThisWorkbook.Sheets("Production Schedule").Cells(Rows.Count, 2).End(xlUp).Row  
EmptySched = LastSched + 1  
  
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedID).Value = TextBox1.Text  
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedItemID).Value = TextBox1.Text + "A"  
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedProd).Value = ComboBox2.Value  
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedQty).Value = TextBox6.Value  
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedDate).Value = TextBox2.Value  
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedDueDate).Value = TextBox3.Value
```

'check if there is a second product

```
If ComboBox3.Value = "" Then GoTo LastLine
```

'check last filled row in Orders worksheet

```
LastRow = ThisWorkbook.Sheets("Orders").Cells(Rows.Count, 1).End(xlUp).Row  
EmptyRow = LastRow + 1  
  
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, ProductID).Value = ComboBox3.Value  
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, Quantity).Value = TextBox7.Text
```

```

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderID).Value = TextBox1.Text
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, CustomerID).Value = ComboBox1.Value
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderDate).Value = TextBox2.Value
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderDueDate).Value = TextBox3.Value
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, Notes).Value = TextBox4.Text

```

'generate OrderItemID

```

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderItemID).Value = TextBox1.Text + "B"

```

'write on next empty line in the Production Schedule

```

LastSched = ThisWorkbook.Sheets("Production Schedule").Cells(Rows.Count, 2).End(xlUp).Row
EmptySched = LastSched + 1

```

```

ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedID).Value = TextBox1.Text
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedItemID).Value = TextBox1.Text + "B"
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedProd).Value = ComboBox3.Value
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedQty).Value = TextBox7.Value
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedDate).Value = TextBox2.Value
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedDueDate).Value = TextBox3.Value

```

'check if there is a third product

```

If ComboBox4.Value = "" Then GoTo LastLine

```

'check last filled row in Orders worksheet

```

LastRow = ThisWorkbook.Sheets("Orders").Cells(Rows.Count, 1).End(xlUp).Row
EmptyRow = LastRow + 1

```

```

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, ProductID).Value = ComboBox4.Value
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, Quantity).Value = TextBox8.Text

```

```

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderID).Value = TextBox1.Text
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, CustomerID).Value = ComboBox1.Value
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderDate).Value = TextBox2.Value
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderDueDate).Value = TextBox3.Value
ThisWorkbook.Sheets("Orders").Cells(EmptyRow, Notes).Value = TextBox4.Text

```



'generate OrderItemID

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderItemID).Value = TextBox1.Text + "C"

'write on next empty line in the Production Schedule

LastSched = ThisWorkbook.Sheets("Production Schedule").Cells(Rows.Count, 2).End(xlUp).Row

EmptySched = LastSched + 1

ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedID).Value = TextBox1.Text

ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedItemID).Value = TextBox1.Text + "C"

ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedProd).Value = ComboBox4.Value

ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedQty).Value = TextBox8.Value

ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedDate).Value = TextBox2.Value

ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedDueDate).Value = TextBox3.Value

'check if there is a fourth product

If ComboBox4.Value = "" Then GoTo LastLine

'check last filled row in Orders worksheet

LastRow = ThisWorkbook.Sheets("Orders").Cells(Rows.Count, 1).End(xlUp).Row

EmptyRow = LastRow + 1

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, ProductID).Value = ComboBox5.Value

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, Quantity).Value = TextBox9.Text

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderID).Value = TextBox1.Text

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, CustomerID).Value = ComboBox1.Value

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderDate).Value = TextBox2.Value

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderDueDate).Value = TextBox3.Value

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, Notes).Value = TextBox4.Text

'generate OrderItemID

ThisWorkbook.Sheets("Orders").Cells(EmptyRow, OrderItemID).Value = TextBox1.Text + "D"

'write on next empty line in the Production Schedule

LastSched = ThisWorkbook.Sheets("Production Schedule").Cells(Rows.Count, 2).End(xlUp).Row

EmptySched = LastSched + 1

```

ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedID).Value = TextBox1.Text
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedItemID).Value = TextBox1.Text + "D"
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedProd).Value = ComboBox5.Value
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedQty).Value = TextBox9.Value
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedDate).Value = TextBox2.Value
ThisWorkbook.Sheets("Production Schedule").Cells(EmptySched, SchedDueDate).Value = TextBox3.Value

```

LastLine:

Unload Me

End If

Call CalcSched

Call Reschedule

Error:

End Sub

Private Sub UserForm\_Initialize()

'CUSTOMERS

'dim variables + create array

Dim CustomerRows As Integer

Dim CustomerArray As Variant

Dim i As Integer

Dim j As Integer

'define number of rows in Customers worksheet

CustomerRows = ThisWorkbook.Sheets("Customers").Cells(Rows.Count, 1).End(xlUp).Row - 2

ReDim CustomerArray(CustomerRows, 1) As Variant

'fill CustomerArray

For j = 0 To 1

For i = 0 To CustomerRows

CustomerArray(i, j) = ThisWorkbook.Sheets("Customers").Cells(i + 2, j + 1).Value

Next i

Next j

'fill ComboBox1 with Customer Names

ComboBox1.List = CustomerArray

'PRODUCTS

'dim variables + create array

Dim ProductRows As Integer

Dim ProductArray As Variant

Dim k As Integer

'define number of rows in Products worksheet

ProductRows = ThisWorkbook.Sheets("Products").Cells(Rows.Count, 1).End(xlUp).Row - 2

ReDim ProductArray(ProductRows, 1) As Variant

'fill ProductArray

For k = 0 To ProductRows

ProductArray(k, 0) = ThisWorkbook.Sheets("Products").Cells(k + 2, 1).Value

ProductArray(k, 1) = ThisWorkbook.Sheets("Products").Cells(k + 2, 13).Value

Next k

'fill ComboBox2, ComboBox3, ComboBox4 & ComboBox5 with Product IDs

ComboBox2.List = ProductArray

ComboBox3.List = ProductArray

ComboBox4.List = ProductArray

ComboBox5.List = ProductArray

End Sub

*New Product UserForm*

Private Sub CancelButton\_Click()

Unload Me

End Sub

Private Sub SaveButton\_Click()

Dim LastRow, EmptyLine As Integer

Dim ProductID, Colour, ColourID, Material, Additive1, Percentage1, Additive2, Percentage2, Packaging, Amount, Note, MouldID, ProductName As Long

'link text to column number

ProductID = 1

Colour = 2

ColourID = 3

Material = 4

Additive1 = 5

Percentage1 = 6

Additive2 = 7

Percentage2 = 8

Packaging = 9

Amount = 10

Note = 11

MouldID = 12

ProductName = 13

'insert product information in the next available row in the Products worksheet

'ensuring that all fields are filled

If TextBox1.Value = "" Or TextBox2.Value = "" Or TextBox4.Value = "" Or TextBox9.Value = "" Or TextBox10.Value = "" Or  
TextBox11.Value = "" Or TextBox12.Value = "" Then

MsgBox "Not all required fields are filled."

GoTo Error

Else

'check last filled row in Products worksheet

LastRow = ThisWorkbook.Sheets("Products").Cells(Rows.Count, 1).End(xlUp).Row

EmptyLine = LastRow + 1

'insert product information into the Products worksheet

ThisWorkbook.Sheets("Products").Cells(EmptyLine, ProductID).Value = TextBox1.Text

ThisWorkbook.Sheets("Products").Cells(EmptyLine, Colour).Value = TextBox2.Text

ThisWorkbook.Sheets("Products").Cells(EmptyLine, ColourID).Value = TextBox3.Text

ThisWorkbook.Sheets("Products").Cells(EmptyLine, Material).Value = TextBox4.Text

ThisWorkbook.Sheets("Products").Cells(EmptyLine, Additive1).Value = TextBox5.Text

ThisWorkbook.Sheets("Products").Cells(EmptyLine, Percentage1).Value = TextBox7.Value

ThisWorkbook.Sheets("Products").Cells(EmptyLine, Additive2).Value = TextBox6.Text

ThisWorkbook.Sheets("Products").Cells(EmptyLine, Percentage2).Value = TextBox8.Value

ThisWorkbook.Sheets("Products").Cells(EmptyLine, Packaging).Value = TextBox9.Text

ThisWorkbook.Sheets("Products").Cells(EmptyLine, Amount).Value = TextBox10.Value

```
ThisWorkbook.Sheets("Products").Cells(EmptyLine, Note).Value = TextBox13.Text  
ThisWorkbook.Sheets("Products").Cells(EmptyLine, MouldID).Value = TextBox11.Text  
ThisWorkbook.Sheets("Products").Cells(EmptyLine, ProductName).Value = TextBox12.Text
```

Unload Me

Error:

End If

End Sub

#### *Order Information UserForm*

Option Explicit

Private Sub CloseButton\_Click()

    Unload Me

End Sub

Private Sub SearchButton\_Click()

Dim RowNum, SearchRow As Long

Dim OrderID, OrderItemID, CustomerID, OrderDate, ProductID, Quantity, OrderDueDate, Notes As Long

RowNum = 2

SearchRow = 2

*'link text to column number*

OrderID = 1

OrderItemID = 2

CustomerID = 3

OrderDate = 4

ProductID = 5

Quantity = 6

OrderDueDate = 7

Notes = 8

*'determine which search method is being used*

If OptionButton1.Value = True Then

*'select and display all orders and details from the selected customer*

'select Orders worksheet

Worksheets("Orders").Activate

'loop over all rows in the Orders worksheet

'loop until first column has an empty row

Do Until Cells(RowNum, 1).Value = ""

    If InStr(1, Cells(RowNum, CustomerID).Value, ComboBox1.Value, vbTextCompare) > 0 Then

        Worksheets("OrderSearch").Cells(SearchRow, OrderID).Value = Cells(RowNum, OrderID).Value

        Worksheets("OrderSearch").Cells(SearchRow, OrderItemID).Value = Cells(RowNum, OrderItemID).Value

        Worksheets("OrderSearch").Cells(SearchRow, CustomerID).Value = Cells(RowNum, CustomerID).Value

        Worksheets("OrderSearch").Cells(SearchRow, OrderDate).Value = Cells(RowNum, OrderDate).Value

        Worksheets("OrderSearch").Cells(SearchRow, ProductID).Value = Cells(RowNum, ProductID).Value

        Worksheets("OrderSearch").Cells(SearchRow, Quantity).Value = Cells(RowNum, Quantity).Value

        Worksheets("OrderSearch").Cells(SearchRow, OrderDueDate).Value = Cells(RowNum, OrderDueDate).Value

        Worksheets("OrderSearch").Cells(SearchRow, Notes).Value = Cells(RowNum, Notes).Value

        SearchRow = SearchRow + 1

    End If

    RowNum = RowNum + 1

Loop

If SearchRow = 2 Then

    MsgBox "No orders were found that match your criteria."

    Exit Sub

End If

End If

If OptionButton2.Value = True Then

'select and display order details of the selected order

'select Orders worksheet

Worksheets("Orders").Activate

'loop over all rows in the Orders worksheet

'loop until first column has an empty row

Do Until Cells(RowNum, 1).Value = ""

    If InStr(1, Cells(RowNum, OrderID).Value, TextBox2.Value, vbTextCompare) > 0 Then

        Worksheets("OrderSearch").Cells(SearchRow, OrderID).Value = Cells(RowNum, OrderID).Value

        Worksheets("OrderSearch").Cells(SearchRow, OrderItemID).Value = Cells(RowNum, OrderItemID).Value

        Worksheets("OrderSearch").Cells(SearchRow, CustomerID).Value = Cells(RowNum, CustomerID).Value

        Worksheets("OrderSearch").Cells(SearchRow, OrderDate).Value = Cells(RowNum, OrderDate).Value

        Worksheets("OrderSearch").Cells(SearchRow, ProductID).Value = Cells(RowNum, ProductID).Value

        Worksheets("OrderSearch").Cells(SearchRow, Quantity).Value = Cells(RowNum, Quantity).Value

        Worksheets("OrderSearch").Cells(SearchRow, OrderDueDate).Value = Cells(RowNum, OrderDueDate).Value

        Worksheets("OrderSearch").Cells(SearchRow, Notes).Value = Cells(RowNum, Notes).Value

        SearchRow = SearchRow + 1

    End If

    RowNum = RowNum + 1

Loop

If SearchRow = 2 Then

    MsgBox "No orders were found that match your criteria."

    Exit Sub

End If

End If

Worksheets("Dashboard").Activate

'Show results in SearchResults listbox

SearchResults.RowSource = "SearchResults"

End Sub

Private Sub UserForm\_Initialize()

'clear contents from the OrderSearch worksheet

Worksheets("OrderSearch").Range("A2:H100").ClearContents

'fill ComboBox1 with Customer ID and Names

```

Dim CustomerRows As Integer

Dim CustomerArray As Variant

Dim i As Integer

Dim j As Integer

'define number of rows in Customers worksheet

CustomerRows = ThisWorkbook.Sheets("Customers").Cells(Rows.Count, 1).End(xlUp).Row - 2

ReDim CustomerArray(CustomerRows, 1) As Variant

'fill CustomerArray

For j = 0 To 1
    For i = 0 To CustomerRows
        CustomerArray(i, j) = ThisWorkbook.Sheets("Customers").Cells(i + 2, j + 1).Value
    Next i
Next j

'fill ComboBox1 with Customer Names

ComboBox1.List = CustomerArray

End Sub

Call Forms Module

Option Explicit

Sub NewOrder_Click()
    NewOrder.Show
End Sub

Sub NewCustomer_Click()
    NewCustomer.Show
End Sub

Sub OrderInformation_Click()
    OrderInformation.Show
End Sub

Sub NewProduct_Click()
    NewProduct.Show

```



End Sub

Sub NewMould\_Click()

NewMould.Show

End Sub

Sub FinishProduction\_Click()

FinishProduction.Show

End Sub

Sub StartProduction\_Click()

StartProduction.Show

End Sub

Sub EditOrder\_Click()

EditOrder.Show

End Sub

### *Scheduling Module*

Option Explicit

Sub CalcSched()

'this sub calculates the missing information in the production schedule

Dim LastRow, EmptyRow As Integer

Dim MachineCol, DurationCol, QtyCol As Integer

Dim ProductID, MouldID, MachineGroup As Long

Dim Duration, Qty, PPM, CT As Long

'assign column numbers from the Production Schedule sheet to variables

QtyCol = 5

MachineCol = 8

DurationCol = 10

'find the first row that is not calculated yet

'this is the first row in which the MachineGroup column is still empty

LastRow = ThisWorkbook.Sheets("Production Schedule").Cells(Rows.Count, MachineCol).End(xlUp).Row

EmptyRow = LastRow + 1

'loop until all rows have been calculated

Do While IsEmpty(ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, 2).Value) = False

'look up MouldID in Products worksheet

ProductID = ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, 4).Text

MouldID = Application.WorksheetFunction.VLookup(ProductID,  
ThisWorkbook.Sheets("Products").Range("A2:L500"), 12)

'look up MachineGroup in Moulds worksheet

MachineGroup = Application.WorksheetFunction.VLookup(MouldID,  
ThisWorkbook.Sheets("Moulds").Range("A2:D500"), 4)

ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, MachineCol).Value = MachineGroup

'calculate duration [duration = (quantity/parts per mould) \* cycle time]

Qty = ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, QtyCol).Value

PPM = Application.WorksheetFunction.VLookup(MouldID, ThisWorkbook.Sheets("Moulds").Range("A2:B500"), 2)

CT = Application.WorksheetFunction.VLookup(MouldID, ThisWorkbook.Sheets("Moulds").Range("A2:G500"), 7)

Duration = ((Qty / PPM) \* CT) / 3600

ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, DurationCol).Value = Duration

EmptyRow = EmptyRow + 1

Loop

End Sub

Sub Reschedule()

Dim OrderItemID, SearchRow As String

Dim LastRow, EmptyRow, RowNum, MachineRow, Row As Integer

Dim Mcol, MGcol, Scol As Integer

Dim MachineGroup, i, j, MR As Integer

Dim MachineID, TryMachine, AssignMachine, EndProduction, StartProduction, PreviousEnd As Variant

Dim OIdcol, Dcol, ODDcol, SPcol, STcol, SDcol, EPcol, ETcol, EDcol, FDcol, Lcol As Integer

Dim SearchRange, ActiveCell As Range

Dim TotalLateness As Integer

Dim StartTime, EndTime, MatchCell, NewDate, DeleteSheet As Variant

'link column numbers to variables for Production Schedule sheet

Mcol = 9

MGcol = 8

Scol = 11

'link column numbers to variables for M0x sheets

OIDcol = 2

Dcol = 3

ODDcol = 4

SPcol = 5

SDcol = 6

STcol = 7

EPcol = 8

EDcol = 9

ETcol = 10

FDcol = 11

Lcol = 12

'set initial value for TotalLateness, to ensure that the order is appointed to a machine

TotalLateness = 1000

'find first OrderItem that is not allocated yet

LastRow = ThisWorkbook.Sheets("Production Schedule").Cells(Rows.Count, Mcol).End(xlUp).Row

EmptyRow = LastRow + 1

'loop over all empty rows

Do While IsEmpty(ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, OIDcol).Value) = False

'look up machine group for this OrderItem

MachineGroup = ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, MGcol).Value

'loop over all possible Machine Groups

For i = 1 To 7

    If MachineGroup = i Then

        'select the machine with the smallest possible weight

        TryMachine = Application.WorksheetFunction.VLookup(MachineGroup,  
        ThisWorkbook.Sheets("Machines").Range("A2:C13"), 2, False)

```

For RowNum = 2 To 13
    If ThisWorkbook.Sheets("Machines").Cells(RowNum, 2) = TryMachine Then
        RowNum = RowNum
        GoTo FirstRowFound
    End If
Next RowNum

```

FirstRowFound:

'loop over every machine bigger or as big as the smallest

```
Do While RowNum < 14
```

'select current MachineID (in the 2nd column of Machines sheet)

```
TryMachine = ThisWorkbook.Sheets("Machines").Cells(RowNum, 2).Text
```

'select first empty row in the worksheet of the selected machine

```
MachineRow = ThisWorkbook.Sheets(TryMachine).Cells(Rows.Count, 2).End(xlUp).Row + 1
```

'add OrderItemID

```
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, OIdcol).Value = ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, 3).Text
```

'add Duration

```
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, Dcol).Value = ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, 10).Value
```

'add OrderDueDate

```
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, ODDcol).Value = ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, 7).Value
```

'add StartProduction (and add 1 for set-up time)

```
PreviousEnd = ThisWorkbook.Sheets(TryMachine).Cells(MachineRow - 1, EPcol).Value
```

```
StartProduction = PreviousEnd + 1
```

```
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SPcol).Value = StartProduction
```

AdjustedSP:

'add StartDate (hidden column)

```
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow - 1, SDcol).Copy
```

```
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SDcol).PasteSpecial  
Paste:=xlPasteFormulas
```

'add StartTime function

```
StartProduction = ThisWorkbook.Sheets(TryMachine).Cells(MachineRow,  
SPcol).Value  
  
StartTime = StartProduction - ThisWorkbook.Sheets(TryMachine).Cells(MachineRow,  
SDcol).Value  
  
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, STcol).Value = StartTime
```

'add EndProduction function

```
EndProduction = ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SPcol).Value  
+ (ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, Dcol).Value / 24)  
  
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, EPcol).Value = EndProduction
```

'add EndDate (hidden column)

```
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow - 1, EDcol).Copy  
  
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, EDcol).PasteSpecial  
Paste:=xlPasteFormulas
```

'add EndTime function

```
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, ETcol).Value = EndProduction  
.Sheets(TryMachine).Cells(MachineRow, EDcol).Value
```

'add FinishDate function -> only works if there is a previous row

```
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow - 1, FDcol).Copy  
  
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, FDcol).PasteSpecial  
Paste:=xlPasteFormulas
```

'add Lateness function

```
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow - 1, Lcol).Copy  
  
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, Lcol).PasteSpecial  
Paste:=xlPasteFormulas
```

'check if the solution is feasible

'if start or end in weekend or vacation -> shift StartProduction to first date after weekend/vacation

```
If Application.WorksheetFunction.VLookup(ThisWorkbook.Sheets(TryMachine).  
Cells(MachineRow, SPcol), ThisWorkbook.Sheets("Calendar").Range("A2:D92"), 3) =  
"FALSE" Then
```

'find the next day where production is allowed

```

MatchCell = ThisWorkbook.Sheets(TryMachine).Cells(MachineRow,
SDcol).Value

For j = 2 To 92

    If ThisWorkbook.Sheets("Calendar").Cells(j, 1).Value = MatchCell
    Then

        SearchRow = j

        GoTo ExitLoop

    End If

Next j

ExitLoop:

SearchRange = ThisWorkbook.Sheets("Calendar").Range(Cell1:="A" &
SearchRow, Cell2:="C92")

For j = SearchRow To 92

    If ThisWorkbook.Sheets("Calendar").Cells(j, 3) = "TRUE" Then

        NewDate = ThisWorkbook.Sheets("Calendar").Cells(j, 1).Value

        GoTo DateFound

    End If

Next j

DateFound:

'new start date and time is 'new date' + 0.375 (09:00:00)
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SPcol).Value =
NewDate + 0.375

GoTo AdjustedSP

End If

If Application.WorksheetFunction.VLookup(ThisWorkbook.Sheets(TryMachine).
Cells(MachineRow, EDcol), ThisWorkbook.Sheets("Calendar").Range("A2:D92"), 3) =
"FALSE" Then

    'find next day where production is allowed

    MatchCell = ThisWorkbook.Sheets(TryMachine).Cells
(MachineRow, EDcol).Value

    For j = 2 To 92

        If ThisWorkbook.Sheets("Calendar").Cells(j, 1).Value = MatchCell
        Then

            SearchRow = j

            GoTo ExitLoop1

        End If

    Next j

ExitLoop1:

SearchRange = ThisWorkbook.Sheets("Calendar").Range(Cell1:="A" & SearchRow,
Cell2:="C92")

```

```

For j = SearchRow To 92
    If ThisWorkbook.Sheets("Calendar").Cells(j, 3) = "TRUE" Then
        NewDate = ThisWorkbook.Sheets("Calendar").Cells(j, 1).Value
        GoTo DateFound1
    End If
Next j

DateFound1:

'new start date and time is 'new date' + 0.375 (09:00:00)
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SPcol).Value = NewDate +
0.375
GoTo AdjustedSP
End If

'if start time < 09:00 then start 09:00
If ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, STcol) < 0.375 Then
    ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SPcol).Value =
    ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SDcol).Value +
    0.375
    GoTo AdjustedSP
End If

'if start time > 16:00 (mon-thu) then start next day 09:00
If ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, STcol) > (2 / 3) Then
    ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SPcol).Value =
    ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SDcol).Value +
    1.375
    GoTo AdjustedSP
End If

'if start time friday > 12:00 then start monday 09:00
If Application.WorksheetFunction.VLookup(ThisWorkbook.Sheets(TryMachine).
Cells(MachineRow, SPcol), ThisWorkbook.Sheets("Calendar").Range("A2:D92"), 2) =
"vrijdag" And ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, STcol) > 0.5
Then
    'find the next monday / day on which production is allowed
    MatchCell = ThisWorkbook.Sheets(TryMachine).Cells(MachineRow,
SDcol).Value
    For j = 2 To 92
        If ThisWorkbook.Sheets("Calendar").Cells(j, 1).Value = MatchCell
        Then
            SearchRow = j

```

```

        GoTo ExitLoop2
    End If
Next j

ExitLoop2:

SearchRange = ThisWorkbook.Sheets("Calendar").Range(Cell1:="A" &
SearchRow, Cell2:="C92")

For j = SearchRow + 1 To 92
    If ThisWorkbook.Sheets("Calendar").Cells(j, 3) = "TRUE" Then
        NewDate = ThisWorkbook.Sheets("Calendar").Cells(j,
        1).Value
        GoTo DateFound2
    End If
Next j

DateFound2:

'new start date and time is 'new date' (next monday) + 0.375 (09:00)
ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SPcol).Value =
NewDate + 0.375
GoTo AdjustedSP
End If

'if end time friday > 15:00 then start monday 09:00
If Application.WorksheetFunction.VLookup(ThisWorkbook.Sheets(TryMachine).
Cells(MachineRow, SPcol), ThisWorkbook.Sheets("Calendar").Range("A2:D92"), 2) =
"vrijdag" And ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, ETcol) > 0.625
Then
    'find the next monday / day on which production is allowed
    MatchCell = ThisWorkbook.Sheets(TryMachine).Cells(MachineRow,
    SDcol).Value
    For j = 2 To 92
        If ThisWorkbook.Sheets("Calendar").Cells(j, 1).Value = MatchCell
        Then
            SearchRow = j
            GoTo ExitLoop3
        End If
    Next j

ExitLoop3:

SearchRange = ThisWorkbook.Sheets("Calendar").Range(Cell1:="A" &
SearchRow, Cell2:="C92")

For j = SearchRow + 1 To 92
    If ThisWorkbook.Sheets("Calendar").Cells(j, 3) = "TRUE" Then

```



```

        NewDate = ThisWorkbook.Sheets("Calendar").Cells(j, 1).Value
        GoTo DateFound3
    End If
Next j

DateFound3:

    'new start date and time is 'new date' (next monday) + 0.375 (09:00)
    ThisWorkbook.Sheets(TryMachine).Cells(MachineRow, SPcol).Value =
        NewDate + 0.375
    GoTo AdjustedSP
End If

'save calculation of total lateness
'current machine is optimal
If ThisWorkbook.Sheets(TryMachine).Cells(2, 12).Value < TotalLateness Then
    TotalLateness = ThisWorkbook.Sheets(TryMachine).Cells(2, 12).Value
    AssignMachine = TryMachine

'current machine is not optimal
Else: AssignMachine = AssignMachine
End If

RowNum = RowNum + 1
Loop

'remove order from machine sheets that is it not assigned to
OrderItemID = ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, 3).Text
For MR = 2 To 13
    DeleteSheet = ThisWorkbook.Sheets("Machines").Cells(MR, 2).Value
    If DeleteSheet = AssignMachine Then GoTo NoDelete
        For Row = 6 To 100
            If ThisWorkbook.Sheets(DeleteSheet).Cells(Row, OIDcol) =
                OrderItemID Then
                ThisWorkbook.Sheets(DeleteSheet).Range(Cell1:="A" &
                    Row, Cell2:="L" & Row).Clear
            End If
        Next Row
    End If
Next MR

NoDelete:

    End If
Next MR

```

'save Machine ID in Production Schedule worksheet

ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, Mcol) = AssignMachine

'save StartProduction in Production Schedule Worksheet

For Row = 6 To 100

    If ThisWorkbook.Sheets(AssignMachine).Cells(Row, OIdcol) = OrderItemID Then

        ThisWorkbook.Sheets("Production Schedule").Cells(EmptyRow, Scol) =  
        ThisWorkbook.Sheets(AssignMachine).Cells(Row, SPcol).Value

    End If

Next Row

'let the user know if all items will be produced before due date

If TotalLateness > 0 Then

    MsgBox "Attention! Order cannot be produced before due date.", vbOKOnly

End If

End If

Next i

'next unassigned Order

EmptyRow = EmptyRow + 1

Loop

End Sub