Improving the production planning of Gietart Kaltenbach

Hengelo, February 2022

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Preface

Dear Reader,

In front of you lies my bachelor thesis assignment "Improving the production planning of Gietart Kaltenbach", written for my bachelor Industrial Engineering and Management at the University of Twente. The research is performed at the company Gietart Kaltenbach, located in Hengelo. This assignment aims to investigate a new repetitive structure and an improved decision-making process based on the production planning.

Gietart Kaltenbach provided me this opportunity and valuable experience for which I am grateful. Next to this, I want to thank all the employees of Gietart Kaltenbach for their help during the process. Special thanks to my supervisor at the company, Stefan Kok. I am thankful for his experiences shared and guidance provided throughout the process. Furthermore, I am very thankful that I was allowed to work on sight, which made the research process more valuable.

I would like to thank Patricia Rogetzer – first supervisor from the University – for the guidance and feedback throughout the process. The feedback truly helped to work towards a completed bachelor thesis. Also, I would like to thank Wouter van Heeswijk – second supervisor from the University – for his time and feedback.

Enjoy reading the thesis.

Mick van Diermen

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Management Summary

The company where the research is conducted, Gietart Kaltenbach – located in Hengelo – designs, engineers, and produces several types of shot blasting machines for steel service treatment. These machines are used to remove the unwanted corrosion and the metallic waste on finished goods. Gietart Kaltenbach is a project-based manufacturer, meaning that complex products (machines) are build that require long build times and a client-specific design. This research is connected to the production planning that is made by the team leaders on the production floor.

Motivation

After the creation of a problem cluster, it can be derived that reliable decisions cannot be made with the current production planning. This has two main causes: there is no clear structure between the production planning and the production process, and the data of the ERP system BaaN is not connected to the production planning on both the tactical and the operational level. Eventually decision-making on the tactical level (e.g., accepting or declining a project order) and on the operational level (e.g., adding or removing production orders (POs) in the current production planning) need to be possible with the future production planning.

Research Question

Connected to the core problem is the main research question formulated as follows: "How can alignment of the production process with the production planning improve the decision-making (of Gietart Kaltenbach)". To work towards an answer for this research question, first a new structure needs to be investigated to align the planning methodology – structure of the production planning – with the execution on the production floor – the production process. Furthermore, the data from ERP-system BaaN needs to be usable within MS Excel. BaaN stores the POs – with connected working hours and routing (sequence of tasks) - a project consist of, but this POs cannot be used within BaaN since there is no decisive planning function within the ERP system. Lastly, with the new structure and input from BaaN, future decision-making based on the tactical planning (TP) and operational planning (OP) needs to be possible.

Methods

For the connection of the planning methodology with the execution on the production floor qualitative research is needed. A new structure of projects integrated within the production planning – both TP and OP – must result from literature studies and interviews within the company. For the connection of the output of POs from BaaN to MS Excel, macro programming within VBA (Visual Basics for Applications) will be used. Due to high flexibility and interdependencies between projects, the data conversion from BaaN to MS Excel must be as user-friendly as possible with repetitive use. Lastly, for the decision-making objectives – descriptions of insights that will be visualized with graphs within MS Excel - on the tactical and operational level must result from literature studies and interviews within the company. By applying macro programming on the data used in the TP and OP, the objectives on the respective level will be visualized via charts/graphs within MS Excel. Based on the graphs, the team leaders responsible for the production planning can e.g. decide to change lead times of included projects or POs in the TP and/or OP.

Results

The future planning methodology and execution on the production floor are aligned with a repetitive nature for future use within the company. The future planning methodology and execution both consist of a 4-level structure: project (1) – main components of a machine (2) – POs (3) - departments (4). For projects within the TP, the project and main components are planned, whereas for the OP the POs and connected departments to the PO are the levels planned.

The POs (level 3 of the planning methodology) stored in BaaN are usable within the OP via

macro programming with VBA. By cleaning the data and removing repeatedly occurring headers, the POs can be used for the production planning on the operational level.

The future workload – distribution of working hours - originating from the TP and OP with their new structure is visualized in graphs in MS Excel – by applying macro programming to extract the data from multiple projects in a distribution of working hours - and used for decision-making. On the tactical level the capacity (e.g., available working hours and machine capacity) is estimated, and the planned working hours plotted on a time horizon. Objectives are to see whether new orders can be accepted, and whether the company does not have peaks and valleys of workload in the future. Next to this, on the operational level, on a 1–2-week workload resulting from the POs and connected departments from BaaN and can be assessed, the working hours are extracted from the POs of active projects via macro programming and visualized in a graph within MS Excel. Planned working hours connected to departments are plotted against available working hours to measure whether the planned POs can be executed. The decision-making is based on the question whether the planned working hours connected to departments can be executed in the planned interval.

Also, KPIs originating from interviews within the company to track the progression and status of projects – also when the researcher leaves - are included in the production planning. These KPIs are introduced to track the working hours from the pre-calculation in the ERP system with real working hours. Differences can be detected and possible changes in the source data from the ERP system implemented. This will be a continuous improvement that the company will be able to do even after the researcher leaves.

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Abbreviation	***Definition***
TP	Tactical Planning
OP	Operational Planning
MS	Microsoft
ERP	Enterprise Resource Planning
PO	Production Order
CAD	Computer-Aided Design
VBA	Visual Basics for Application
MPC	Manufacturing Planning and Control
S&OP	Sales and Operations Planning
CODP	Customer Order Decoupling Point
RCCP	Rough-Cut Capacity Planning
MPS	Master Production Schedule
MRP	Material Requirements Planning
CRP	Capacity Requirements Planning
BPMN	Business Process Model and Notation
SWOT	Strengths, Weaknesses, Opportunities, Threats
WBS	Work Breakdown Structure
FTE	Full-Time Equivalent

1. Introduction

This chapter starts with background information on the company. Hereafter, the problem identification is elaborated, and a core problem chosen for the research. The remaining part of this chapter is dedicated to the problem-solving approach of this core problem.

1.1 The company

Gietart Kaltenbach – located in Hengelo – designs, engineers, and produces several types of shot blasting machines for steel service treatment. These machines are used to remove the unwanted corrosion and the metallic waste on finished goods. The company has approximately 20,000 m^2 of working space and 80 employees. The company is closely connected to the headquarters located in Germany, since they make complementary painting machines for steel in the factories in Germany.

To give an understanding of the types of shot blasting machines that are produced at Gietart, two examples are shown - the Sprint 1504 (Figure 1) and the Triathlon A3010 (Figure 2). The Sprint-collection contains the smallest shot blasting machines, whereas the Triathlon-collection contains the largest. To elaborate on this, the four digits within the machine's name denote some characteristics. The first two digits denote the width – in decimetre - of the entrance to the machine and the last two denote the number of turbines that drive the machine. The width of the machine's entrance determines the maximum width of the steel structures that can be shotblasted, Figure 2 gives a representation of the entrance of a steel structure.

Also, the clients have a variety of client-specific choices that they can make for their own machine, for example, one's own color, superstructure, type of disposal, and so on. Gietart Kaltenbach wants to make sure that they do not lose orders due to inflexibility. A necessary remark here is that the drawback of their flexibility is the difficulty to plan and schedule the production of the machines. Almost no machine is the same and therefore no fixed number of working hours can be connected to the machines. Next to the variety, Gietart Kaltenbach fluctuates with the number of employees that can manufacture the machines. This causes a situation where there is never a fixed number of available labor - every week is unique in this sense. It is an interesting challenge to base a production planning on fluctuating employees and available working hours.

As a last remark in this section, it needs to be addressed that Gietart Kaltenbach does not only work on complete machines (in the company referred to as '**projects**'), from scratch to finished product. They also have a maintenance department, where owners of a Gietart Kaltenbach shot blasting machine can order wear- and spare parts. Wear parts are parts that are bound to or designed to wear out or fail with repetitive use and will require periodic repair or replacement – like tool receptions, grippers, liners, crucibles, they wear out (Kok, 2021), whereas spare parts are interchangeable parts that need to be replaced due to failed units – like a motor or a turbine (Kok, 2021). Both the complete products as well as the maintenance are of great importance for the financial health of the company. Nevertheless, the scope of this project will be mainly around the complete products. Further references to the production planning of Gietart Kaltenbach is the production planning based on the complete machines – projects.

Figure 1: Sprint 1504
Source: [Products / GIETART - the ART of Shotblasting]

Figure 2: Thriathlon A3010
Source: [Products / GIETART - the ART of Shotblasting]

1.2. Problem identification

1.2.1 Action problem

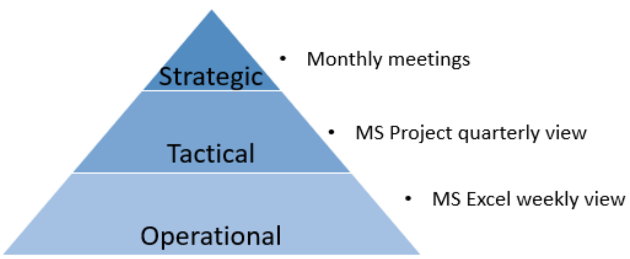
Currently, Gietart Kaltenbach utilizes an experience-based production planning to manage their projects. Future lead times – period between the start and end of production - and workings hours of projects are determined by the experience of the team leaders on the production floor. Gietart Kaltenbach utilizes the production planning on three different levels shown in Figure 3. On the strategic level, monthly meetings with the board generate insights for the vision on a 6 months-basis. The strategic planning will not be within the scope of this research. The tactical and operational level deliver insights into the production planning on a quarterly and weekly horizon respectively. The tactical planning (TP) monitors an interval of two quarters and is made in Microsoft (MS) Project, whereas the operational planning (OP) monitors an interval of about two weeks and is made in MS Excel. The TP must provide a visualization of dependencies of the projects included, e.g., showing whether different projects can start on the same time and whether there is no spike in working hours connected to the projects in the weeks to come. The OP must provide a day-to-day task list that the team leaders can use for their operations. Since lead times and working hours connected to the projects are based on experience, inaccuracies in the planning are often detected.

Next to this, errors in the TP directly shine through the OP. After an order is accepted, the project will be included in the TP in MS Project. If e.g., the welding of a substructure of a Sprint 1504 (Figure 1) is included in the OP, the working hours will result from the denotation of workings hours connected to the Sprint 1504's substructure in the TP. The OP uses the same working hours and lead times as – but on a smaller horizon than- the TP.

The enterprise resource planning (ERP) system being used at Gietart Kaltenbach called BaaN tracks a lot of activities/tasks, with respective machine- and working hours. The activities/tasks with working hours are merged the ERP system in production orders (POs) – (smaller) parts of the project. The working hours originate from machines that read out the **workload**, for example the laser cutter, or are based on historically scanned work from activities (for example the amount of time that is needed to weld a specific surface of steel). The workload is the number of productive hours connected to an activity or a complete product. Due to different formatting, discrepancy in denotation of departments and tasks and no usable export from BaaN to MS Excel, it is till this moment not possible to have an interaction with the ERP system and the production planning – both TP and OP - in MS Project/MS Excel.

Looking into a possible connection between the ERP system and the production planning levels, Figure 4 is introduced. Shown is that not just the data from ERP will solve the errors in the experience-based production planning. A start of the production of a project is needed from the TP to let the ERP system calculate working hours and lead times. These working hours originate from the computer-aided design (CAD) model of the engineers that is put into the ERP system. Then, the OP will be based on the data from ERP, e.g., working hours for day-to-day tasks. When there are inconsistencies in day-to-day tasks (breakdown, no delivery of a project-oriented article) the OP will give insights for a change in the ERP system. This will be passed on to the TP again, which closes the first cycle.

Figure 3: Planning Hierarchy at Gietart Kaltenbach



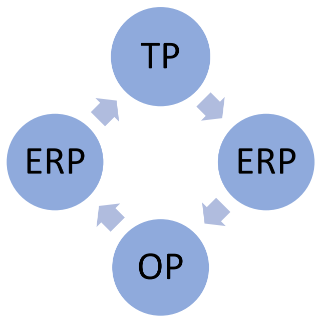


Figure 4: Connection of planning levels with ERP

1.2.2 Identification core and research problem

In Figure 5 the current problem cluster of Gietart Kaltenbach regarding their production planning is shown. Different sub-problems for the overarching action problem are denoted as consequences, for the overview. The cluster starts with the main indicator of the problem description, the contents of the production planning is based on expertise, the bottom of Figure 5. This cause of the potential core problems can itself not be a core problem, since there is no direct action connected to this (yet). The cause of the core problem causes two direct effects; There is no clear structure between the production process and the production planning, and the data of ERP, the TP and the OP are not integrated – the stored data within the ERP system is currently no usable for the TP and OP. Both are for this case interesting potential core problems to deal with and they are denoted as such.

A fellow researcher will work on the similar overarching action problem. Therefore, both potential core problems will be addressed in this research to make this research integral. Without a clear structure between the production process and production planning it is not possible to feedback activities and tasks on the work floor to the production planning on a repetitive manner, whereas the data from ERP containing calculated working hours of tasks and the routing of tasks – sequence or order in which the tasks take place – is necessary to get insights in a realistic workload. In depth insights will be made to this integration of data from the ERP system within the production planning, imposed focus from the company – therefore highlighted as the core problem of this research. This mere data is not enough to monitor the progression of orders, update working times and make decisions on whether to accept a new order. The data from the ERP system needs to be formatted to use the data within the production planning and to get the components in Figure 4 to work. The data can for example be monitored on departments and plotted against the available labor of a time interval.

The goal of this research at the company is to solve the action problem: **"With the current production planning – both TP and OP - no reliable decisions can be made"**. Despite mentioning a different core problem, the overarching action problem is the problem to tackle within this research. Both potential core problems are connected to this research problem. A repetitive structure is needed between the production process and production planning to monitor projects objectively – all projects will be monitored similar, whereas the data from ERP needs to provide realistic working hours and sequences of tasks to the production planning. Decisions on whether to take on orders, when to schedule projects, what to manufacture on a day-to-day basis, need to become clear.

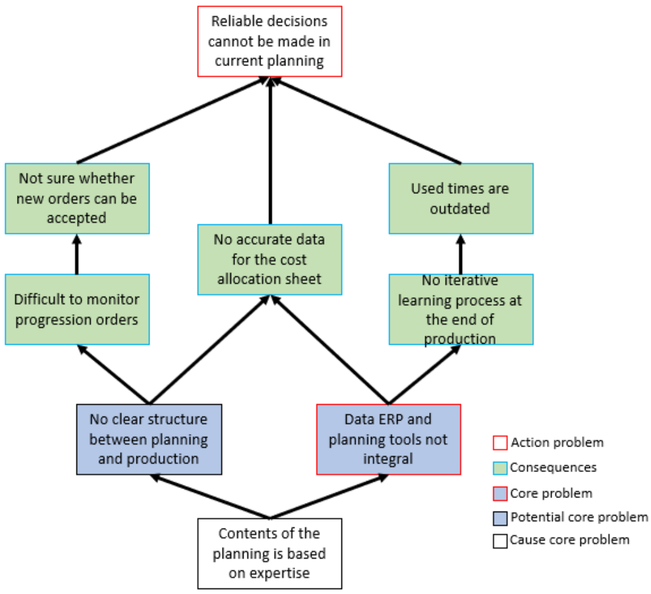


Figure 5: Problem cluster

1.2.3 Norm and reality

To come up with a clear norm and reality in this case, is not particularly straightforward, especially since the product of this research consists of different (now unsure) formats and structures to align both the TP and the OP more with reality, and eventually improve decision-making. Therefore, the norm and reality will be elaborated in this section. The first norm and reality comparison is connected to the integration of the ERP system within the production planning. The norm is that the communication between the ERP system and the planning tools is repetitively usable – realizing an export from ERP system BaaN to MS Excel that can update or fill in the production planning - while the reality is that there is no communication between the ERP system and the production tools at all. This is not a strong measure and refers more to the as-is elaboration.

What can possibly be a strong measure is a norm-reality analysis between scheduled and actual workload. If there is enough time to monitor the improvement, the discrepancy between what is denoted in the OP or TP and the actual working hours can be measured. It can be stated that the reality – which needs to be measured – is that there is an average deviation of 30% between actual and scheduled hours, while the norm needs to be that this is mostly 15%.

To operationalize this further, the workload – accumulation of working hours - needs to be addressed. The company works with different departments on the production floor (surface treatment, sheet metal machining, welding, and assembly). The workload of the different departments needs to be visualized to monitor whether specific departments encounter problems. There can for example be a lot of work for the welding department in the upcoming weeks, where the team leaders on the production floor need to anticipate on. This refers to the lack of reliable decision-making. A visualization of workload connected to the departments (more OP-based) – a bar chart that tracks the available department workload in comparison with the planned department workload – or a visualization of workload connected to projects (more TP-based) – a bar chart that tracks available total workload in comparison with planned total workload – will help the decision-making on the production planning.

At the moment, none of this is visualized. The norm is that this is possible at the end of the research on both operational and tactical level. By making this possible Gietart Kaltenbach can visualize possible planning bottlenecks (e.g., over-used departments) or an overload of total workload in the upcoming weeks that can be prevented from occurring.

1.3. Problem solving approach

1.3.1. Deliverables

At the end of the research project, multiple deliverables will be made. To start off a **data conversion tool** for transferring data from the ERP system to MS Excel – most likely with use of Visual Basics for Application (VBA) - in combination with visualizable **KPIs** regarding the newly integrated production planning for the decision-making. This can e.g., be a comparison between scheduled and actual work on projects or a comparison between available and planned workload connected to departments. Next to this, a **detailed** report that describes the used **methodology** and the **theoretical background**. Lastly, r**esults, conclusions,** and possible **recommendations** for further research with – if needed – a user manual for the data conversion. Most important remark for the company is that they can use the data conversion tool on a regular (weekly) basis. Therefore, it is crucial that these deliverables will be elaborated and guided at the company. User-friendliness is key since the data conversion tool and KPIs need to be used and monitored even when the researcher leaves the building.

1.3.2. Methodology problem solving approach

The research is equipped to align the production planning on an operational and tactical level with reality – the production process. The company needs to be able to monitor **real** workload throughout the projects and respond accordingly. This cannot be an event and therefore needs multiple iterations. To monitor this and keep an overview, a framework is needed. To help the company with this, the PDCA-cycle (Figure 6) will be used during the research. Eventually the team leaders and supervisors need to work themselves with and on a new production planning structure and outputs of the ERP system BaaN as result of this research. Applying the PDCA-cycle in this research will be a guideline to get used to the new structure and outputs of the ERP system.

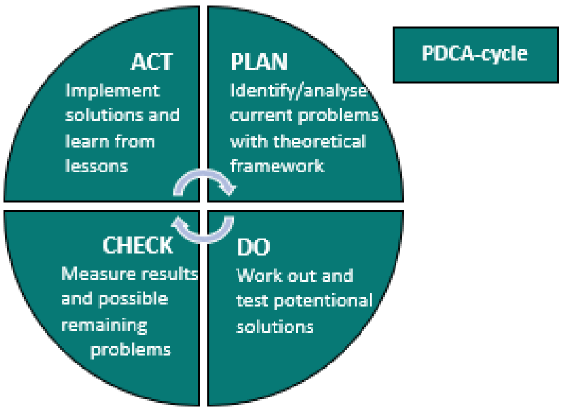


Figure 6: PDCA-cycle

To put this more into perspective, an elaboration on applying the cycle during this research will be made. Firstly, the future state needs to be investigated at the company. After writing the project plan and Chapter 2 *Current system analysis*, a solid view of the current situation is at hand. Thereafter, the desired situation of the company must be clear. Interviews and literature studies need to deliver those answers – more in the next section. This first step is all about **planning** where the project is heading, monitoring current and future state.

During the **do** phase the discrepancy between the current and future state needs to be solved. This can for example be an updated conversion tool, while not all data convers the way the company wants, or even a discrepancy between the components of Figure 4. Tasks of projects within the TP get for example a different name than tasks in ERP/OP. Working towards the best solution is the endpoint of this phase.

Next, one needs to check the results of the solution(s) and work on possible 'finetunes'. The solution(s) need to have the effect described during the **plan** phase, e.g., the conversion tool needs to bring all the data from the ERP system in a usable format for the production planning. **Act** on this and learn lessons from failures will be the last step of the cycle.

The first iterations will have the most impact within the research, but it is necessary to continuously ask yourself whether the current state is the state you want the production planning to be in. As earlier mentioned, the company needs to be able to do similar cycles after the research – user-friendliness is key.

1.3.3. Research questions

Within the problem cluster in Figure 5, the research problem is akin to the overarching action problem. Connected to this is the following research question: **"How can alignment of the production process with the production planning improve the decision-making (of Gietart Kaltenbach)"**. This alignment of the production process with the production planning originates from both the integration of the realistic data from the ERP system with the production planning and a repetitive structure for both the TP and the OP that can be used for every project. If e.g., the welding department needs to manufacture a substructure, this needs to be visible within the OP without subjective interpretation. With the new structure and integration of the ERP system, the decision-making needs to be improved by providing visualizations on both the tactical and the operational level. Whether or not there is space left in the upcoming weeks for a new order, or whether the assembly department can do more or less work next week are two examples. To answer the research question, sub-questions are needed tackle parts of this research question. An overview of sub-questions with elaboration are mentioned below:

SQ1: ***What is the desired structure of the production planning for the company?***
After the elaboration of the current situation in Chapter 2 of the research, close contact with the supervisor and team leaders is needed to get insights into the new desired structure of the production planning – both TP and OP. Based on the lean 4M's principle – tool to identify and investigate root cause(s) of problems - consisting of man, machine, method, and materials (Favi et al., 2017) the current situation (Chapter 2) will be displayed in a figure against the future desired situation (Chapter 4). What are the preferred insights on the operational and tactical level, in other words: how do they want to structure the data, considering the tasks within the production process? For this new structure the discrepancy between the TP and OP is of importance. Also, from literature studies it needs to be clear what parts of projects the TP and OP must include and exclude. E.g., small activities convenient for the OP but of no use for the TP. Within this new structure the data from the ERP system resulting from SQ2 can be implemented.

SQ2: What conversion is needed to integrate the data from the ERP system with the production planning?
When the desired production planning structure of the company is determined, the data from ERP needs to be exported to MS Excel (ERP system BaaN does not provide a user-friendly planning function) and converted for direct use. The following components will play a role to make the output from the ERP system usable:

- Formatting the data from ERP into Excel in a way that the workload – accumulation of working hours - of projects and tasks is directly visible
- Cleaning the data from ERP that are of no **direct** use in the OP
- Link the POs of a project/machine in ERP to the projects within the production planning on the operational level
- Link to the next sub-question; making sure that the converted data directly shows the visualization needed for the decision-making
- Using the converted data for progression (percentage finished) and status description of POs and projects

Programming in MS Excel VBA is probably needed to realize this on a repeatable basis. Every week the company needs to be able to generate data from ERP and implement this into the production planning after the conversion. Again, it will be convenient to look at best practices and get co-reflection from the stakeholders in the company. The stakeholders need to work with the conversion tool in the future, so user-friendliness is again of importance.

SQ3: How can decision-making be improved with use of visualizations based on the production planning?

The last sub-question is related to the decision-making based on the production planning. The new structure resulting from sub-question one in combination with the realistic data from the ERP system being used in the production planning after sub-question two, both contribute to the alignment of the production process with the production planning, are followed by the decision-making in this sub-question. With use of literature studies objectives on both the tactical and operational level need to become clear. What decision-making within companies is connected to the TP and what to the OP? Also important is to have talks with the employees in the company connected to the production planning – the stakeholders. In conversations it must become clear what insights and decision-making they want to get out of the production planning. Weighing out both the literate studies and the conversations must result in visualizations – graphs/charts in MS Excel – on which decision-making can be based. On the tactical level an example is whether to take or reject an order, whereas on the operational level adding or removing a PO in the daily schedule are examples of decision-making

1.3.4 Scope & validity

Since the research only covers ten weeks of time, it is not realistic to state that all segments of a newly fully working production planning are running and monitored. As stated earlier in Section 1.2.3 *Norm and reality*, it is probably not possible to monitor the new production planning over multiple weeks. Therefore, the user-friendliness and PDCA-cycles are introduced, such that the company can fully use the production planning even when the researchers leave.

Next to that, as mentioned during the introduction section, the project will mostly be about projects – so not the wear- and spare parts. These projects – completed products – are planned within the production planning on both the tactical and operational level.

Also, since the production planning entails projects with a high flexibility and client-specific POs, the lead time will mostly be a best guess. The TP needs to give input regarding the starting point of a project, then the ERP system can calculate times and the sequence. Due to the flexibility, unforeseen delays can occur that cannot be integrated within the production planning on both tactical and operational level. The same thing holds for the resources within the projects. Now, there is a shortage in electrical devices for specific projects. These unforeseen delays only confirm that is necessary for the user-friendliness of the production planning that changes within the planning can be made easily.

Looking at the employees on the production floor, there is a trade-off between quality and production speed. It is not possible nor convenient to work with different ratios for the employees. Therefore, an average for the departments/activities will be used as a calculation of the production times of production orders and underlying tasks.

Regarding the validity, I will ensure that the internal and external validity of my research are considered. To make sure that both the used assumptions/simplifications and all the factors that are included are unambiguous and known by the company, the production planning can be used in a valid way over a large time span. Also, all the articles from the literature studies as well as the conversions/inputs from the company will be considered during this research. No prejudices will play a role in finding the best solution for the company during this 10-week research.

Looking at the external validity, it will be difficult to possibly implement this company-specific production planning at another company. However, with use of the literature studies, best practices can be monitored against this company-specific solution. Factors that are not relevant for Gietart Kaltenbach are not included within the scope of this project, so testing this solution elsewhere will need some adjustments.

2. Current situation analysis

To work on the identified core problem, the current situation needs to be clear, therefore a current situation analysis will be conducted in this chapter. To start this chapter, in Section 2.1 the current 4M-principle analysis will be conducted; the four aspects will be elaborated in the current situation and graphically displayed. In Section 2.2, the current use of data will be elaborated, what project's data is included and excluded, and where does the data come from? Section 2.3 will be about the current structure of the production planning, with attention to the display of both the OP and TP. Lastly, a multidisciplinary perspective is featured in Section 2.4, listing multiple departments that are somehow connected to the production planning with their respective links and influences.

2.1 Current 4M-principle analysis

Based on the 4M-principle consisting of huMan, machine, method, and materials (Favi et al., 2017), the current working method regarding the production planning – TP and OP - will be visualized. In this global visualization, the total production planning will be assessed with the four aspects, as not to differentiate between the TP and OP. Despite the complexity of problems, it is often a surprise to many people how powerful the 4M-principle is in solving problems by identification and eradication of root cause(s) (Houston, 2020). This approach is designed to identify, explore, and graphically display possible causes related to the core problem. To get a better understanding of the current working method, the 4Ms will be linked. Since this approach is normally attached to a production process – nevertheless also applicable for planning issues - the link between the aspect and reality will be mentioned explicitly for a greater understanding. Lastly, elaborating on the 4M-principle on current and future state, is a decisive way to compare a production process (Kok, 2021).

huMan

The first aspect is the huMan. How are the people at the company working with and around the production planning? Currently, the team leaders on the production floor updating the production planning make a planning mostly for their own use. Despite the great influence of the production planning on almost every employee of Gietart Kaltenbach, almost no one can understand the current contents of the production planning. This mostly results from attaching unfixed modules to the projects – more on this in the *material* section – and currently having no visualization of workload originating from the production planning. This results in laborious communication between the team leaders and employees of other departments.

Machine

The second aspect is the machine. What applications are in use for the production planning? Now, the production planning is made and updated in supporting planning tools MS Project and MS Excel. The data of MS Excel is extracted from MS Project on a smaller time interval, this will be elaborated in future sections. Currently, no role for the ERP system is reserved for this aspect.

Material

The third aspect of the 4M-principle is the material. What is currently visualized in the production planning? This is closely related to the used data within the production planning. Looking at the hierarchy of a project in the current production planning, a project consists of three levels: project (1), modules (2) and departments (3) (shown in Figure 7). The modules are components of the project (e.g., a machine Sprint1504) determined by the team leader on the production floor. For the continuation of this research, the discrepancy between a module and a PO will be explicitly mentioned. Both are parts of a project's machine and weigh up to the whole project.

Module
A module is a self-determined part of a project's machine. Examples are the machine housing, inner frame of the machine and the substructure of a machine. The modules are determined by the team leaders responsible for the production planning and the attached lead times and working hours are experience-based. The modules are determined to get better insights in the progression of different parts of a project. On average 6-8 modules are used to cover a project for the team leaders.

PO
A PO is a part of the project's machine as well but originates from the ERP system BaaN. These POs are stored in BaaN and based on the CAD-model of the engineers. When the design of the CAD-model is finished, the different parts of the machine become available POs in BaaN. Connected to a PO are calculated working hours from BaaN and a routing – sequence of tasks to execute. The POs of a project within BaaN can also be used to get insights in the progression of different parts of a project but are currently not included in the production planning.

The arrows between the levels emphasize the relationship. Both ends of the line between project (level 1) and modules (level 2) contain arrows, since the projects consist of multiple modules, and the progression of the modules give information about the progression of the overarching project. The same applies to the relationship between modules and corresponding departments. Multiple departments work on the modules, and the progressions of these departments give information about the progression of the overarching module.

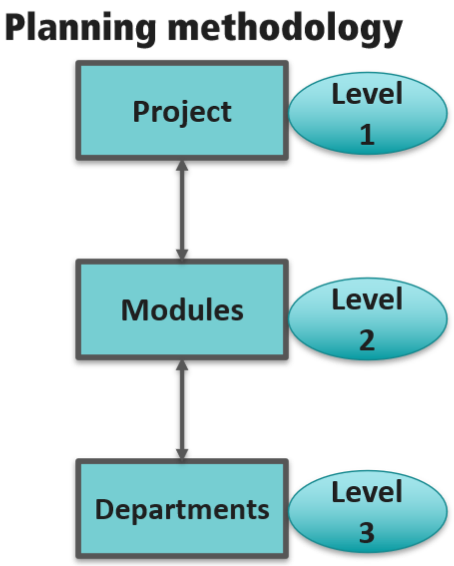


Figure 7: Current levels of the project planning

Method
The last aspect is the method. How are the stakeholders updating the production planning? Currently the production planning within MS Project, related to the TP, is updated every time a new order comes in. The lead times of current projects are not updated regularly when the lead time of a project changes. Next to that, the MS Excel production planning, related to the OP, is updated on a weekly basis.

To get to see the overall completion and current status of the 4M-principle, Figure 8 shows an aggregated view (where PP stands for production planning). In Chapter 4, a reference will be made to this current 4M-principle completion. A current and future state comparison based on the 4M-principle serves as an overview of change based on the four aspects.

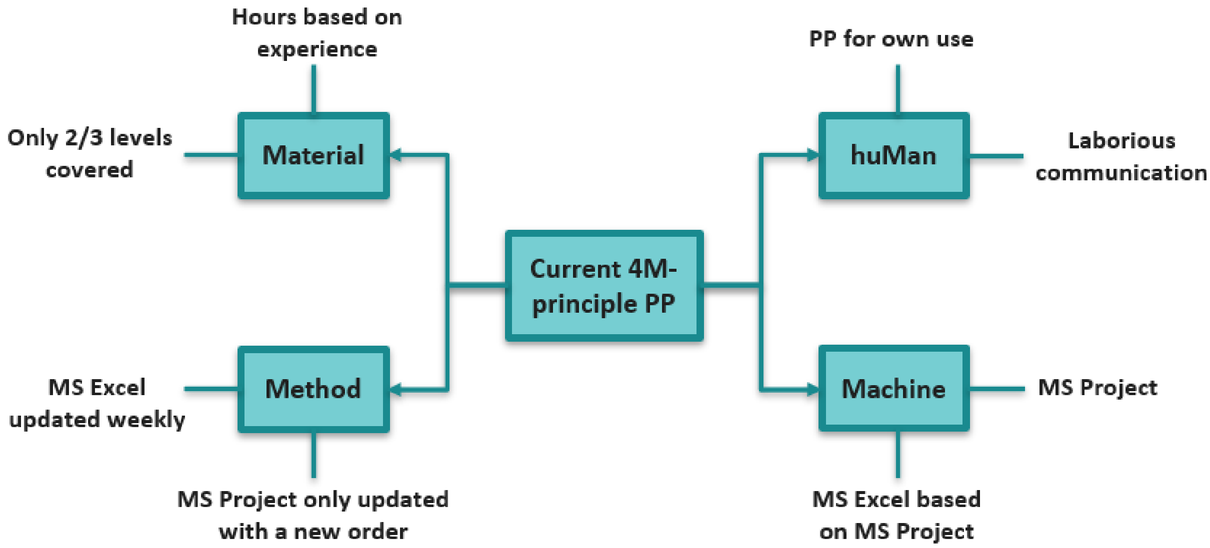


Figure 8: Current 4M-principle of the production planning

2.2 Current utilization of data

Looking at the core problem of this research, with the current production planning – both TP and OP - no reliable decisions can be made, it is crucial to elaborate on what data is in-use regarding the planning now. In this section, first the global use of data will be elaborated; what components can be found in the production planning, covering both the tactical as well as the operational level. After this general understanding, a distinction will be made between the TP and OP.

2.2.1. Global use of data

As visualized in Figure 7, there exist three levels in the structure of a project. The whole project – complete machine - at the highest level, followed by the modules from a respective project and thereafter the underlying departments connected to the module. This is a fixed structure for a project regarding the production planning. The departments include tasks that are executed on the production floor. A level lower than the departments – the tasks in this case – are currently not included within the production planning but will be mentioned for a global understanding.

Department	Tasks
Sheet metal Machining	Laser cutting, Bending
Mechanical Machining	Drilling, Sawing, Turning, Rolling, Milling
Welding	Welding, Welding robot
Surface Treatment Area	Painting
Assembly	Assembly, Expedition, Testing, Electrical Assembly

Table 1: Overview production departments with respective tasks

In Table 1 an overview is provided of the production department-task combinations within Gietart Kaltenbach. The denotation of the departments is in chronological order – the production starts with sheet metal machining and ends with the assembly of the machine.

Quantitative data assigned to the departments in the current production planning are also experience-based. Nevertheless, the ERP system – that is currently not in use for the production planning – explicitly stores working hours on the task-level. To provide a visualization of this storage, an example of the denotation within the ERP system can be found in Appendix 1. The ERP system plays no **active** role in this chapter since the current use of data is fully based on experience.

Before examining the use of working hours within the TP and OP, a global observation needs to be made. The supervisor within the company mentions the important distinction between the planning method – or planning methodology – visualized in Figure 7 and the actual execution of a project.

Planning methodology

The planning methodology visualized in Figure 7 are the three components – connected to the three corresponding levels – that are planned by the team leaders on the production floor. These components can be found in the TP and OP and are tracked for progression. As mentioned, the data connected to the levels is experience-based and the modules of level two are self-determined parts that the team leaders on the production floor want to monitor.

Execution

Looking at the actual manufacturing of a machine, again three levels are encountered. The overview of the levels with their relationships is shown in Figure 9. At the first level, the project is mentioned again. The execution is finished when a machine, project, is completed. However, level two of the execution is the POs. So, the POs from the ERP system are in-use for directing the production but are not included in the production planning. The routing of the POs – the tasks that are connected to it in chronological order – are the third level of the execution of a project.

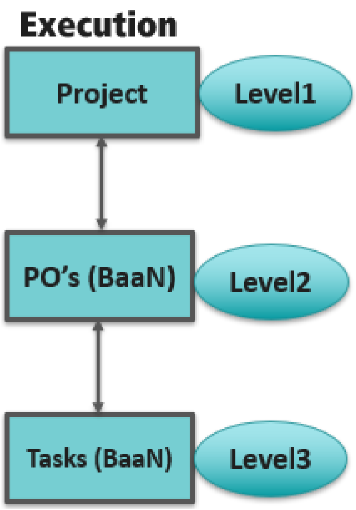


Figure 9: Levels of execution of production

Connection

For this research, it is important to see the current connection between the planning methodology and the execution. An overview can be found in Figure 10. Shown is the problem on the second and third level. Currently the self-determined modules are not connected to the POs from the CAD-model within the ERP system. This is one of the main reasons why the data from BaaN is currently not in use. Consequently, the production departments are not connected to the tasks resulting from the POs. This leaves the departments with an unsure workload from the experience-based working hours connected to the modules.

This observation provides background information on the alignment of the production process and the production planning. In the next two sections, the current use of data in the TP and OP will be elaborated based on the current three levels of the planning methodology.

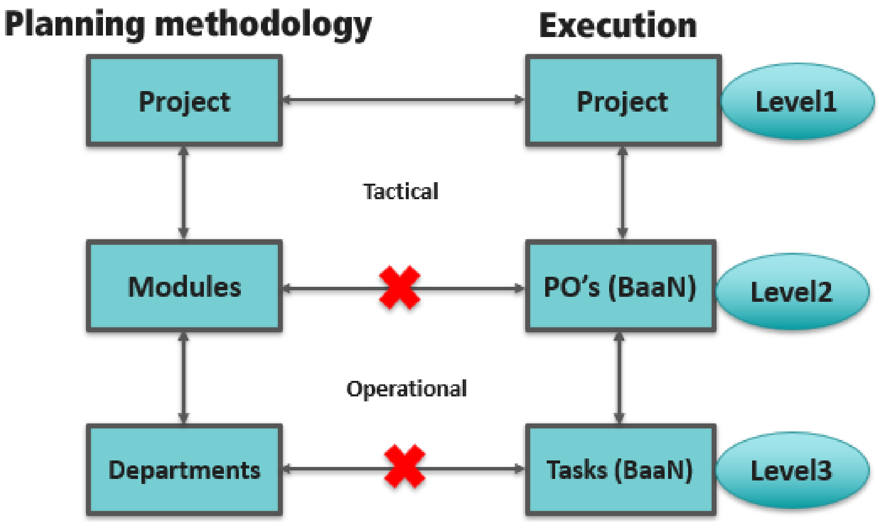


Figure 10: Connection between the planning methodology and execution

2.2.2. Current use of data TP

The TP is displayed and monitored in MS Project. Currently, the TP shows all three levels of the planning methodology. These components will be elaborated one-by-one to gain an understanding on how the data is currently used within the TP. The interpretation of the data connected to the levels of the planning methodology in this section will be purely textual. In the visualization sections of Section 2.3, graphical examples will be provided.

Project

On the highest level within the TP the project gets a lead time (with a corresponding start and end date), a total number of working hours and a percentage completed (that can be updated continuously). The lead times and working hours of the projects are based on historical data and current expertise.

Module

As stated, a project consists of multiple modules. These modules have own self-determined lead times themselves, which cannot exceed the lead time of the project on start and end date. Also working hours are determined for the modules based on historical data and current expertise. The working hours of the modules sum up to the working hours of the project. The progression of the modules is reflected to the overarching project.

Department

Lastly, the departments are currently also denoted in the TP. This is a fixed chronological order, with in addition to the production departments of Table 1 also the departments engineering and work preparation. These two departments must finish their works prior to the start of production. The display of all departments visualized in the TP will be shown in Section 2.3. Connected to the departments are experience-based working hours and lead times. The progression of the departments will also indicate a status for the respective overarching module.

2.2.3. Current use of data OP

For the current OP within MS Excel, level two (modules) and level three (departments) of the planning methodology are addressed in their own company-specific way. The employees on the production floor are assigned to a module from a project, on a weekly basis. So, the modules determined by the team leader are now plotted on a smaller time horizon of a week. No specification of hours is provided, nor is it clear what the workload contains for a given week. Nevertheless, the team leaders on the production floor manage to get everything done within time. But they have no insight into the actual workload nor insights into whether some departments are fully stocked with work, while others have lots of idle time. Therefore, the decision-making cannot be backed-up with visualizations of data connected to the current OP. It is e.g., not possible to visualize the difference between planned and available working hours in a week.

The current OP with the brief amount of data available could be seen as a light version of the TP. A clear distinction between the two levels is missing and needs to be researched. The OP plots the planned modules of the TP on a smaller time horizon and does not address any scheduled working hours. The additional value of the OP is the connection of an employee – with specific background – to a module. The next section provides insights into the visualization of the current OP.

2.3 Current visualization of data

After examining the inclusion and exclusion data on the different levels in the planning methodology, the translation to the visualization will be made in this section. 'How does the company visualize the data within the applications on both the tactical and operational level?', will be answered in this section. Special attention to the repetitive nature of the production planning's structure will be given.

2.3.1. Current visualization TP

In Table 2, an example is provided of the visualization of projects in MS Project. In this overview, seven projects – with a unique color - are shown in combination with one unfolded project, project 110343 with machine ECO 2506. All projects have a unique code, consisting of six numbers, in combination with a name and possible machine specification. Looking at the third project from above, the 110340 Librado Sprint 1504, the 110340 is the project unique code, Librado the project name and sprint 1504 the machine type (machine shown in Figure 1).

The unfolded project, 110343 ECO 2506, shows the self-determined underlying modules of the project. In MS Project subtasks – in this case the modules - represent more detailed work that falls under larger phases or tasks (Microsoft, 2021). This is in correspondence with the planning methodology of Figure 7, where all the determined modules of level two are connected to the overarching project. As mentioned in the previous section, the cumulation of working hours from the modules count to the total working hours for the project. Next to that, the duration – or lead time - of the modules, do not exceed the duration nor the start and end date of the project.

nr	Task Name	Duration	Start	Finish	exp	Predecessors	Work
222209	222209 Kircherer-onderdelen	21.56 days	Mon 9/13/21	Mon 10/11/21			88 hrs
110339	110339 Aceresa sprint 2506	56.88 days	Mon 10/11/21	Thu 12/23/21	51		1,007 hrs
110340	110340 Librado sprint 1504	89.63 days	Mon 7/26/21	Fri 11/19/21	47		1,221 hrs
110341	110341 Standish metaltreatmen	55.75 days	Mon 9/6/21	Wed 11/17/21	45		1,323 hrs
221353	221353 Dentsteel waterafblaas	18.13 days	Thu 10/28/21	Mon 11/22/21	ntb		77 hrs
110327	110327 Henschke 2H gw3300 tr	23 days	Mon 2/7/22	Tue 3/8/22	ntb		106 hrs
110343	110343 ECO 2506	88.81 days?	Fri 10/8/21	Wed 2/9/22	ntb		661 hrs
110343	st.kon.Machinehuis	38.31 days?	Fri 10/8/21	Mon 11/29/21			166 hrs
110343	st.kon.buitenkast afbl.	32.25 days?	Mon 10/18/21	Mon 11/29/21			53 hrs
110343	st.kon binnenframe	11.31 days	Mon 11/15/21	Mon 11/29/21			32 hrs
110343	sam.onderbouw	29.94 days	Mon 11/8/21	Thu 12/16/21			106 hrs
110343	bovenbouw	56.94 days	Fri 11/19/21	Wed 2/9/22			240 hrs
110343	aanvullende delen	49.94 days	Fri 11/19/21	Mon 1/31/22			64 hrs

Table 2: Visualization tactical level of projects within MS Project

But, also level three of the planning methodology is integrated in the TP in MS Project. In Table 3 all three levels of the 110341 Standish metaltreatment Triathlon A1508 HE are shown. The departments are within the production planning in MS Project a subtask of the modules. For the departments, a fixed structure is used. This structure is based on the chronological order of the production. An overview of the departments with their relation regarding the production, is shown in Table 4.

nr	Task Name	Duration	Start	Finish	exp	Predecessors	Work
110341	110341 Standish metaltreatmen	55.75 days	Mon 9/6/21	Wed 11/17/21	45		1,323 hrs
110341	invooerkast 3	49.5 days	Mon 9/6/21	Tue 11/9/21			125 hrs
110341	engineering	5 days	Mon 9/6/21	Fri 9/10/21			4 hrs
110341	wvb	2 days	Wed 9/15/21	Fri 9/17/21		686	8 hrs
110341	plaatbewerking	5 days	Fri 9/17/21	Fri 9/24/21		670	16 hrs
110341	mechanisch	2 days	Fri 10/1/21	Mon 10/4/21			1 hr
110341	constructie	8 days	Mon 10/11/21	Wed 10/20/21		672	80 hrs
110341	spuiten	2 days	Wed 11/3/21	Fri 11/5/21		689	8 hrs
110341	assemblage	2 days	Fri 11/5/21	Tue 11/9/21		674	8 hrs
110341	uitvoerkast 3	49.5 days	Mon 9/6/21	Tue 11/9/21			125 hrs
110341	engineering	5 days	Mon 9/6/21	Fri 9/10/21			4 hrs
110341	wvb	2 days	Wed 9/15/21	Fri 9/17/21		686	8 hrs
110341	plaatbewerking	5 days	Fri 9/17/21	Fri 9/24/21		678	16 hrs
110341	mechanisch	2 days	Fri 10/1/21	Mon 10/4/21			1 hr
110341	constructie	8 days	Mon 10/11/21	Wed 10/20/21		680	80 hrs
110341	spuiten	2 days	Wed 11/3/21	Fri 11/5/21		689	8 hrs
110341	assemblage	2 days	Fri 11/5/21	Tue 11/9/21		682	8 hrs
110341	machinehuis 1	53.5 days	Mon 9/6/21	Mon 11/15/21			303 hrs
110341	engineering	5 days	Mon 9/6/21	Fri 9/10/21			8 hrs
110341	wvb	3 days	Mon 9/13/21	Wed 9/15/21		685	8 hrs
110341	plaatbewerking	5 days	Wed 9/15/21	Wed 9/22/21		686	21 hrs
110341	mechanisch	3 days	Fri 10/8/21	Tue 10/12/21			10 hrs
110341	constructie	20 days	Fri 10/8/21	Wed 11/3/21			200 hrs
110341	spuiten	3 days	Wed 11/3/21	Mon 11/8/21		689	8 hrs
110341	assemblage	5 days	Mon 11/8/21	Mon 11/15/21		690	48 hrs

Table 3: Example 3-level tactical planning methodology within MS Project

Department	Needed before production	Connected to production
1. Engineering	X	
2. Work preparation	X	
3. Sheet metal Machining		X
4. Mechanical Machining		X
5. Welding		X
6. Surface Treatment Area		X
7. Assembly		X

Table 4: Overview of departments included in MS Project

In Table 4, the first two departments are mainly included since they determine the start of the manufacturing of a project. Lead times connected to the first two departments provide insights in the start of production. When the engineering and work preparation department finish their work, the production of a project can start. These are insights the team leaders on the production floor can participate on. Currently, working hours are also included for the engineering and work preparation departments. The team leaders on the production floor mention that the working hours are not of much importance, while accurate lead times of these departments are essential to determine the start of production.

Despite the use of an application (MS Project) for the TP, the workload on a tactical level – 3 to 6 months – cannot be visualized. A rough estimation of the workload on the tactical level can foresee possible peaks and valleys of work, where the company can react on proactively. The only current workload visualization is based on a Gantt-chart within MS Project. The limitation of this Gantt-chart is that there is no differentiation based on working hours. The chart covers the lead times on all three levels and shows dependencies in working order.

Shortcomings

Next to the missing workload, more shortcomings in the current visualization arise with a thorough inspection of the current TP in MS Project. First, the structure of the modules. The determined modules are not always on the same level in MS Project, meaning that the structure of subtasks : Project → Module → Department is not consistent. Figure 11 provides an example of such a structure inconsistency. In Figure 11 the unfolded module '**opties**' - Dutch for options - consists of a module itself (the 'transport 14mtr.inv+14mtr). The additional subtask in this example obliviates the 3-level structure.

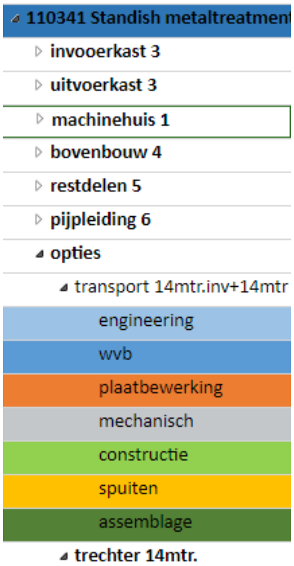


Figure 11: Incorrect use of subtasks in MS Project

Next to this, the numbering of the planning methodology levels in MS Project is not clear. Now – as shown in Table 2 – all rows connected to a project get a the 'nr' in the first column from the project. There is no distinction between a project, module or department, the numbering is only referring to the project. For the overview of different levels, it is desirable to update the numbering with respect to the levels of the planning methodology.

Lastly, the chronological order of departments – shown in Table 4 – is not respected as the chronological order under every module in MS Project. This results in inconsistencies and disadvantages for the repetitive use of this structure. By respecting this chronologically department structure for every module – which is representable with the production process according to the team leaders - a new project can be added to the active TP in MS Project more efficiently on a repetitive basis.

2.3.2. Current visualization OP

The current OP was already referred to as a light version of the TP. Meaning that there is no other used data or components within the OP now. Nevertheless, the team leaders use two different MS Excel files to keep track of the modules on the operational level – covering one to two weeks. First, a broad example can be found in Table 5. This is a made-up example with fictional names, but it serves the purpose of providing a visualization of the OP.

The first thing that immediately grabs attention is that this OP does not have any numerical data included. Next to that, when looking back at the planning methodology of Figure 7, level two (modules) is connected to fictional employees. Again, this visualization on the operational level is a personal preference. The team leader responsible for this OP knows the qualities and responsibilities of the production employees very good. So, indirectly the departments are connected to the modules by attaching an employee – for example a welder, department five of Table 4– to a module.

The OP in Table 5 is completely extracted from the TP. The lead times of the TP determine when a module will be connected to the employees on a shorter time horizon in the OP. A disadvantage again is that there is no possibility to visualize the workload on this level. The working hours are not connected to the modules included in the OP, resulting in no data to compare available working hours with planned working hours. This current OP is a best estimated guess to get some insights into the weekly work in progress. Due to flexibility, the team leaders did not further look at improving the production planning on the operational level. With the current mechanism of extracting the OP from the TP, the improvements are also limited. The representative working hours need to come from the POs incorporated in BaaN in the future desired state.

Week 47	Monday	Tuesday	Wednesday	Thursday	Friday
Samuel Meyer	St.kon.Machinehuis - 110343 ECO 2506	St.kon.Machinehuis - 110343 ECO 2506	St.kon.Machinehuis - 110343 ECO 2506	St.kon.buitenkast afbl. - 110343 ECO 2506	St.kon.buitenkast afbl. - 110343 ECO 2506
Dawn Brown	St.kon.Machinehuis - 110343 ECO 2506	St.kon.Machinehuis - 110343 ECO 2506	St.kon.Machinehuis - 110343 ECO 2506	St.kon.buitenkast afbl. - 110343 ECO 2506	St.kon.buitenkast afbl. - 110343 ECO 2506
Stewart Foster	St.kon.Machinehuis - 110343 ECO 2506	St.kon.Machinehuis - 110343 ECO 2506	St.kon.buitenkast afbl. - 110343 ECO 2506	St.kon.buitenkast afbl. - 110343 ECO 2506	St.kon.buitenkast afbl. - 110343 ECO 2506
Larry Woolery	Uitvoerkast 3 - 110341 Standish Metaltreatment Triathlon	Uitvoerkast 3 - 110341 Standish Metaltreatment Triathlon	Uitvoerkast 3 - 110341 Standish Metaltreatment Triathlon	Uitvoerkast 3 - 110341 Standish Metaltreatment Triathlon	Uitvoerkast 3 - 110341 Standish Metaltreatment Triathlon
Justin Holden	Uitvoerkast 3 - 110341 Standish Metaltreatment Triathlon	Uitvoerkast 3 - 110341 Standish Metaltreatment Triathlon	Uitvoerkast 3 - 110341 Standish Metaltreatment Triathlon	Uitvoerkast 3 - 110341 Standish Metaltreatment Triathlon	Uitvoerkast 3 - 110341 Standish Metaltreatment Triathlon

Table 5: Example of a fictional operational planning on a weekly basis

2.4 Multidisciplinary perspective

During this chapter - in the previous sections - the focus was mainly on the team leaders on the production floor responsible for the employees executing the production and the production planning itself. Despite these two team leaders directly working with and on the production planning, the production planning – especially on the tactical level – concerns the whole company. To illustrate this, the connection between the production planning and three other departments is elaborated in this section.

Sales

For the sales department, the workload on the tactical level is of major importance. The sales department is in close contact with potential clients and need to know whether they can accept a possible order or not. Not only the decision to take the order is of importance, but also the lead time. A client wants to know the week they can expect the delivery of the machine. This is mostly a specific date on the tactical level – for example delivery in week 20 of 2022 – and needs to be met to keep away possible future payment errors.

Looking at the current TP that needs to provide this data, the workload is very unsure. The team leaders can state that there will be three active projects in the beginning of 2022, and that it is therefore not possible to deliver in week 20. But this decision-making is not backed-up with visualizations or displayed argumentation. The distribution of working hours is not proportionate over the lead time and projects differ a lot in project-specific workload. Due to this, the current acceptance of orders is mostly experience-based, there is no visualization of workload over time that assists the sales department in their decision-making.

Engineering

Also for the engineering department – responsible for the CAD-models and layouts - it is important to know the current workload from both the TP as well as the OP. As shown in Table 4, the work of the engineering department is needed before production. Good communication with the engineering department regarding the lead times is key for a continuous production, the engineering employees need to know when to start and finish their layouts - from the TP the engineering department needs to gain insights when to finish layouts of projects included in the TP.

The CAD-model made by the engineers is also the input for the POs within the ERP system. Managing day-to-day (operational) tasks requires the POs (Figure 10). The engineers need to know on time when to finish their design prior to the production.

Maintenance & Service

Next to the completed products (machines), also wear and spare parts are manufactured on the production floor. The installed base, a measure of the number of units of a product or service that are in use (Farrell & Saloner, 1986), is monitored by the maintenance & service department to forecast expected manufacturing of wear and spare parts. As mentioned in the introduction chapter, the total production of the company consists of whole products (projects) **and** the maintenance – wear and spare – parts, where the scope of this research is the planning of the whole products.

Again, it is important for the maintenance & service department to gain an insight into the workload to determine the number of maintenances that can be provided on weekly basis. Just as the decision-making of the sales department can be improved by visualization of the workload, for the maintenance & service, the same applies. Currently, a standard number of workings hours is detached to the production of wear and spare parts – around 100 working hours. By gaining insight into the working hours connected to completed products (projects), the maintenance & service department have a better understanding of available hours on their respect.

2.5 Conclusion

This chapter, the current situation analysis, is a starting point for the research on improved decision-making by aligning the production process with the production planning – on both the tactical and operational level. To give a global display of this current state, the 4M-principle was introduced to get a better understanding of the current working method. Shown in Figure 8 is the current 4M-principle status. The four aspects are connected to current perceptions, which will be monitored against the future desired state in Chapter 4.

Special attention was given to the aspect 'material'. Within this aspect, the different levels of the current production planning are elaborated and visualized in Figure 7 – consisting of project (1) → modules (2) → departments (3). This level-structure is a steppingstone for the two following sections on the current use and visualization of the data. The structure also emphasizes the relationships between the different levels. For example, the modules consist of departments responsible for tasks and the completion of work from a department updates the status of a module.

Also, an important comparison is made between a production order (PO) and a module. A modules is a self-determined part of a project's machine thought of by the team leaders responsible for the production planning with experience-based data connected to the module. A PO is a part of a project's machine that originates from the ERP system BaaN based on the CAD-model of the engineers. Calculated working hours and a routing – sequence of tasks – are attached via BaaN.

Looking at the current use of data, a fixed order for the production departments is used for the third level (departments) of the planning methodology. An overview can be found in Table 1. Next to this, it became clear that the current planning methodology is not connected to the execution of work on the production floor. Shown in Figure 10, the second and third level of the planning methodology and execution do not communicate with each other. The modules determined by the team leaders do not connect with the POs from ERP system BaaN. Salient is that the POs consist of working hours calculated within the ERP system, but these hours are not connected to the modules. Also, the departments are not connected the underlying tasks of a PO from BaaN.

Doing research on the current data use within the tactical planning (TP) and operational planning (OP), there is a lack of data to representatively determine the workload on the tactical and operational level. The data from the TP is based on experience and the OP does not explicitly mention working hours. Nevertheless, the team leaders can work around their current production planning, but decision-making cannot be supported with the lack of workload visualization in the production planning

For the current visualization of the TP (Table 2), there is a clear structure based on the planning methodology of Figure 7. The departments are structured in a fixed order mentioned in Table 4. Nevertheless, the structure is not always consistent, resulting in an ambiguous overview. Within some projects, modules are not always the second level of the planning methodology. Also, the numbering of the different levels of the planning methodology and the order of departments is not always consistent in the TP overview.

The current visualization of the OP (Table 5) is based on employees. The team leaders use an employee-module combination to get insights into the production planning on the operational level. The employee has a background – responsible department – and is in that way connected to an active module. An overview or data on the departments, level three of the planning methodology – is lacking in the current OP.

Lastly, the influence of the current production planning is connected to other departments. For three departments decision-making based on the current production planning – both operational and tactical – is elaborated. Common denominator is the lack of visualization of workload from the production planning. Despite hours detached to the different levels of the planning methodology within the TP, insight into the workload is not available yet.

3. Literature study

After elaborating on the current situation, a literature study will be conducted to get more insights into the theoretical background connected to the problem. In four sections, different applicable theories are analyzed to generate a greater understanding in the problem approach of this research. Chapters 2 and 3 combined will be the steppingstones for the continuation of the research.

3.1 Positioning multi-project organization

For Gietart Kaltenbach as a multi-project organization it is needed to gain insights into the fundaments of the projects (shot blasting machines) within the production planning. To distinguish various multi-project organizations a positioning framework that allows to categorize various forms and multi-project environments will be introduced. This framework is needed since not all projects of companies have the same characteristics with respect to technological uncertainty and system complexity (Shenhar, 2001).

Leus (2003) and Herroelen and Leus (2003) describe a methodological framework to position project planning methods, in which they distinguish two key determinants: the degree of general *variability* in the work environment and the degree of *dependency* of the project (Hans et al., 2007). Hans et al. (2007) state that variability is a measure for the uncertainty due to or the lack of information in the tactical stage and/or, on the other hand, operational uncertainties on the shop floor, whereas dependency measures to what extent a project is dependent on influences on the individual project. This can both be extern influences (actors outside the company, e.g., a supplier) as well as internal influences (e.g., shared resources with other projects). Positioning on the framework shown in Table 6 is determined by either scoring high or low on the two variables.

Dependency / Variability	LOW → HIGH	
LOW ↓ HIGH	LL	LH
	HL	HH

Table 6: Positioning framework for multi-project organizations (Hans et al., 2007)

Low-Low

Positioning with low variability and low dependency is typically connected to a dedicated single-project organization (Hans et al., 2007). Resources are dedicated to one project and specification of activities often happen in advance. The degree of uncertainty is low and with little interaction with other projects the degree of dependency is low as well.

Low-high

An environment with low variability and high dependency is mostly dependent on external actors (Hans et al., 2007). A contemporary example is a wooden furniture manufacturer with high dependency on the wood supply. The variability in this environment is low because of the low degree of complexity of the products produced. A low-high setting is mostly related to the classical job shop (Hans et al., 2007).

High-low

Environments with high variability with low dependency are typically subject to large environmental uncertainties such as bad weather conditions and changing project specifications (Hans et al., 2007). The dependency is low because of the easy access of the resources used for the projects. Example of a high-low environment are large construction projects.

High-high
High variability with high dependency is typically found in an engineer-to-order environment with several complex projects parallel manufactured (Hans et al., 2007). The projects are typically new to the company with a high number of client-specific options. For example, manufacturing welding equipment for the automotive industry, with products designed for specific new cars and frequent modifications of the design. This in combination with the production of multiple products simultaneously results in a high-high environment.

It can be interpreted that the high-high environment will be the most difficult to manage. By positioning a company within the framework, it will be clear whether the production planning requires high flexibility – or more standardization – and whether interdependencies between projects play a big role within the production planning.

3.2 Planning hierarchy MPC

As described in Chapter 2, there is overlap in the current TP and OP. Within the TP operational indicators – the departments – are used, whereas the OP contains the same contents as the TP on a smaller timescale. Throughout distinction on these two planning levels need to be researched. To get an understanding in the discrepancy of objectives between the tactical and operational level, a literature study on this matter will be conducted in this section.

To get an understanding of the objectives and goals of the different levels within the planning hierarchy, the Manufacturing Planning and Control (MPC) will be introduced in this section. MPC is a framework that identifies the required steps in the field of production planning and capacity planning to get to a production schedule (De Gaaij, 2019). As a starting point, an overview of the MPC components and business hierarchy – based on levels from strategic up until operational – can be found in Table 7.

Level	Horizon	Frequency	Detail Level	Process	Validation
Strategic	>2 years	Annually	Summary	Business planning	Financing
Tactical	~18 months	Monthly	Aggregate	S&OP	Resource planning
	~3 months	Weekly	♦ MTS = End item ♦ ATO = Subassembly ♦ MTO = Raw materials	Master scheduling	RCCP
Operational	~10 weeks	Daily	Intense	MRP	CRP
	~6 weeks	Shift	Most intense	♦ Work orders ♦ Purchase orders	Scheduling

Table 7: MPC Components and Business Hierarchy (APICS, 2020)

In Table 7 a business hierarchy with respective MPC components is plotted. With use of this overview the different planning levels will be explained in the coming sections. Note again that the strategic level will be included in this literature study but is not in the scope of the research within the company.

3.2.1 Strategic level MPC

The strategic level covers the decisions on the long-term. This is connected to the vision and long-term goals of a company. Financial statements are made on this level and a global vision on e.g., the number of possible orders to accept in future years is created.

In Table 7 a horizon of more than two years and annual frequency is displayed at the strategic level. Forecasting income statements and budgets is connected to this horizon. The objective is to give a summarized prediction of the future, without providing too many details just yet.

Despite it being connected to the tactical level in Table 7, the second – 18 months tactical level - row with monthly (update) frequency will be in the scope and connected to the strategic level. Based on the capacity perspective, it is the goal to determine the number of projects or work a company can take on in the upcoming 1-1.5 years – this is the aggregated detail level shown in Table 7. Next to this, for the production – or process in the overview – a Sales and Operations Planning (S&OP) is needed to create a balance between the sales plan and the production plan (De Gaaij, 2019). The demand must be modified to match the constraint of the production and the capacity must match the sales plan. If for example a new product is introduced, the demand will be modified.

3.2.2 Tactical level MPC

The next level – the tactical level – is connected to medium-term decisions. With a time horizon of approximately a quartile and weekly updates, the tactical level shows a significant greater detailed view than the strategic level. The tactical decisions mostly relate to the implementation of strategic decisions. On the strategic level, a company decides the possible number of orders or work to accept, whereas on the tactical level orders are chosen till a maximum is reached.

On the detail level in Table 7, a company needs to provide herself a Customer Order Decoupling Point (CODP). The CODP is the point where product specifications get frozen in most cases, and more important, it is the last point at which inventory is held (Olhager, 2010). An overview of possible customer order decoupling points can be found in Figure 12. Managing inventory is a task that differs a lot when comparing a make-to-stock with an engineering-to-stock. Inventory is higher when customer influence is later in the process, whereas most of the procurement is executed only after an order with an engineering-to-order CODP. Before a production planning can be formed, the CODP needs to be clear for a company.

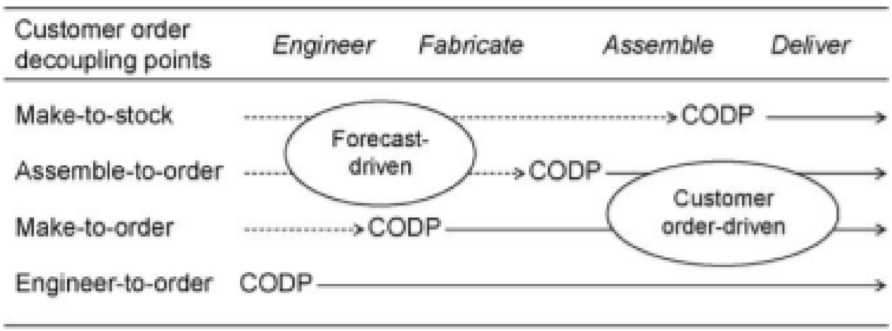


Figure 12: Customer order decoupling points (Olhager, 2010)

Next to the CODP, the objective of the process on a tactical level is to gain insight into how much of each product or service will be made/provided, the master scheduling. In this master scheduling factors such as working hours, capacity and inventory levels needs to be known. Based on these insights tactical decisions can be made within a company. An example of a possible decision on the tactical level is: 'is it possible to deliver order X in week 15 given the connected working hours Y and a machine capacity during that period Z'?

Also, the validation on the tactical level is executed with the use of Rough-Cut Capacity Planning (RCCP). RCCP is a medium-term capacity planning method that verifies whether there is sufficient available capacity to meet the capacity requirements (De Gaaij, 2019). RCCP calculates a rough estimation of the workload of the resources that were proposed by the master scheduling. The determined workload can then be compared to the maximum capacity on the working floor to see whether the proposed Master Production Schedule (MPS) is executable.

Lastly, the process phase of the Material Requirements Planning (MRP) is for the company also connected to the tactical level. The MRP follows the MPS (and validation via RCCP). The MRP provides via the Bill of materials an overview of all the parts of that a project consists of. The MRP results in a list of articles that are needed for different parts of the total project.

The connected Capacity Requirements Planning (CRP) is just as the RCCP a validation support. The CRP checks whether the MRP is feasible based on a comparison between the available production capacity of the company and the contents of the MRP.

3.2.3 Operational level MPC

The last insights of the planning hierarchy MPC will be on the operational level. These are short-term daily decisions and are connected to the decisions made on the tactical level. Within an OP the day-to-day execution of tasks need to be clear. The operational level is therefore also the most detailed level within the planning hierarchy.

The process on the operational level and contents of the OP are the POs (or in the overview denoted as work orders) and purchase orders shown in Table 7. The POs and purchase orders are scheduled and used for day-to-day execution of work.

The validation phase occurs with the use of a schedule, meaning that the contents of the POs and purchase orders are plotted on a small horizon. The objective is to maximize the utilization considered the capacity within a company. Special attention is made to the bottleneck of the process that determines the pace of the previous and upcoming tasks. Maximizing bottleneck utilization on the operational level is needed to be as little dependent on the bottleneck as possible.

3.3 BPMN

To generate an understanding of the location of the problem within the company, Business Process Model and Notation (BPMN) will be used to visualize the location of the problem. A BPMN is a handy tool to visualize internal company processes. Goal of the BPMN-diagram is to provide a visualization of a specific process with its stakeholders (Lucid Software Inc., n.d.). A simplified view with different stakeholders will be provided as the end-product after this literature studies in Chapter 4.

Elements BPMN

A BPMN-diagram consists of core elements categorized into four groups: Flow objects, connecting objects, pools (with swimlanes), and artifacts (Lucid Software Inc., n.d.). Based on these categorizations, different elements of the BPMN will be explained.

Flow objects

Flow objects are elements that are connected and result in a process flow within the BPMN-diagram (Lucid Software Inc., n.d.). The following elements are grouped under the *flow objects*:

Events

An event triggers a start, change of end of a process. There are three different types of events: start, intermediate and end (shown in Figure 13). The events are depicted as circles, and they represent a 'happening' within a process.

Figure 13: Events (Lucid Software Inc., n.d.)

Activities

Activities are flow objects that describe a performance (Lucid Software Inc., n.d.). These are business processes are specific tasks that can be performed by a person, department, or a system. The different activities are show in Figure 14.

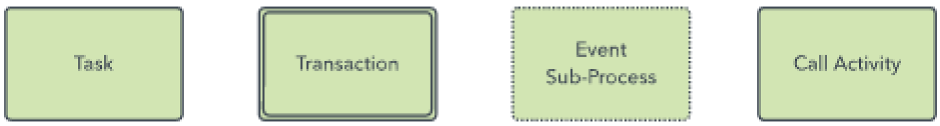


Figure 14: Activities (Lucid Software Inc., n.d.)

Gateways

If an activity needs to go through different business process flows, a gateway is used to point the activity to two different activities in the process flow (Lucid Software Inc., n.d.). Examples of activities are shown in Figure 15.

Figure 15: Gateways (Lucid Software Inc., n.d.)

Connecting objects
Connecting objects symbolize how objects are connected to each other and represent things that flow through a process (Lucid Software Inc., n.d.). The following elements are grouped under the *connecting objects*:

Sequence flow
A flow that shows the order of activities in which they are performed (Lucid Software Inc., n.d.). It is displayed as a solid line and arrowhead and is shown in Figure 16.

Figure 16: Sequence flow element (Lucid Software Inc., n.d.)

Message flow
A message flow also shows the order of activities in which they are performed. The difference with the sequence flow is that the message flow also communicates between different swimlanes/pools (see section swimlanes/pool below). It is displayed as a dashed line with an arrowhead and is shown in Figure 17.

Figure 17: Message flow element (Lucid Software Inc., n.d.)

Association
An association is a dotted line that shows the relationships between an artifact or text and an event, activity, or gateway (Lucid Software Inc., n.d.). The association is shown in Figure 18.

Figure 18: Association flow element (Lucid Software Inc., n.d.)

Swimlanes/Pool
The pool can be seen as the organization or part of the organization in the business process. Different lanes within the pool can describe departments or employees within the organization. The stakeholders representing the lanes all have influence on the process within the BPMN-diagram. According to Lucid Software Inc. swimlanes organize different aspects of a business process on a cross functional flowchart. An example is shown in Figure 19.

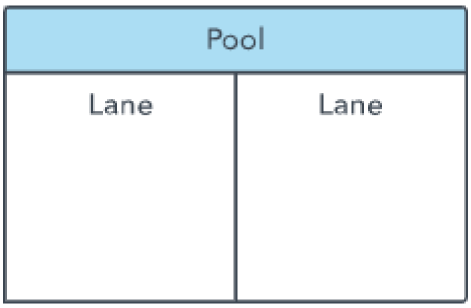


Figure 19: Pool/swimlanes element (Lucid Software Inc., n.d.)

Artifact
The last category of elements is the artifact. The artifacts can be used to include more information about a process in the BPMN-diagram (Lucid Software Inc., n.d.). Examples are the *Data Object* that displays additional data needed for a process, a *Group* that groups different activities within the process, or a *Text annotation* that provides needed background information. The symbols of these examples are shown in Figure 20.

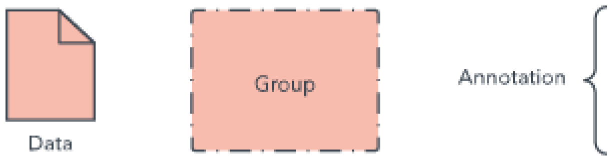


Figure 20: Artifact elements (Lucid Software Inc., n.d.)

3.4 Supporting planning tool

An important recommendation during this research is the choice of the supporting planning tool. The ERP system BaaN does not provide a sufficient planning/scheduling option, so a supportive application is needed to visualize the workload on both the tactical and operational level. This is putting the data to work, checking capacities, and making decisions based on the current TP and checking the detailed scheduling connected to the OP. The two applications that are considered are MS Excel and MS Project. Currently these two applications are both in use, but with the integration of the ERP system in the production planning, the company wants to stick with one additional application (not switching back and forth between MS Project and MS Excel). MS Excel is a spreadsheet developed for calculation, graphing tools, pivot tables, macro programming and more (Microsoft, n.d.), whereas MS Project is a project management software product that is designed to assist a project manager in developing a schedule based on resources, tracking progress, and more (Microsoft, n.d.).

To compare the two supporting planning tools a Strengths, Weakness, Opportunities, and Threats (SWOT) analysis will be executed. A SWOT analysis is an effective framework to help organizations make decisions on project planning and implementation (Sabbaghi & Vaidyanathan, 2004). Strengths define any internal asset – or motivation - that helps to meet demand, which will be decisive visualization in this case. Opportunities describe any circumstances that possibly favor demand in the future for the organization's specific competence. Weaknesses emphasize the disadvantages of a business process or project within the company. Lastly, threats are elements that could cause trouble for the business (process) or project.

A SWOT analysis is executable in quantitative and qualitative perspectives, the SWOT analysis is performed in various company scenarios using empirical studies (Gürel, 2017). The comparison between two supporting planning tools within a company will be connected to a qualitative perspective with an empirical appreciation. Important to realize is that the scope of a supporting planning tool benchmark SWOT analysis, is that there can be other options that are better applications. But within the scope of the research, the supporting planning tools MS Project and MS Excel will be compared.

By implementing this section in the Literature Study chapter, a conversion tool can be based on the chosen application by the company supported by the SWOT analysis. The conversion tool will enable an export from the ERP system to the chosen supporting planning tool.

3.5 Conclusion

For a multi-project organization insights into the fundaments of the projects – within the research company shot blasting machines – is needed to distinguish between various multi-project organizations. To do this, in Table 6, a positioning framework is introduced based on two determinants: variability and dependency. By either scoring high or low on the two determinants a position – low-low, low-high, high-low or high-high – on the framework makes clear whether a production planning requires high flexibility or more standardization. Also, it becomes clear whether interdependencies play a role within the production planning with the determinant dependency.

To gain insights in the objectives and goals of the different levels within the planning hierarchy the Manufacturing Planning and Control (MPC) is used. The MPC distinguishes time horizions, update frequencies, detail levels, processes, and validation on the strategic, tactical, and operational level. Companies can use the MPC components of Table 7 to distinguish objectives between the different planning levels.

For problem-solving the Business Process Model and Notation (BPMN) can be used to visualize the location of a problem. Influences of stakeholders connected to the problem become clear within a process. In Chapter 4 the BPMN will be used to allocate the research problem.

Lastly, to benchmark the choices within a company/or performance between different companies a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis can be used. A qualitative SWOT analysis will part of Chapter 4.

4. Desired future state

In this chapter the sections of Chapter 2 – the current state – will be used to describe the preferred future state of the company. With use of gained knowledge on applicable theories from Chapter 3 – Literature study – and conversations with stakeholders within the company, a future state of the production planning will be outlined in this chapter.

4.1 Visualization of future state

To create a global understanding in the change between the current and future state, two visualizations will be provided. Firstly, the 4M-principle will be displayed on the future state. In Chapter 2 the 4M-principle is introduced and applied to the current state – shown in Figure 8. The future 4M-principle analysis will show the future characteristics connected to the four aspects.

In Section 3.3, BPMN is introduced. With the use of elements from Lucidchart, a BPMN-diagram of first the current and thereafter the future state will be provided to allocate the problem of the research.

4.1.1 Future 4M-principle analysis

Based on Figure 21 the four aspects of the 4M-principle will be elaborated below with their own subsection.

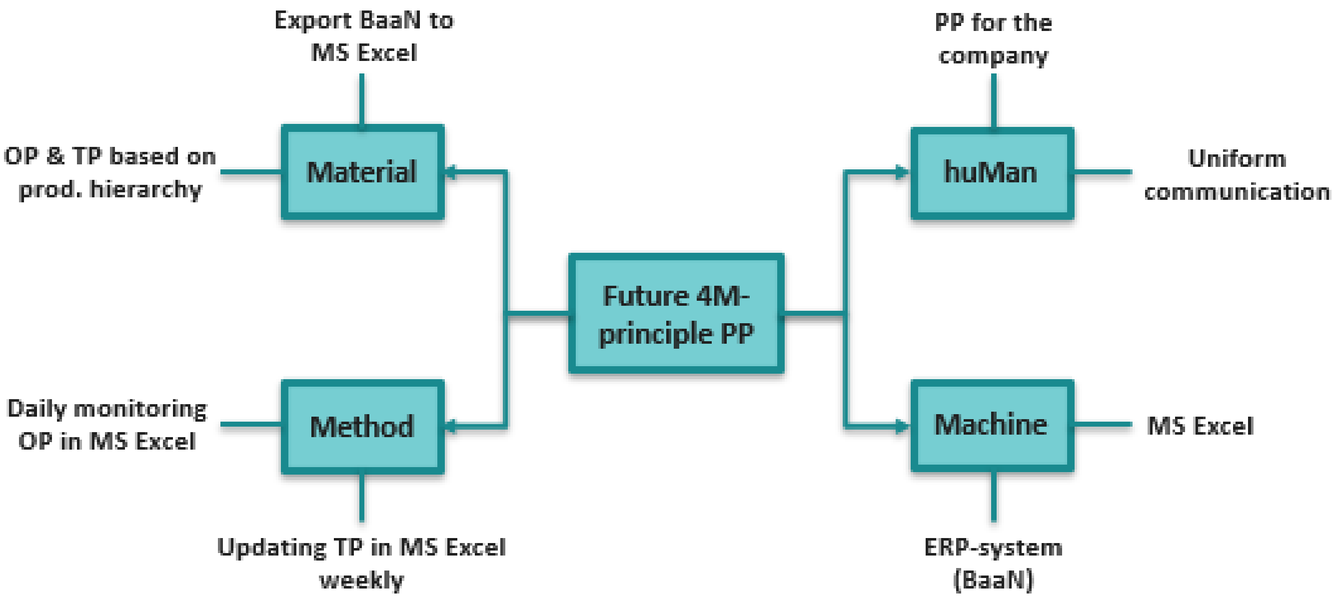


Figure 21: Future 4M-principle of the production planning

huMan

Looking at the huMan aspect of the 4M-principle, the production planning on the tactical level needs to be uniformly understood. Different departments need to understand the contents of the TP. A future consequence of this overall understanding needs to be uniform communication during meetings. Every morning employees from different departments come together for a ‘start-up meeting’. In this meeting the status of the active projects and prognosis of planned projects are being discussed. These ‘start-up’ meetings could qualitatively improve with a better understanding of the production planning.

Machine

The first important remark on this aspect is the use of MS Excel as a supporting planning tool – both for the TP as well as the OP - in the future. Both the qualitative SWOT analysis – attached to Appendix 2 – and the conversations with stakeholders at the company supported the choice of MS Excel over MS Project to display and future visualize data of the production planning. The flexibility advantage (changing lead times and working hours for example) of MS Excel compared to MS Project and the direct output from ERP system BaaN to MS Excel where the two key arguments for the choice. To put the future role of the ERP system in perspective, Figure 22 is introduced again – also used in for the introduction in Chapter 1. The TP in MS Excel will provide a starting point for a project to the ERP system, to let the ERP system calculate working hours and start for the POs (based on the CAD-layouts of the engineers). These POs can be exported from the ERP system to MS Excel again – the OP – for monitoring and visualization of working hours. Possible changes in status of a project or malfunctions can be communicated to the ERP system. Lastly, the ERP system can provide the TP with historical data of projects – e.g., old projects on the same machine can be analyzed as an input for the projects in the TP.

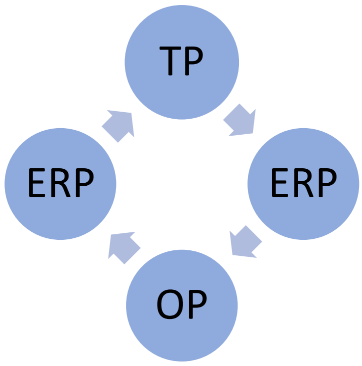


Figure 22: Connection of planning levels with ERP

Material

For the future material aspect of the 4M-principle, the planning methodology of Figure 7 needs to be reshaped. In Figure 23 a new 4-level planning methodology can be visualized.

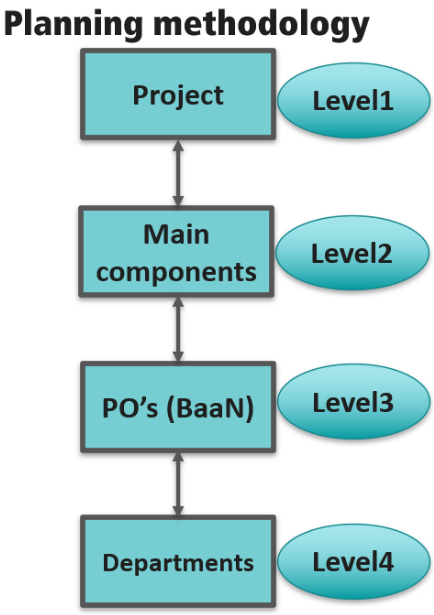


Figure 23: Future levels of project planning

This future planning methodology is based on a layered production scheme that is in-use within the company. This layered production scheme shows the hierarchy of components of a machine shown in Figure 23. Based on a part of a layered production scheme in Figure 24, the different levels will be elaborated on – a more comprehensive view of the layered production scheme can be found in Appendix 3.

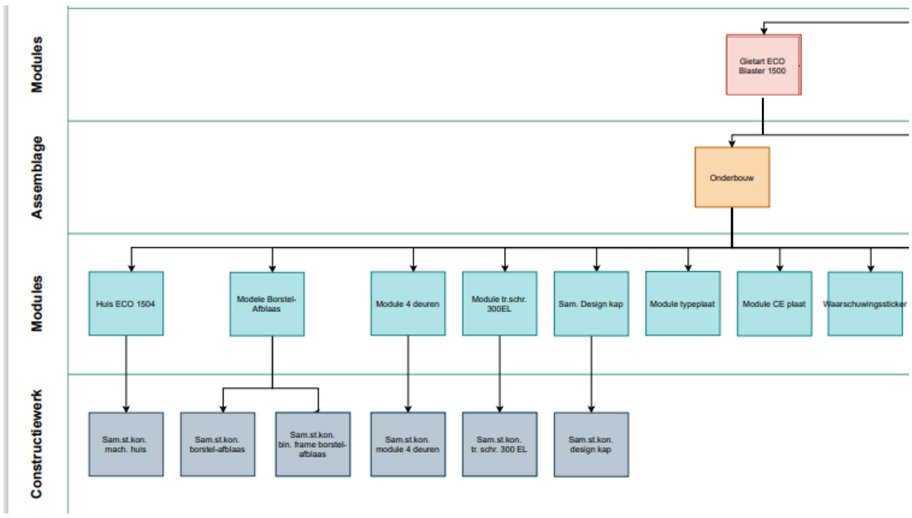


Figure 24: Part of a layered production scheme of a ECO1504

In the upper layer called 'Modules' (colored red) the whole machine is mentioned. This corresponds with a project of – in this case – an ECO1504 machine.

One layer down, called 'Assemblage' (colored orange) the main components of a machine are mentioned. There are four main components, three connected to the machine itself and one optional referred to as 'transport'. The main component 'transport' entails roller conveyers to transport the rough metal into the shot blasting machine (the picture on the cover sheet provides an example). The other three main components are 'substructure', 'superstructure' and 'additional parts'. These three or four main components together cover the machine/project. The substructure is the main component shown in Figure 24.

The last two levels 'Modules' and 'Constructiewerk' (colored blue and grey) can be seen as the POs of a project, stored in the ERP system. In the layered production scheme, all main components are connected to standardized POs. Customers have a lot of customer-specific options, but the main components with corresponding POs connection remains the same. Important to mention is that the experience-based modules will not be used anymore. The POs from the ERP system originating from the CAD-layout of the engineers will be used as a substitute. Sticking to this layered production scheme, integrating the structure of a project into the production planning will be possible on a repetitive basis. This results in a new planning methodology for a project, with an extra level connected to the main components.

Method

For the last aspect – the method – of the 4M-principle, the OP will be daily monitored and updated. The OP will provide a weekly overview of the to be executed POs. The OP will only cover the POs of **active** projects, whereas the TP will cover the projects and main components of both active and planned projects (more on this in Section 4.3 Future visualization of data). The TP will be updated weekly, based on the day-to-day updates of the OP and changes in lead times of projects.

4.1.2 BPMN-diagram

In Section 3.3 BPMN is introduced and the elements of BPMN are explained accordingly. In this section, first the current BPMN-diagram of the production planning process will be elaborated to allocate the location of the problem. Thereafter, a future BPMN-diagram will be elaborated which focuses on the changes compared to the current BPMN-diagram.

4.1.2.1 Current BPMN-diagram

The current BPMN-diagram is shown in Figure 25. The lanes of the pool are described as departments that are connected to the business process. For this case, the Sales, Projects (or Engineering), Work preparation/Purchase and Production department are included. In this BPMN-diagram there is a focus on the origin of the production planning. In this chronological process the timing of the creation of the production planning can be visualized. To support the BPMN-diagram, a textual description will be provided below.

The starting event of this business process is a sales order of a client. The sales department stays in touch with the client and if the order is accepted a gateway occurs in the process – if the down payment is received the credit is OK and the process can continue - otherwise leads to an event-end.

Now, the team leaders on the production floor responsible for the production planning includes this project (or order) to the overall production planning. The sales department delivers an end date and based on experience the team leaders include the project in the production planning. Also, the Projects department can start working 2D/3D CAD-layout of this project. If there are any changes needed on these layouts, more engineering is needed.

When the layout is approved the work preparation and purchase can start based on the CAD-driven bill of materials. This is also the part of the process where the POs are implemented into the ERP system. With use of the data artifact in the BPMN-diagram the start of the production originates from the assigned time interval of the project. Note that the work of the work preparator/purchaser needs to be finished before the production can start.

If the execution of the project is finished the machine will be transported to the customer and an event-end occurs. Important to mention is that this BPMN-diagram is a simplified view with as purpose generating a global understanding of the timing and inclusion of a new project in the production planning.

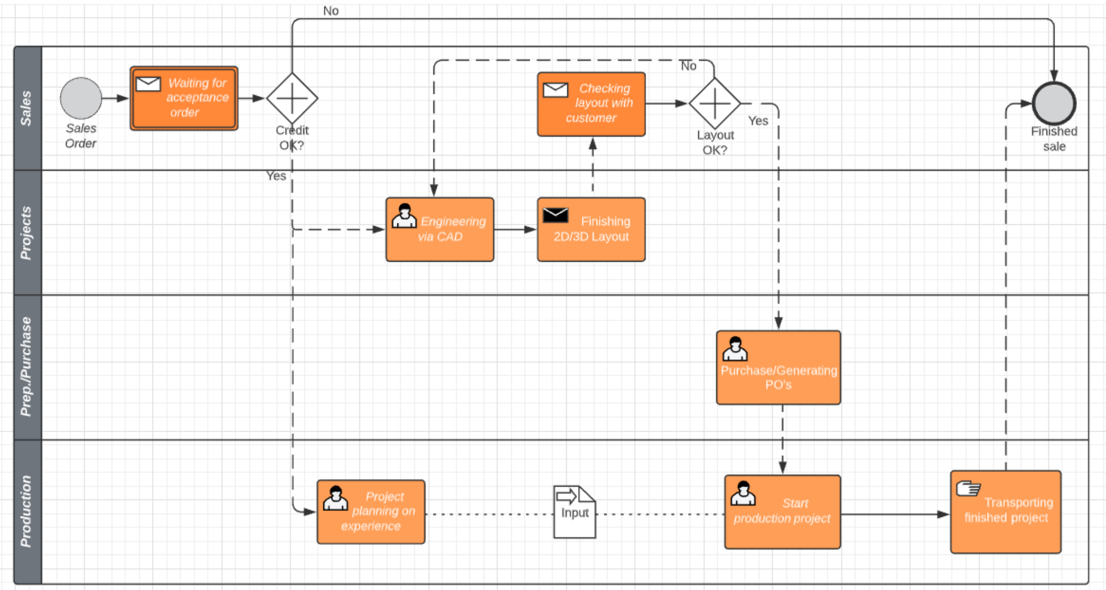


Figure 25: Current BPMN-diagram production planning process

4.1.2.2 Future BPMN-diagram

In the future BPMN-diagram the changes of the business process 'origin of the production planning' compared to the current business process with corresponding BPMN-diagram will be displayed and explained. Based on the future BPMN-diagram shown in Figure 26, the difference between current and future state can be visualized.

The two important changes are highlighted with a red frame in Figure 26. First change is the production planning that is created after an order is accepted. Previously, a complete project would be included in the production planning based on the 3-level planning methodology shown in Figure 7. The working hours, routing and modules were all based on experience of the team leaders on the production floor. Lead and end times were connected to the projects and modules – without visualization of the dependencies of other already included projects.

In the future, after an order is accepted, first only a planning based on the tactical level will be made – based on the project and main components of the future planning methodology (Figure 23). This is a rough planning of a project based on historical data from BaaN or post calculation in MS Excel. This rough planning is sufficient to make decisions on the capacity planning of projects – and answers the question related to the MRP: 'when do we need the materials for this project?'.

The second change is related to the production planning after the POs are released within BaaN. Previously, at this time, the production planning was already fixed, and the OP was extracted from the TP without input from the ERP system. No changes in structure or working hours were necessary.

Now, the operational level of a project is based on the POs in BaaN and is exported to MS Excel for further analysis. This means that the OP has a different planning methodology than the TP, not just an extraction from the TP. These POs originate from the CAD-model of the engineers. The POs of the active projects will thereafter be used to schedule the weeks based on department capacity. The departments connected to the production of Table 4 will be scheduled until the capacity is reached. As mentioned in Section 3.2.3 maximizing the bottleneck – which is the sheet metal machining department (Kok, 2021) – is the priority.

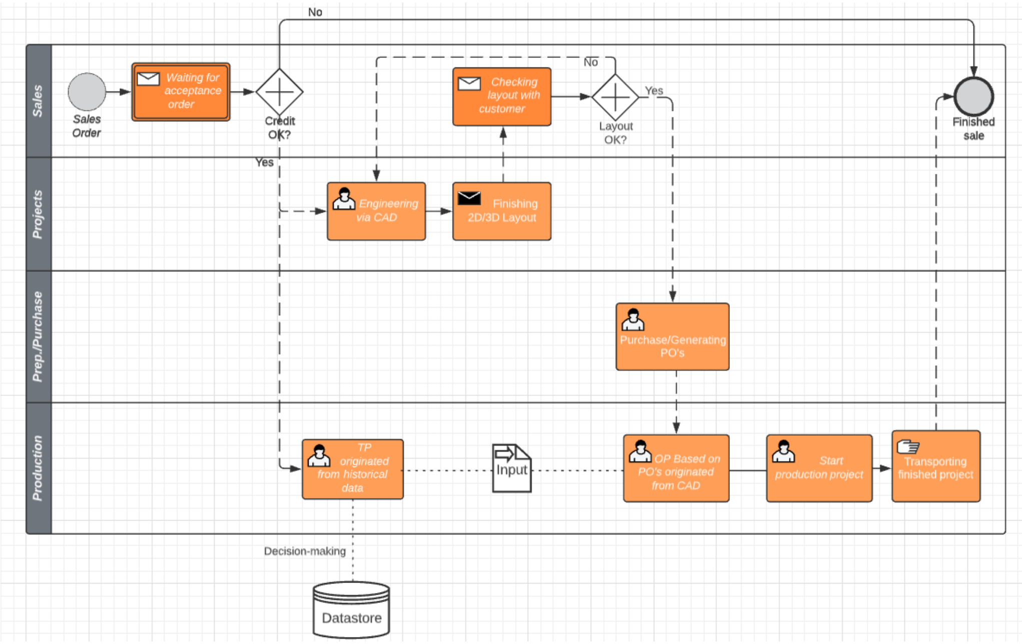


Figure 26: Future BPMN-diagram production planning process

4.2 Future utilization of data

The core problem of this research is 'with the current production planning – both TP and OP - no reliable decisions can be made'. Therefore, the previous section provided a future planning methodology based on a layered production scheme. In this way future projects in the production planning can be based on the integral fixed structure of a machine. This future planning methodology will be connected to the execution on the production floor, this serves as a comparison to the connection shown in Figure 10 of Chapter 2. Next to this, the future interpretation of the planning methodology of both the TP and OP will be elaborated in this section.

After conversations with stakeholders within the company, the observation is that the environment of the company is related to a high-high positioning in Table 6. This observation will be taken into consideration in the next subsection, since the high variability and high dependable environment of the company requires high flexibility with project interdependencies playing a role (Hans et al., 2007). It needs to be easy in the future to change lead times and working hours of projects for the team leaders that are responsible for the production planning.

4.2.1 Future global use of data

The structure of the future planning methodology needs to connect with the execution on the production floor. The planning methodology can be seen as the level-contents of the production planning, whereas the execution on the production floor is related to the production process. By measuring whether this connection exists, it becomes clear if the research is heading towards the decision-making based on the research question: 'how can alignment of the production process with the production planning improve the decision-making (of Gietart Kaltenbach)'?

Connection

In Figure 10 is shown that the planning methodology and execution of a project are not connected on the second and third level. To put this connection into perspective for the future situation, Figure 27 is created. Due to the change of using the POs from ERP system BaaN as the third level of the planning methodology (based on the layered production scheme)– and not self-invented modules – there arises a connection on the third and fourth level between the planning methodology and the execution. The POs from BaaN are also linked to departments – shown in the example in Appendix 1 – which makes it possible to link level 4 of the planning methodology with the execution of departments on the production floor. In Figure 27 no indication of the tactical and operational level is provided as in Figure 10. The future use of data on both the TP and OP will be elaborated in the next two sections.

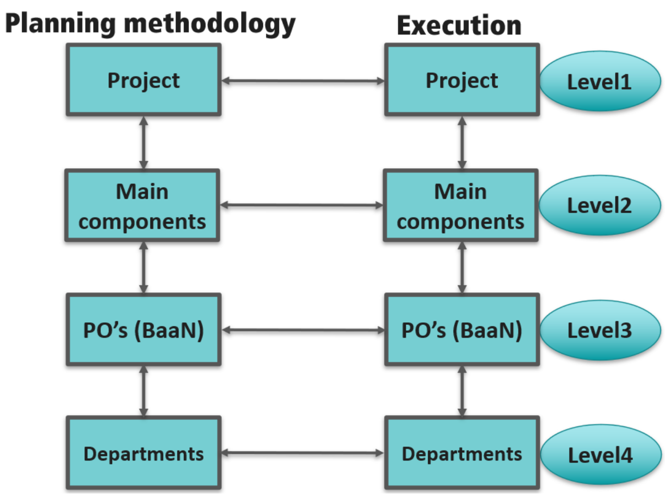


Figure 27: New connection between the planning methodology and execution

4.2.2 Future use of data TP

Looking at the connection in Figure 27, the future TP is attached to the planning methodology on the first and second level. Meaning that the TP will cover projects with the components ‘Project’ (level 1) and ‘Main components’ (level 2). On the time horizon of about three to six months, the TP will cover **both** active and planned projects. Next to this, to gain more global insights on the type of workload connected to the projects, the departments are merely used in the TP to differentiate between the assigned working hours of the ‘Main components’. The objective of the TP is to make the planning on the tactical level as pragmatic as possible, but still being able to make medium-term decisions on the capacity levels of the company.

Project

The highest level of projects within the TP will be the whole project/machine again, the project covers the total lead time, total number of working hours and a percentage completed. The working hours of the projects will be based on historical data, an estimation of the total workload of the project – differentiations in the workload of projects are mainly connected to the type of machine that is or will be in production.

Main components

A project consists of three or optional four ‘Main components’: ‘substructure’, ‘superstructure’, ‘additional parts’, and optional ‘transport’. The ‘Main components’ all get a lead time and working hours attached to it. Just as with the modules of the current situation explained in Section 2.2.2, the ‘Main components’ cannot exceed the working hours nor the lead time of the project. Progression of the ‘Main components’ is reflected to the overarching project.

Departments

The data in the TP must provide the handles to make decisions on the medium-term. Not only the total workings hours or workload on an interval of three to six months is relevant, but also the origin of the working hours. For a RCCP connected to the TP, the different resources (departments in this case) need to have connected working hours and lead times themselves. By doing this, the company prevents itself from having departments overloaded with work, while other departments being idle.

4.2.3 Future use of data OP

Looking again at the connection in Figure 27, the OP will cover the planning methodology and connection on the third and fourth level. On the small horizon – a few weeks - of the operational level, the OP will only cover PO overviews of **active** projects. The departments differentiate the working hours of the POs in resources. Weekly insights into resource capacity is made possible with the connection of departments. On a weekly-basis scheduled department working hours can be plotted against available department working hours.

The POs with routing are exported from BaaN, where departments are already attached to the underlying tasks of a PO. In the next section on the future visualization of data, the repetitive structure of projects within both the TP and OP will become clear.

4.3 Future visualization of data

After the elaboration on the planning methodology of both the TP and OP, it is time to look at the future structure of projects on both planning levels within MS Excel. How does the company visualize the data within MS Excel on both the tactical and operational level in the future? Special attention will be given to the repetitive and iterative nature of the production planning.

4.3.1 Future visualization TP

In Table 8, an example is provided of the future visualization of a project – 110306 HMV Sprint A 3008 - within MS Excel. Marked in blue is the row corresponding to the first level of the planning methodology – the project. Next to this, the rows connected to the 'Main components' – the second level of the planning methodology – are marked grey. Denoted under the 'Main components' are the departments. The departments follow the same sequence as Table 4.

Just as in the current situation, the departments 'engineering' and 'work preparation' are only included for the lead times. When these two departments finished work on a project, the first production department – 'sheet metal machining' - can start (assumed that all materials are available). Despite attached working hours to the 'engineering' and 'work preparation' departments, the working hours are not included for the workload of the production planning – more for an overview of the stakeholders of the 'engineering' and 'work preparation' departments.

Project Structure	Name	Duration (WD)	Start Date	End Date	Project_Status	Working hours	Working hours completed	Remaining working hours
110306	110306 HMV sprint A 3008	76 days	22 November 2021	3 March 2022	Active	1.825u	249u	1.576u
110306.1	Substructure	64 days	22-11-2021	17-2-2022		693u	97u	596u
110306.1.A	Engineering	10 days	22-11-2021	3-12-2021		20u	20u	0u
110306.1.B	Work preparation	3 days	1-12-2021	3-12-2021		20u	20u	0u
110306.1.C	Sheet metal Machining	5 days	6-12-2021	10-12-2021		110u	56u	54u
110306.1.D	Mechanical Machining	7 days	4-1-2022	12-1-2022		11u	1u	10u
110306.1.E	Welding	19 days	3-1-2022	27-1-2022		350u	0u	350u
110306.1.F	Surface Treatment Area	11 days	27-1-2022	10-2-2022		32u	0u	32u
110306.1.G	Assembly	12 days	2-2-2022	17-2-2022		150u	0u	150u
110306.2	Superstructure	54 days	1-12-2021	11-2-2022		374u	36u	338u
110306.2.A	Engineering	16 days	1-12-2021	22-12-2021		18u	18u	0u
110306.2.B	Work preparation	7 days	13-12-2021	21-12-2021		18u	18u	0u
110306.2.C	Sheet metal Machining	4 days	5-1-2022	10-1-2022		39u	0u	39u
110306.2.D	Mechanical Machining	3 days	5-1-2022	7-1-2022		33u	0u	33u
110306.2.E	Welding	17 days	10-1-2022	1-2-2022		196u	0u	196u
110306.2.F	Surface Treatment Area	4 days	1-2-2022	4-2-2022		24u	0u	24u
110306.2.G	Assembly	6 days	4-2-2022	11-2-2022		46u	0u	46u
110306.3	Additional Parts	58 days	29-11-2021	16-2-2022		332u	48u	284u
110306.3.A	Engineering	12 days	29-11-2021	14-12-2021		20u	20u	0u
110306.3.B	Work preparation	15 days	30-11-2021	20-12-2021		24u	16u	8u
110306.3.C	Sheet metal Machining	5 days	2-12-2021	8-12-2021		43u	10u	33u
110306.3.D	Mechanical Machining	14 days	6-12-2021	23-12-2021		4u	2u	2u
110306.3.E	Welding	20 days	13-12-2021	7-1-2022		169u	0u	169u
110306.3.F	Surface Treatment Area	3 days	7-2-2022	9-2-2022		32u	0u	32u
110306.3.G	Assembly	6 days	9-2-2022	16-2-2022		40u	0u	40u
110306.4	Transport	39 days	10-1-2022	3-3-2022		426u	68u	358u
110306.4.A	Engineering	12 days	10-1-2022	25-1-2022		40u	40u	0u
110306.4.B	Work preparation	13 days	12-1-2022	28-1-2022		44u	28u	16u
110306.4.C	Sheet metal Machining	17 days	14-1-2022	7-2-2022		30u	0u	30u
110306.4.D	Mechanical Machining	17 days	14-1-2022	7-2-2022		42u	0u	42u
110306.4.E	Welding	19 days	19-1-2022	14-2-2022		100u	0u	100u
110306.4.F	Surface Treatment Area	15 days	27-1-2022	16-2-2022		48u	0u	48u
110306.4.G	Assembly	21 days	3-2-2022	3-3-2022		122u	0u	122u

Table 8: Example TP structure of a project within MS Excel

In Table 9 a part of Table 8 is featured. Characteristic of the display in Table 9 is the project structure in the first column. To create an overview on a repetitive basis, a WBS is integrated in the first column. In Table 3 for every line - regardless of the planning methodology level – only the project number is included in the first column. In the future, a WBS is introduced giving only the first level just the project number (110306), the 'Main components' connected to the second level of the planning methodology an addition dot with a number (110306.1), and the underlying indicators (representing the departments) get additionally a letter (e.g., 110306.1.E for welding).

To make the visualization and integration of new projects within MS Excel user-friendly, the structure of the projects within the TP is fixed. This means that other projects will have the same structure as project 110306 shown in Table 8, only with different indicators (duration, start, end, working hours) and project code. The three to four 'Main components' with their respective seven department-indicators remain the same.

Project Structure	Name	Duration (WD)	Start Date	End Date	Project_Status	Working hours	Working hours completed	Remaining working hours
110306	110306 HMV sprint A 3008	76 days	22 November 2021	3 March 2022	Active	1.825u	249u	1.576u
110306.1	Substructure	64 days	22-11-2021	17-2-2022		693u	97u	596u
110306.1.A	Engineering	10 days	22-11-2021	3-12-2021		20u	20u	0u
110306.1.B	Work preparation	3 days	1-12-2021	3-12-2021		20u	20u	0u
110306.1.C	Sheet metal Machining	5 days	6-12-2021	10-12-2021		110u	56u	54u
110306.1.D	Mechanical Machining	7 days	4-1-2022	12-1-2022		11u	1u	10u
110306.1.E	Welding	19 days	3-1-2022	27-1-2022		350u	0u	350u
110306.1.F	Surface Treatment Area	11 days	27-1-2022	10-2-2022		32u	0u	32u
110306.1.G	Assembly	12 days	2-2-2022	17-2-2022		150u	0u	150u

Table 9: Example WBS in the TP

4.3.2 Future visualization OP

In Table 10, a future display of three POs of the project 110306 HMV Sprint A 3008 are provided. The columns ‘PO’, ‘Task Code’, ‘Task Description’, ‘Department’, and ‘Prod. hours BaaN’ all originate from ERP system BaaN. The columns ‘Start’, and ‘End’ need to be manually attached by the team leader responsible for the production planning – as mentioned BaaN does not provide a clear production planning function where lead times are calculated. For this example, fixed (non-representative) start and end dates are used. The future OP in MS Excel consists of two parts, a total overview of the POs (approximately twenty per project) originated from **active** projects in separate worksheets – as in Table 10, and a master-sheet where the POs that need to be executed on a weekly basis are displayed. The reasoning behind having total views of projects is the data conversion tool needed to make the data from BaaN usable. A ‘standard’ export from BaaN to MS Excel is not sufficient to work with the data from BaaN. The conversion tool and the use of the master-sheet will be future explained in the next chapter regarding the decision-making.

PO	Task code	Task Description	Department	Start	End	Prod.hours BaaN
138839	**110306-G_HMV_SprintA3008**	**Sam.mach. Sprint**		**7-2-2022**	**27-2-2022**	**17,7167**
138839	2500	Lasersnijden	Sheet metal Machining	7-2-2022	27-2-2022	0,1167
138839	3015	Boren en/of Tappen	Sheet metal Machining	7-2-2022	27-2-2022	0,0667
138839	2600	Kanten	Sheet metal Machining	7-2-2022	27-2-2022	0,5333
138839	3000	Konstruktiewerk	Welding	7-2-2022	27-2-2022	1
138839	3005	Onvoorzien werk	Surface Treatment Area	7-2-2022	27-2-2022	0
138839	4737	Spuiten Stofgrijs RAL	Surface Treatment Area	7-2-2022	27-2-2022	0
138839	3055	Eind Assemblage	Assembly	7-2-2022	27-2-2022	10
138839	3070	Bekabelen	Assembly	7-2-2022	27-2-2022	4
138839	3080	Testen	Assembly	7-2-2022	27-2-2022	2
138841	**110306-G_HMV_SprintA3008**	**Bovenbouw Sprint**		**7-2-2022**	**27-2-2022**	**41,9833**
138841	2500	Lasersnijden	Sheet metal Machining	7-2-2022	27-2-2022	3,35
138841	3012	Zagen	Mechanical Machining	7-2-2022	27-2-2022	0,3333
138841	3015	Boren en/of Tappen	Sheet metal Machining	7-2-2022	27-2-2022	2,6667
138841	2600	Kanten	Sheet metal Machining	7-2-2022	27-2-2022	3,0833
138841	3000	Konstruktiewerk	Welding	7-2-2022	27-2-2022	22,2167
138841	3005	Onvoorzien werk	Surface Treatment Area	7-2-2022	27-2-2022	0
138841	4737	Spuiten Stofgrijs RAL	Surface Treatment Area	7-2-2022	27-2-2022	0
138841	3055	Eind Assemblage	Assembly	7-2-2022	27-2-2022	8,3333
138841	3070	Bekabelen	Assembly	7-2-2022	27-2-2022	2
138842	**110306-G_HMV_SprintA3008**	**Restdelen Sprint**		**7-2-2022**	**27-2-2022**	**80,95**
138842	2500	Lasersnijden	Sheet metal Machining	7-2-2022	27-2-2022	5,4333
138842	3012	Zagen	Mechanical Machining	7-2-2022	27-2-2022	0,5
138842	3015	Boren en/of Tappen	Sheet metal Machining	7-2-2022	27-2-2022	0,5
138842	2600	Kanten	Sheet metal Machining	7-2-2022	27-2-2022	4,0167
138842	3000	Konstruktiewerk	Welding	7-2-2022	27-2-2022	54
138842	3005	Onvoorzien werk	Surface Treatment Area	7-2-2022	27-2-2022	0
138842	4737	Spuiten Stofgrijs RAL	Surface Treatment Area	7-2-2022	27-2-2022	0
138842	3055	Eind Assemblage	Assembly	7-2-2022	27-2-2022	8,5
138842	3070	Bekabelen	Assembly	7-2-2022	27-2-2022	8

Table 10: Example partially OP structure of a project within MS Excel

4.4 Multidisciplinary perspective

Following up on the multidisciplinary perspective of Chapter 2, for the future state the new production planning will be projected on the departments sales, engineering, and maintenance & service. The elaboration will be used to create an understanding in the connection of the production planning to the execution of these three departments. These elaborations will be mainly based on the changes when comparing the TP from Chapter 2 with the future state TP of Chapter 4.

Sales

With the fixed structure of the planning methodology, it will be easier for the sales department to understand the working hours distribution of the projects. But, more importantly, the fixed structure lays the foundations for insights on the workload on a horizon – elaboration on the visualization of the workload can be found in Chapter 5. Based on the workload, the sales department and the planner can communicate uniformly on the decision whether a new order can be planned on a specific time horizon. Lead times of orders can be accepted or rejected based on the visualization of the workload.

Engineering

With the fixed structure for projects within the TP, the engineering department can view the determined deadlines of the main components within a project. Due to the integration of the engineering department within this structure, they become an active part of the TP. The fixed structure needs to result in improved communication between the engineering department and the team leaders responsible for the production planning on the production floor. For similar machines these two stakeholders can get better insights into lead times and the dependencies (prior to the finished work of the engineering department, no work preparation, and thereafter production can start).

Maintenance & Service

The maintenance & service department can get insights into the future workload based on projects. The maintenance & service department is responsible for the production of wear and spare parts for existing clients. The decision-making will be improved by the insights on the workload; the maintenance & service department can see whether it is possible to do extra or less work in specific weeks. Also, the team leaders on the production floor can argue why service parts can or cannot be manufactured in specific weeks, the workload advocates the future decision.

4.5 Conclusion

This chapter started with a new 4M-principle overview in Figure 21. This figure serves as a comparison with the displayed 4M-principle of the current state in Figure 8 in Chapter 2. Most decisive changes are the future uniform communication regarding the production planning – every stakeholder needs to understand it - connected to the 'huMan' aspect, the choice of using MS Excel over MS Project - next to the ERP system - as a supporting planning tool connected to the 'machine' aspect, and a new future planning methodology based on four levels shown in Figure 23 connected to the 'material' aspect. This future planning methodology is originated from the layered production scheme that displays an actual structure of a project shown in Figure 24.

Next to the new 4M-principle overview, BPMN is just to allocate the problem and connected stakeholders within the process of creating the production planning. In the current BPMN-diagram (Figure 25) the timing of creation of the production planning can be visualized as well. A future BPMN-diagram is used in Figure 26 to compare the process of the current with the future state. The future BPMN-diagram has a lot in common with the BPMN-diagram of the current state. Remarkable changes are made in the 'lane' of the production department. There are two different moments where a part (TP or OP) of the production planning is made. Firstly, the TP of a project will be made after an order is accepted. Secondly, the OP of a project will be created ones the POs are released in BaaN. These POs can be exported from BaaN to MS Excel for further use.

Looking at the future use of data, a comparison is made to the future planning methodology of the production planning and the actual execution on the production floor. The future four levels of the planning methodology make it possible to connect to the four levels of the execution within the production. The connection of the planning methodology and the execution will be an integral connection, meaning that on all four levels the used components in the planning methodology correspond with the execution (Figure 27).

Zooming in on the future use of data in the TP, the TP will cover the first two levels of Figure 23 of both active **and** planned projects. The departments will also be used in the TP to differentiate between the assigned working hours on the department-level. There is no steering on departments based on the TP, but it is necessary to get insights into the workload on the medium-long – three to six months - horizon (more on this in Chapter 5). Zooming in on the future use of data in the OP, the OP will cover the third and fourth level of Figure 23 for **active** projects. The data related to this third and fourth level will originate from an export of POs connected to a project from BaaN to MS Excel. In Table 8 the new structure for a project in the TP can be visualized. The always included main components (marked in grey) 'substructure', 'superstructure', 'additional parts', and optional 'transport' will be included in the structure for every project. Under the main components the seven departments outlined in Table 4 are used. All active and planned projects will get the structure of project (1) > main component (2) > department (origin working hours)

For the future visualization of the OP, the **active** projects all get an own worksheet within MS Excel. The export from BaaN is converted to the structure shown in Table 10. Shown are all POs connected to a project with underlying task with respective department combinations. Elaboration on the conversion tool for the formatting and the decision-making based on the OP will be part of Chapter 5.

Lastly, the multidisciplinary perspective is projected on the future state, to address the connection of the production planning to multiple affiliated departments. With the fixed structure on both the tactical and the operational level, there needs to arise uniform communication on the data within the production planning (with understandable language). Next to this, with use of the new structure, a workload can be visualized on a time horizon. With this visualization, the other departments connected to the production planning should be able to make decisions form their own perspective. With the future fixed structure of projects included in the production planning based on the execution on the production floor and structure of the machines, the stepping stones for the decision-making are set. Based on future visualizations originated from the data of both the TP and OP, decisions on the production planning addressed in Chapter 5.

5. Decision-making

Now that the future state regarding the structure of the production planning is outlined, it is time to look at the function of this future state within the process. First, future decision-making on the tactical level will be explained. The tool created to visualize the data within MS Excel in the new TP structure will be explained and decision-making based on the process and validations indicators – objectives - of Table 7 elaborated. Thereafter, future decision-making on the operational level will be explained. The conversion tool to use the POs from the ERP system for the OP in MS Excel and the tool to visualize the data within MS Excel in the new OP structure will be elaborated on. Also, the process and validations indicators of Table 7 will be clarified in the section on the objectives operational level. Lastly, KPIs will be introduced that guarantee measuring the performance of the new production-planning.

5.1 Decision-making tactical level

For the workload on the tactical level all active and planned projects will be used. The projects are included with a structure shown in Table 8. First the newly introduced tool used to visualize the workload on a horizon is described. After this understanding, the objectives and decision-making based on this output on the tactical level are explained.

5.1.1 Tool

The tool in this section is created by a fellow researcher within the company. Therefore, the macro programming will not be explained, and the contents of this chapter will be based on the visualization and successive decision-making after use of the tool.

In Figure 28 a visualization of the workload on the tactical level is provided. In this example the distribution of hours is fictional. In the legend at the bottom of Figure 28, the projects included in the TP are shown. The distribution of working hours of these projects is plotted on multiple-month overview, where the horizontal axis mentions the week number. The tool plots the connected working hours from the projects to the corresponding weeks. An overview of the data on which the workload graph is based on the tactical level, is shown in Table 11, the workload originates from the structure mentioned in Table 8 of the projects. In Table 11 the projects with corresponding lead times (between the start week number and end week number) and working hours distribution is shown.

Where the working hours from the main components in the TP – level two of the planning methodology shown in Figure 23 - 'substructure', 'superstructure' and 'additional parts' are all booked on the overarching project, main component 'transport' is seen as an entity on its own. The manufacturing of the roller conveyers of a project is performed separately. Therefore, to gain insights into the capacity of 'transport', the main component is tracked separately. In Figure 28 the red line with yellow dots on the week numbers represent the number of 'transport' working hours.

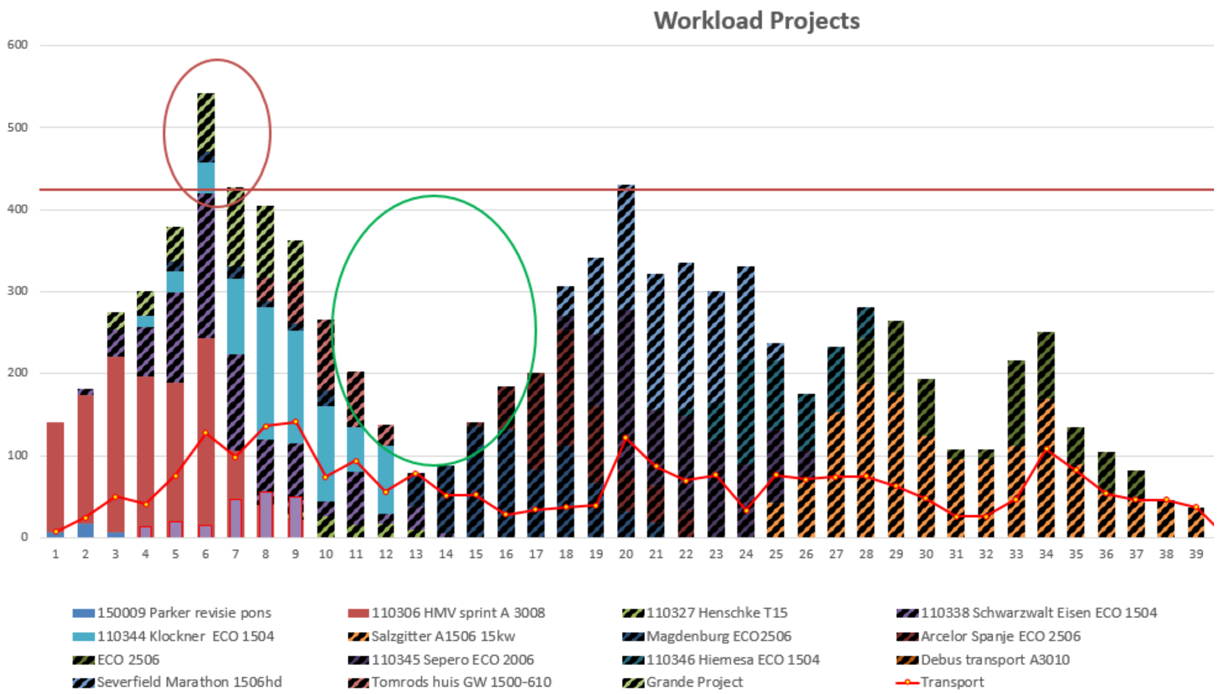


Figure 28: Visualization of workload on the tactical level

	Week Start - Week End	Total Hours	2022 1	2022 2	2022 3	2022 4	2022 5	2022 6	2022 7	2022 8	2022 9	2022 10
150009 Parker revisie pons	1 - 3	32	7	17,8	7,1	0	0	0	0	0	0	0
110306 HMV sprint A 3008	1 - 9	1299	133	156,6	213,6	196,9	188,8	242,7	106,8	39,5	21,3	0
110327 Henschke T15	9 - 13	80	0	0	0	0	0	0	0	0	10,4	26,4
110338 Schwarzwalt Eisen ECO 1504	2 - 14	797	0	6,7	33,6	59,9	109,8	176,5	117,4	81	83,8	18
110344 Klockner ECO 1504	4 - 12	719	0	0	0	13,1	26,3	37,8	92	159,9	136,9	116,6
Salzgitter A1506 15kw	25 - 39	1502	0	0	0	0	0	0	0	0	0	0
Magdenburg ECO2506	5 - 21	780	0	0	0	0	12	14	14	8	9	19
Arcelor Spanje ECO 2506	15 - 22	537	0	0	0	0	0	0	0	0	0	0
ECO 2506	28 - 37	552	0	0	0	0	0	0	0	0	0	0
110345 Sepero ECO 2006	18 - 26	843	0	0	0	0	0	0	0	0	0	0
110346 Hiemesa ECO 1504	22 - 28	455	0	0	0	0	0	0	0	0	0	0
Debus transport A3010	43 - 51	320	0	0	0	0	0	0	0	0	0	0
Severfield Marathon 1506hd	18 - 25	896	0	0	0	0	0	0	0	0	0	0
Tomrods huis GW 1500-610	8 - 12	261	0	0	0	0	0	0	0	29	51	86,3
Grande Project	3 - 9	400	0	0	21,4	30,8	42,1	71,4	97,6	86,7	50	0
Transport		2835	7	24,3	50	41	75,3	127,5	98,3	136	141,3	74,4

Table 11: Distribution of working hours of projects in TP

5.1.2 Objectives

For the future decision-making on the tactical level, it is crucial to get insights into the workload plotted on a multiple month horizon (APICS, 2020). In this section tactical level components of the MPC shown in Table 7 will be used. A distinction will be made on the tactical level between decision-making based on master scheduling – focused on working hours and space capacity - with RCCP validation and the availability of materials with the MRP with CRP validation.

Master scheduling/RCCP

After estimating the number of working hours and machine capacity over a period, this determination can be tested on the scheduled projects included in the TP. A validation on this matter connected to the RCCP is shown in Figure 28.

The new tool mentioned in Section 5.1.1. generated a visualizable workload over multiple months in the future. Two ovals in Figure 28 highlight situations where some decision-making is needed to prevent problems in the production to occur. Firstly, the red oval highlighting the red spike around week 6-7. This spike is clearly above the determined available production hours, marked around 425. Concludingly, this superfluous number of scheduled working hours can become a problem in the near future. Next to this, the green oval highlights a workload valley, displaying a period around week 10-17 with a shortage of working hours compared to the available working hours in the factory.

Rescheduling projects - considering the pre-arranged delivery time with the customer – can lead to more evenly distributed working hours over time. Validations on this distribution can happen time and time again to preventively act decisively.

Only the total working hours are covered in the decision-making above, but for this matter also the distribution of hours over departments is crucial. Despite it not being included yet, for the long run it is important to get insights into the origin of the working hours. If for example in week 15, 400 working hours are scheduled, it seems workable for the global working hours distribution. If it becomes clear on a later stadium that 200 of these 400 working hours are connected to the sheet metal machining department (with a limit of about 50 working hours), the 400 working hours become unrealistic. Therefore, creating insights into the origin of the working hours is crucial to make deliberate decisions.

MRP/CRP

Also connected to the tactical level and TP, but on a shorter notice, is the MRP. As previously mentioned, the end date of execution of the 'work preparation' department defines the start of the production – this is also the reason that the 'work preparation' department is integrated in the production planning. This end date also indicates the time when the materials need to be available for that connected main component. The MRP is integrated in BaaN. Materials are connected to a combination of a PO and a date. The date attached to the PO is an indicator of the time that all materials need to be available. The production cannot start before the materials are available. Therefore, BaaN also functions as a CRP to see whether the materials are available for a PO.

5.2 Decision-making operational level

For the workload on the operational level all active projects will be used. The projects are included with a structure shown in Table 10. For monitoring the future workload on the operational level, a starting point is making an estimation of the available working hours on a one- or two-week basis of the production departments shown in Table 4. The visualization of the workload on the operational level needs to provide insights into the feasibility of the execution of scheduled POs.

5.2.1 Tool

The tool used to create the future OP has two main functions: convert the data from BaaN into a usable format and create a master-sheet where the scheduled POs - of multiple active project – can be visualized. This section will be dissected in these two parts.

Data conversion

Firstly, the data conversion tool will be explained. The starting point of the export is shown in Table 12. The export to MS Excel from BaaN is based on the POs of one project. The issue with this export is the repetition of the headers above a PO. Due to these headers, it is not possible to make a pivot table nor a workload graph as background for the decision-making.

Datum :	06-01-22	[15:08]		PRODUKTIEPLANNING PER ORDER					Blad :	18
Testbedrijf									Bedrijf :	550
Prod.order :		138843		Actief			Produktiedatum :		31-01-22/ 19	
Project :		110306		110306-G_HMV_SprintA3008			Leverdatum :		02-03-22/100	
Artikel :		1100058044		St.kon.Sprint A3008/C380-B/9/K			Orderhoeveelheid :		1,00 st	
							Hoeveelheid geleverd:		0,00 st	
Bew	Taak	Omschrijving	Afd	Omschrijving	Machine	Geplande	Prod.	Bestede	Hoeveelh.	Ger.
						startdatum	tijd	uren	gereed	[%]
10	2500	Lasersnijden	250	Laserafdeling	250001	31-01-22/ 19	12,6167	12,6167	1,00	100*
20	3015	Boren en/of Tappen	300	Machinebouw		02-02-22/ 77	7,8000	0,0000	0,00	0
30	3000	Konstruktiewerk	300	Machinebouw		04-02-22/ 75	130,0000	0,0000	0,00	0
40	3005	Onvoorzien werk	300	Machinebouw		01-03-22/100	0,0000	0,0000	0,00	0
Datum :	**06-01-22**	**[15:08]**		**PRODUKTIEPLANNING PER ORDER**					**Blad :**	**19**
Testbedrijf									Bedrijf :	550
Prod.order :		138844		Actief			Produktiedatum :		02-03-22/ 37	
Project :		110306		110306-G_HMV_SprintA3008			Leverdatum :		24-03-22/100	
Artikel :		1100058081		St.kon.uitv.kast Sprint		/ Mara	Orderhoeveelheid :		1,00 st	
							Hoeveelheid geleverd:		0,00 st	
Bew	Taak	Omschrijving	Afd	Omschrijving	Machine	Geplande	Prod.	Bestede	Hoeveelh.	Ger.
						startdatum	tijd	uren	gereed	[%]
10	2500	Lasersnijden	250	Laserafdeling	250001	02-03-22/ 37	2,0167	2,0167	1,00	100*
20	3012	Zagen	300	Machinebouw		03-03-22/ 62	1,0000	1,0000	1,00	100*
30	3015	Boren en/of Tappen	300	Machinebouw		04-03-22/ 75	1,4167	1,4167	1,00	100*
40	2600	Kanten	260	Kantbank	260001	07-03-22/ 93	1,6167	1,6167	1,00	100*
50	3000	Konstruktiewerk	300	Machinebouw		09-03-22/ 13	46,5000	41,6640	0,00	90
60	3005	Onvoorzien werk	300	Machinebouw		17-03-22/ 94	0,0000	0,0000	0,00	0
70	4716	Spuiten Antracietgrij	400	Spuiterij		18-03-22/ 94	0,0000	0,0000	0,00	0
80	3055	Eind Assemblage	300	Machinebouw		23-03-22/ 94	0,5000	0,0000	0,00	0
Datum :	**06-01-22**	**[15:08]**		**PRODUKTIEPLANNING PER ORDER**					**Blad :**	**20**
Testbedrijf									Bedrijf :	550
Prod.order :		138845		Actief			Produktiedatum :		02-03-22/ 43	
Project :		110306		110306-G_HMV_SprintA3008			Leverdatum :		23-03-22/100	

Table 12: Starting point export POs of a project from BaaN

Shown in Table 13 is the new structure of the POs of a project. A new PO starts with every bold row. The headers are removed, and PO information (column one containing a dix digit PO-number) is added to every row. With this structure it is possible to turn the data into visualizable graphs and tables. Level three (PO's) and level four (departments) of the planning methodology can be visualized in a graph with the connected working hours form BaaN. In Section 5.2.2 Objectives, these levels will be elaborated on with a view to decision-making on the operational level.

Prod. Order	Taak	Omschrijving	Afd	Omschrijving	Prod.uren BaaN	Bestede uren	Hoeveelheid	Ger (%)	Status
138843	**110306-G_HMV_SprintA3008**	**St.kon.Sprint A3008/C380-B/9/K**			**150,4167**	**12,6167**		**8,4%**	**Actief**
138843	2500	Lasersnijden	250	Plaatbewerking	12,6167	12,6167	1,00	100*	
138843	3015	Boren en/of Tappen	300	Plaatbewerking	7,8	0	0,00	0	
138843	3000	Konstruktiewerk	300	Constructie	130	0	0,00	0	
138843	3005	Onvoorzien werk	300	Overig	0	0	0,00	0	
138844	**110306-G_HMV_SprintA3008**	**St.kon.uitv.kast Sprint**			**53,0501**	**47,7141**		**89,9%**	**Actief**
138844	2500	Lasersnijden	250	Plaatbewerking	2,0167	2,0167	1,00	100*	
138844	3012	Zagen	300	Mechanisch	1	1	1,00	100*	
138844	3015	Boren en/of Tappen	300	Plaatbewerking	1,4167	1,4167	1,00	100*	
138844	2600	Kanten	260	Plaatbewerking	1,6167	1,6167	1,00	100*	
138844	3000	Konstruktiewerk	300	Constructie	46,5	41,664	0,00	90	
138844	3005	Onvoorzien werk	300	Overig	0	0	0,00	0	
138844	4716	Spuiten Antracietgrij	400	Overig	0	0	0,00	0	
138844	3055	Eind Assemblage	300	Assemblage	0,5	0	0,00	0	
138845	**110306-G_HMV_SprintA3008**	**St.kon.inv.kast Sprint**			**52,5501**	**30,1836**		**57,4%**	**Actief**
138845	2500	Lasersnijden	250	Plaatbewerking	2,0167	2,0167	1,00	100*	
138845	3012	Zagen	300	Mechanisch	1	1	1,00	100*	
138845	3015	Boren en/of Tappen	300	Plaatbewerking	1,4167	1,4167	1,00	100*	
138845	2600	Kanten	260	Plaatbewerking	1,6167	1,6167	1,00	100*	
138845	3000	Konstruktiewerk	300	Constructie	46,5	24,1335	0,00	52	
138845	3005	Onvoorzien werk	300	Overig	0	0	0,00	0	
138845	4716	Spuiten Antracietgrij	400	Overig	0	0	0,00	0	
138846	**110306-G_HMV_SprintA3008**	**Slijtstrippen Sprint**			**14,3167**	**6,3167**		**44,1%**	**Actief**
138846	2500	Lasersnijden	250	Plaatbewerking	6,3167	6,3167	1,00	100*	
138846	3000	Konstruktiewerk	300	Constructie	8	0	0,00	0	
138847	**110306-G_HMV_SprintA3008**	**Sam.pijpleiding Sprint**			**17,4363**	**0**		**0,0%**	**Vrijgegeven**
138847	2500	Lasersnijden	250	Plaatbewerking	0,3197	0	0,00	0	
138847	3012	Zagen	300	Mechanisch	0,25	0	0,00	0	
138847	3015	Boren en/of Tappen	300	Plaatbewerking	0,3333	0	0,00	0	
138847	2600	Kanten	260	Plaatbewerking	0,5333	0	0,00	0	
138847	3000	Konstruktiewerk	300	Constructie	16	0	0,00	0	

Table 13: Overview POs from a project after the data conversion

To elaborate on the macro programming within VBA, a screenshot of the macro used for the data conversion is shown in Appendix 4.1. In pseudo code (visualized as green lines) – a plain language description of the steps in VBA – the macro programming used for the conversion tool is explained. For creating a greater understanding, smaller additions – specific details - are excluded.

Master-sheet

In Table 14, an image of the master-sheet is provided. For this example, the start and end dates are fictitious, and three projects are included - two are shown in the image – 110341 Standish Triath A1508HE and 110306 G HMV SprintA3008. In the master-sheet a production planning consisting of POs is generated on a self-determined interval of one or more work weeks. This overview of POs is simultaneously sorted on the start date of the POs regardless of the connected project.

PO	Task code	Departments	Start	End	Prod. Hours BaaN	Days wihtin interval	Hours within interval
138458	**110341_Standish_Triath_A1508HE**		**01/02/2022**	**04/03/2022**	**52,3**	**5**	11
138458	2500	Sheet metal Machining	02/02/2022	05/03/2022	4,0167	5	1
138458	3012	Mechanical Machining	03/02/2022	06/03/2022	2	5	0
138458	3015	Sheet metal Machining	04/02/2022	07/03/2022	2	5	0
138458	2600	Sheet metal Machining	05/02/2022	08/03/2022	4,2833	5	1
138458	3000	Welding	06/02/2022	09/03/2022	40	5	9
138458	7000	Surface Treatment Area	07/02/2022	10/03/2022	0	5	0
138839	**110306-G_HMV_SprintA3008**		**07/02/2022**	**27/02/2022**	**17,7167**	**5**	6
138839	2500	Sheet metal Machining	07/02/2022	27/02/2022	0,1167	5	0
138839	3015	Sheet metal Machining	07/02/2022	27/02/2022	0,0667	5	0
138839	2600	Sheet metal Machining	07/02/2022	27/02/2022	0,5333	5	0
138839	3000	Welding	07/02/2022	27/02/2022	1	5	0
138839	3005	Surface Treatment Area	07/02/2022	27/02/2022	0	5	0
138839	4737	Surface Treatment Area	07/02/2022	27/02/2022	0	5	0
138839	3055	Assembly	07/02/2022	27/02/2022	10	5	3
138839	3070	Assembly	07/02/2022	27/02/2022	4	5	1
138839	3080	Assembly	07/02/2022	27/02/2022	2	5	1
138841	**110306-G_HMV_SprintA3008**		**07/02/2022**	**27/02/2022**	**41,9833**	**5**	14
138841	2500	Sheet metal Machining	07/02/2022	27/02/2022	3,35	5	1
138841	3012	Mechanical Machining	07/02/2022	27/02/2022	0,3333	5	0
138841	3015	Sheet metal Machining	07/02/2022	27/02/2022	2,6667	5	1
138841	2600	Sheet metal Machining	07/02/2022	27/02/2022	3,0833	5	1
138841	3000	Welding	07/02/2022	27/02/2022	22,2167	5	7
138841	3005	Surface Treatment Area	07/02/2022	27/02/2022	0	5	0
138841	4737	Surface Treatment Area	07/02/2022	27/02/2022	0	5	0
138841	3055	Assembly	07/02/2022	27/02/2022	8,3333	5	3
138841	3070	Assembly	07/02/2022	27/02/2022	2	5	1
138842	**110306-G_HMV_SprintA3008**		**07/02/2022**	**27/02/2022**	**80,95**	**5**	27
138842	2500	Sheet metal Machining	07/02/2022	27/02/2022	5,4333	5	2
138842	3012	Mechanical Machining	07/02/2022	27/02/2022	0,5	5	0
138842	3015	Sheet metal Machining	07/02/2022	27/02/2022	0,5	5	0
138842	2600	Sheet metal Machining	07/02/2022	27/02/2022	4,0167	5	1
138842	3000	Welding	07/02/2022	27/02/2022	54	5	18
138842	3005	Surface Treatment Area	07/02/2022	27/02/2022	0,0	5	0
138842	4737	Surface Treatment Area	07/02/2022	27/02/2022	0,0	5	0
138842	3055	Assemblage	07/02/2022	27/02/2022	8,5	5	3

Table 14: Master-sheet OP covering overview of POs within an interval

Compared to Table 13, in Table 14 one column is excluded, and two additional columns are integrated. The excluded column is the task description. The departments are the smallest indictors of the total production planning, on the operational level the departments are the determining factor of the planning. Based on the departments the decision-making explained in Section 5.2.2 Objectives is equipped.

Next to this, to determine the number of working hours on the interval in the master-sheet, two columns 'days within interval' and 'hours within interval' are integrated. The tasks of a PO can range over large periods of time, for example 20 days, whereas the used interval of the master-sheet only covers 5 days. Since in these 5 days only a part of the total working hours of the range of 20 days needs to be executed, the hours on the interval are calculated and used for the master-sheet 'hours within interval'. To elaborate on the macro programming behind the master-sheet in Table 14, just as with the data conversion, screen shots of the macro programming with pseudo code are provided in Appendix 4.2.

5.2.2 Objectives

When it comes down to the decision-making on the operational level, the workload connected to the departments is the indicator. In MS Excel the estimated available working hours are plotted against the planned working hours from the master-sheet for future decision-making. To create an understanding of this measure, Figure 29 is introduced.

Activities	Task Code	Departments	Hours	Total:	775,222
Lasersnijden	250	Sheet metal Machining	53,6		
Zagen	300	Mechanical Machining	8,6		
Boren en/of Tappen	300	Sheet metal Machining	27,2		
Kanten	260	Sheet metal Machining	55,3		
Konstruktiewerk	300	Welding	456,4		
Spuiten algemeen	400	Surface Treatment Area	0,0		
Eind Assemblage	300	Assembly	120,8		
Onvoorzien werk	300	Surface Treatment Area	0,0		
Spuiten Antracietgrij	400	Surface Treatment Area	0,0		
Bekabelen	300	Assembly	20,4		
Uitgifte Goederen	700	Surface Treatment Area	0,0		
Spuiten Stofgrijs RAL	400	Surface Treatment Area	0,0		
Testen	300	Assembly	0,7		
Voordraaien	200	Mechanical Machining	3,3		
Laswerk Robot (VALK)	200	Welding	1,0		
Nadraaien	200	Mechanical Machining	2,2		
Konstruktiewerk Demme	300	Welding	4,5		
Voor Assemblage	300	Assembly	8,0		
Spuiten Turksblauw RA	400	Surface Treatment Area	0,0		
Zagen - Zaagmachine	200	Mechanical Machining	1,3		
Boren - Boorbank	200	Mechanical Machining	11,2		
Draaien	200	Mechanical Machining	0,8		
Walsen	300	Mechanical Machining	0,0		

Departments	Planned hours	Available hours	FTE	Weeks
Sheet metal Machining	136	128	2	2
Mechanical Machining	27	128	2	
Welding	462	448	7	
Assembly	150	320	5	
Surface Treatment Area	0			
Total	775	1024		

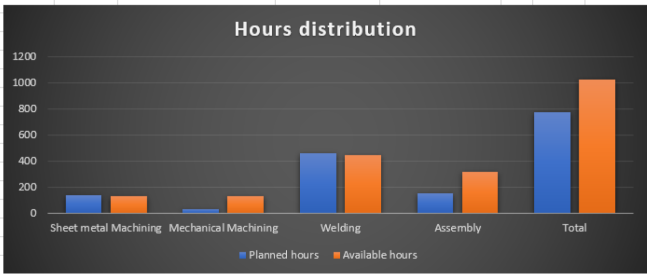


Figure 29: Department hours distribution based on master-sheet

Shown in Figure 29 are all the activities (column 1) that originate from the master-sheet. Connected to these activities are the departments (column 3) and summed hours from the master-sheet. Also, all the hours originated from the activities are summed up and displayed as the total hours in the first row.

At the right side of Figure 29, the total hours of the departments originated from the master-sheet are plotted against the available hours. The available working hours can be manually changed with different Full-Time Equivalent (FTE) – e.g., if more employees work in week 28 than in week 27 - levels and expression of weeks. In this example the available working hours are based on the estimated available hours of two weeks with corresponding FTEs for the departments. The planned hours from the master-sheet are marked red if the planned hours transcend the available hours and vice versa marked green if the available hours transcend the planned hours. Within the graph in Figure 29, the working hours can be visualized (the planned hours shown in blue, and available hours shown in orange).

After the insights on the operational level, the planner can act on the current OP. For example, when the visualization shows a spike in the welding hours – where also the planned hours transcend the available hours – the planner can proactively reschedule POs to make the planning achievable. Vice versa, if the number of planned welding hours from the master-sheet is just the half of the estimated available working hours, the planner can include more welding work from other POs. The chronological order of the execution of POs originates from the sequence within the master-sheet in Table 14, which will be sorted on the start date – first to last date on the determined interval.

5.3 KPIs

For the company to track the future performance of the production planning – both TP and OP – KPIs will be introduced and explained in this section. The first two KPIs are connected to the workload visualization explained in the previous two sections. The explanation of the latter three newly introduced KPIs will be supported with a figure. Behind the KPI the indicator will be mentioned between brackets.

Project specific workload (hours)

This first KPI will be tracked with use of the workload tool on the tactical level. As shown in Figure 28, the projects will be accumulated and distributed on a time horizon. As mentioned in Section 5.1.2. the indication is the working hours compared to the estimated working hours corresponding with the red line around 425 working hours.

Department specific workload (hours)

The second KPI 'department specific workload' is currently only tracked on the operational level. As a recommendation the distribution of working hours within the departments will be made visible on the tactical level. Over a medium-long period the distribution can be tracked.

On the operational level, Figure 29 gives a visualization of the distribution of working hours within departments on the short term. This ratio between planned and available working hours can be continuously checked on this worksheet. Different intervals can be compared and used for the decision-making on the operational level.

Difference between scheduled and actual work (hours)

In Chapter 1 it was described that the PDCA-cycle will be used during this research. Since this is the first time that the working hours from BaaN are used for the production planning, and not the experience-based hours, the hours need to be tracked to check the validity. To make this possible, for the active projects an extra column is integrated – this is an addition to project overviews as in **Fout! Verwijzingsbron niet gevonden.** In this column, own, experience-based hours can be added as a comparison to the previous state. Figure 30 shows an example of tracking the pre-calculated hours from BaaN, own experience-based hours and spent hours booked in BaaN. These graphs are plotted and monitored in MS Excel, next to an active project overview as in Table 13. At the end of a project, an analysis can be conducted to see where the discrepancy originates and whether the hours from BaaN are representative.

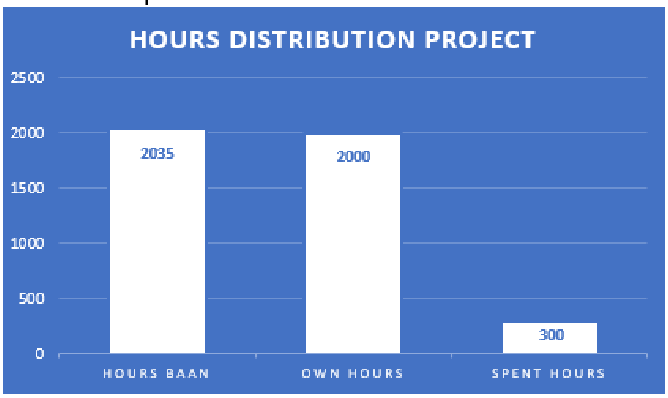


Figure 30: Graphical view hours distribution of a project

Progression of projects (percentages)

Also, the progression of the projects is tracked, to generate an understanding in the current status of the project. In the worksheets of the active projects within MS Excel, a graph is used to visualize the progression of the project. Shown in Figure 31 is the graph of the status of a project. In this graph, again, the discrepancy between the percentage completed based on the hours from BaaN **and** the percentage completed based on self-determined hours can be visualized.

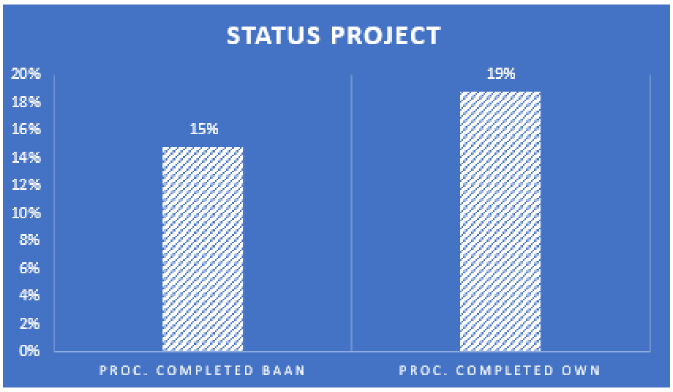


Figure 31: Graphical view progression of a project

Productivity, direct hours (percentage)
Lastly, the productivity of employees is tracked. To determine representative working hours for the different department, insights into the productivity are needed. The FTE cannot be used on 100% since an employee cannot be productive 8 hours a day. Therefore, the productivity is an indicator where the planner can anticipate on. As an example, as retrospective productivity is visualized in Figure 32. The productivity is also tracked and visualized in MS Excel, but not (directly) connected to the project overviews as the previous two KPIs.

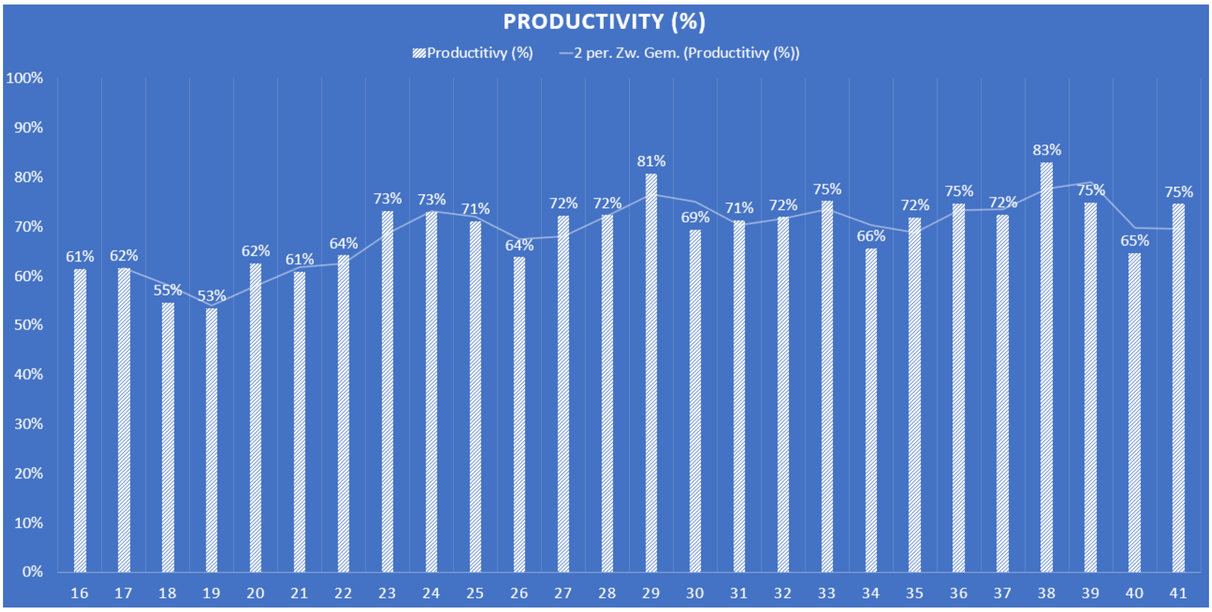


Figure 32: Retrospective graphical view of the productivity per week

5.4 Conclusion

As a subsequent chapter upon Chapter 4, Chapter 5 offers insights into the future possibilities regarding decision-making based on the workload originating from the TP and OP in their newly future structure.

In Figure 28, an example of a workload originated from the future TP is shown. All the working hours from active and planned projects are projected on a time horizon in a graph with MS Excel, via macro programming with VBA. With master scheduling average estimated available production hours and machine capacity become known. Looking at different peaks and valleys in Figure 28, the planner can decisively choose to change the lead times and/or start of some projects to create a more evenly distributed total workload over time - provided that the end date arranged with the customer is met. By weekly updating changes in lead times from projects and updating working hours, the company can visualize whether their TP is representative based on capacity restrictions. Also, for new orders it is a tool to decide whether an order can be accepted with a suggested lead time. An order can be added to the tool and plotted on the graph to see whether it is possible to accept the order.

The future OP consisting of the POs from active projects originates from BaaN. The default output from BaaN is insufficient to visualize the working hours connected to the POs. Therefore, macro programming in VBA is needed to put the data in a usable structure. Default output shown in Table 12 is converted to the structured display shown in Table 13.

Next to the data conversion of POs from BaaN to MS Excel, a master-sheet is created within MS Excel to have an overview of the multi-project OP. In the master-sheet all the POs that have lead times within the self-entered interval – for example POs planned within work week 25 - are shown. An example can be visualized in Table 14. To be certain that not too many working hours are considered within the interval, only the hours connected to the days **within** the interval are calculated and displayed.

The workload from the OP master-sheet – consisting of POs from multiple projects – is divided into the five production departments of Figure 29. On a one- or two-week basis, estimated available working hours connected to the departments can be plotted against the planned working hours originated from the master-sheet in MS Excel. An example is shown in Figure 29, where the hours distribution is visualized in a graph. Based on the data above the graph, and the graph itself, the team managers on the production floor can decide to leave POs out of the planning – planned work transcends available work – or to include more POs – available work transcends planned work.

Lastly, the production planning consisting of both TP and OP is connected to KPIs that the company can track over time to measure the performance of the future production planning. An overview of these KPIs is provided below:

- Projects specific workload in hours
- Department specific workload in hours
- Difference between scheduled and actual work in percentages
- Progression of projects in percentages
- Productive based on direct hours in percentages

6. Conclusion and Recommendations

6.1 Conclusion

Recalling the research question of this research: 'How can alignment of the production process with the production planning improve the decision-making (of Gietart Kaltenbach)'. This research question will be answered in this section.

With use of the 4M-principle – an approach to design and identify root cause(s) of problems, projecting on the four aspects huMan, machine, method, and materials - for the future state, multiple changes are highlighted in comparison with the current state 4M-principle. This current state 4M-principle can be seen as the starting point of the research. The most important observations of the production planning based on the 4M-principlpe of the future state are highlighted below:

- The future production planning must provide uniform communication, general understanding of the production planning for all stakeholders – aspect huMan
- Separation of the tactical planning (TP) and the operational planning (OP) as two unique parts of the production planning – aspect method
- ERP system BaaN & MS Excel will be used for the production planning. BaaN provides the POs (production orders) a project consist of with routing and connected production departments for the OP (exported to MS Excel), whereas MS Excel is used for the planning and visualization of both the TP and OP – aspect machine
- A fixed structure for projects included in the TP and OP based on a layered production scheme that shows the components a machine consists of – aspect material

The company wishes to align the planning methodology – way of planning – with the actual execution on the production floor, alignment of production planning and production process. The layered production scheme offers handles to connect the future planning methodology with the execution on 4-levels shown in Figure 27.

Within this future planning methodology. The project and main components – level one and two respectively – are connected to the TP, whereas the POs and departments – level three and four respectively - are planned within the OP. Departments are also included in the TP to investigate working hours distributions based on the departments and connected lead times – departments are not actually planned on the tactical level. The active **and** planned (future) projects in the TP and **only** the active included projects in the OP have a fixed structure that can be used time and time again. What came to light in the current situation analysis is that the team leaders on the production floor - responsible for the production planning - needed to think about inclusion and exclusion to describe the contents of a project.

With the fixed structure and both included working hours and lead times of projects in the TP, a workload – distribution of working hours connected to projects - can be projected on a time horizon of multiple months (Figure 28). With this visualization it is possible to look whether the master scheduling based on capacity restrictions (e.g., number of available working hours) is possible with the current planning on the tactical level. Peaks and valleys in the workload need to awaken proactive choices on changes in lead times of projects and whether to accept or decline new projects orders – future decision-making on the tactical level.

The output of ERP system BaaN, consisting of the POs of projects, is the input for projects in the OP. The output first needs to be converted to remove headers and put the data in the right columns to use the POs for further analysis. On a self-determined interval of 1-2 weeks the POs of multiple active projects covered in the interval are displayed in the OP master-sheet (Table 14). This master-sheet covers the to be executed POs on the self-determined interval. To look whether the planning is feasible, planned working hours originated from the OP master-sheet connected to departments can be monitored against estimated available working hours. In Figure 29 the output of working hours originating from an interval - connected to one or multiple work weeks - is shown. In the graph within MS Excel, it is possible to visualize planned against available working hours of the departments - future decision-making on the operational level.

To keep track of the performance of the TP and OP in the future, five KPIs originated from conversations with stakeholders in the company to measure status and progression of the production planning. These KPIs are outlined below – where the first two KPIs are the visualizations of the decision-making – both TP and OP – described in the previous paragraph:

- Projects specific workload in hours
- Department specific workload in hours
- Difference between scheduled and actual work in percentages
- Progression of projects in percentages
- Productive based on direct hours in percentages

By keeping track of the working hours from ERP system BaaN in the future, the working hours can correspond more with reality. This will be a continuous process with the use of the PDCA-cycle, after the execution of POs and completed projects, a check of future work in comparison with the originated output from BaaN is needed. The working hours of complete projects can be looked up in the historical projects within Baan, whereas the working hours of POs can be updated in BaaN and used again in the future for the OP.

6.2 Recommendations

In this research, the projects within the production planning of Gietart Kaltenbach are restructured and the ERP system has become a crucial part to align the production planning with the production process These two developments provided improved insights on the decision-making on both the tactical and operational level. Since in the scope of the research not all facets of this new production planning are considered yet, this section will elaborate on multiple recommendations for the (near) future.

The first recommendation is connected to the decision-making described in Chapter 5, namely the possibility to get insights in the distribution of the working hours connected to the TP. The investigated future workload visualization makes no distinction between the origin – attached departments - of the working hours. Some departments could be fully utilized or even overbooked, while other departments have too little hours to keep busy during that week(s). Especially with the bottleneck department – the 'sheet metal machining' – it is good to know the number of working hours connected to this department explicitly.

The next recommendation is connected to the data conversion tool – which will be used in the future to make the output of POs form BaaN usable in MS Excel. This data conversion tool is at the moment integrated in MS Excel via macro programming in MS Excel. One of the goals from the company was to make the process to the production planning as user-friendly as possible. Flexibility and reproducibility are two concepts closely connected to the user-friendliness. In the coding within Visual Basic for Applications (VBA), a lot of personalized code is encrypted. When the company wants some small changes in the structure in the future, it can result into a problem.

Therefore, the system administrator offered to put the format resulting from the data conversion tool as a 'standardized' format in ERP system BaaN. When the planner on the production floor wants to reupload POs from a project from BaaN, the output will already be in the new planning methodology structure shown in Figure 23. Small changes in the future can be added or integrated and by having the source data already in the right format, the repetitive process of integrating projects in the production planning will be more time efficient.

The third recommendation is based on a possible dashboard that can result from the KPIs mentioned in Section 5.3. The KPIs that track the progression and status of the components of the TP and OP are clear, but momentarily not viewed in one overarching dashboard. The delicate background of having KPIs connected to the production planning – both TP and OP - and having KPIs connected to just one project (hours distribution) make it difficult to get to one all-covering dashboard.

Nevertheless, the company can choose to collect and display a few KPIs with use of a dashboard in the future. At the moment the KPIs displayed on different sheets already provide a throughout insight into the progression and status of projects.

The last recommendation is based on the monitoring of the TP and OP in the future. After implementation of the new structure with improved decision-making, it is within the scope of the research not possible to monitor the newly integrated production planning in practice. The KPIs need to provide handles to monitor working hours in the future, by making a comparison to planned, experience-based and actual working hours.

The company eventually wants to have the right number of hours denoted in the source data, the ERP system BaaN. The last part of the PDCA-cycle, the act-phase, is changing the number of working hours in BaaN if large error margins are detected and can be explained. Eventually, the company wants to improve their preliminary calculation connected to the working hours. As a result of monitoring the hours a representative picture must arise of working hours connected to frequent occurring machines attached to projects. The often-recurring machines can be monitored multiple times a year to get to representative working hours connected to the machine.

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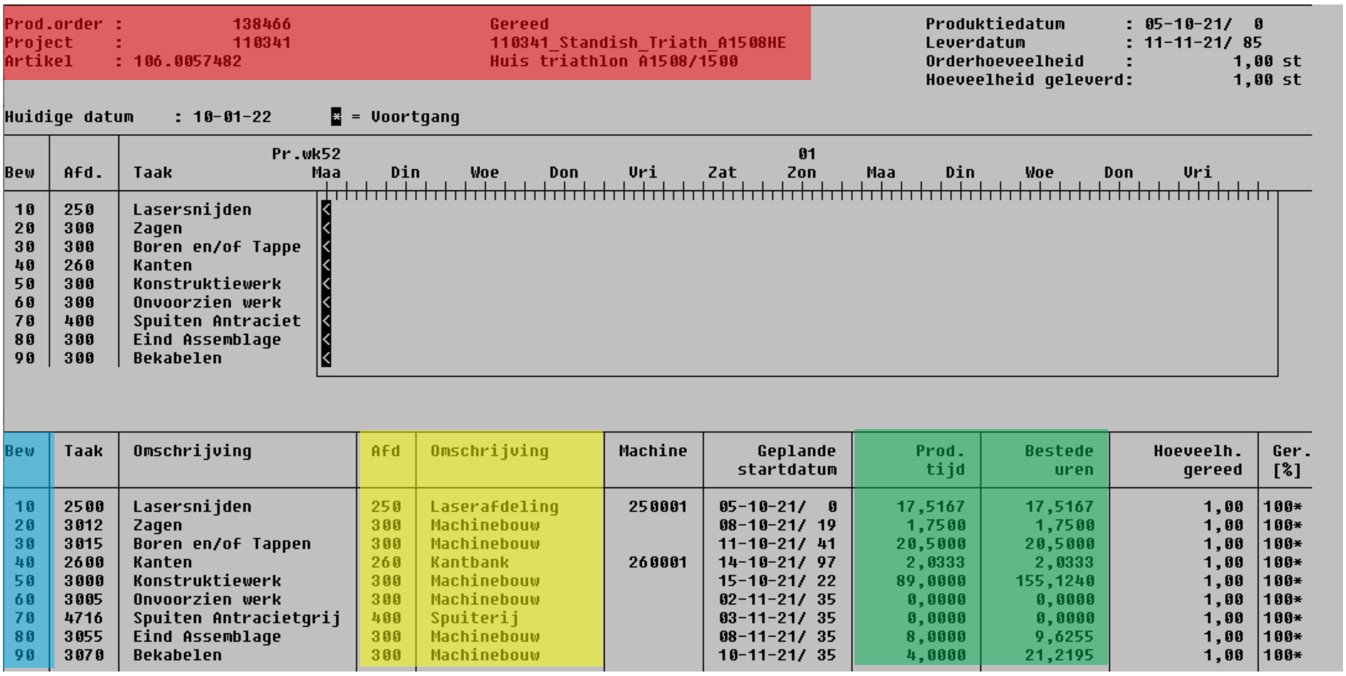
Appendices

Appendix 1: Visualization PO within ERP system BaaN



Prod.order : 138466	Gereed	Produktiedatum	: 05-10-21/ 0
Project : 110341	110341_Standish_Triath_A1508HE	Leverdatum	: 11-11-21/ 85
Artikel : 106.0057482	Huis triathlon A1508/1500	Orderhoeveelheid	: 1,00 st
		Hoeveelheid geleverd:	1,00 st

Huidige datum : 10-01-22   * = Voortgang

Pr.wk52 Maa Din Woe Don Vri Zat 01 Zon Maa Din Woe Don Vri

Bew	Afd.	Taak
10	250	Lasersnijden
20	300	Zagen
30	300	Boren en/of Tappe
40	260	Kanten
50	300	Konstruktiewerk
60	300	Onvoorzien werk
70	400	Spuiten Antraciet
80	300	Eind Assemblage
90	300	Bekabelen

Bew	Taak	Omschrijving	Afd	Omschrijving	Machine	Geplande startdatum	Prod. tijd	Bestede uren	Hoeveelh. gereed	Ger. [%]
10	2500	Lasersnijden	250	Laserafdeling	250001	05-10-21/ 0	17,5167	17,5167	1,00	100*
20	3012	Zagen	300	Machinebouw		08-10-21/ 19	1,7500	1,7500	1,00	100*
30	3015	Boren en/of Tappen	300	Machinebouw		11-10-21/ 41	20,5000	20,5000	1,00	100*
40	2600	Kanten	260	Kantbank	260001	14-10-21/ 97	2,0333	2,0333	1,00	100*
50	3000	Konstruktiewerk	300	Machinebouw		15-10-21/ 22	89,0000	155,1240	1,00	100*
60	3005	Onvoorzien werk	300	Machinebouw		02-11-21/ 35	0,0000	0,0000	1,00	100*
70	4716	Spuiten Antracietgrij	400	Spuiterij		03-11-21/ 35	0,0000	0,0000	1,00	100*
80	3055	Eind Assemblage	300	Machinebouw		08-11-21/ 35	8,0000	9,6255	1,00	100*
90	3070	Bekabelen	300	Machinebouw		10-11-21/ 35	4,0000	21,2195	1,00	100*

- Marked in red: PO information
- Marked in blue: routing, sequence of tasks starting from ‘10’ (task 1) up until ‘90’ (task 9)
- Marked in yellow: connected department codes and department description
- Marked in green: connected production-/working hours

Appendix 2: SWOT analysis supporting planning tool

Strengths

MS Project	MS Excel
• Designed to make an overview of projects	• Changes in the time interval directly visible in connected workload
• Work Breakdown Structure (WBS) that supports the three-layered planning methodology shown in Figure 7	• Flexibility in workload visualization and data usability
• Critical path that updates lead times of sequential tasks after a change in the prior task	• Export from ERP system directly usable in MS Excel → Level 2 in Figure 10 of the planning methodology and execution can become connected

Weaknesses

MS Project	MS Excel
• No direct updates from ERP system, all updates manual-based	• Due to no WBS within MS Excel, changes in lead time need to be implemented manually
• All contents of a project need to be inserted manually; structure of ERP system cannot be copied	• Formatting is not as unambiguous as MS Project, the three-level structure is more difficult to quickly update and visualize
• Visualization of the workload with the dashboard function within MS Project is static, own preferences cannot be visualized easily •	
• Capacity on the operational level cannot be visualized easily, MS Project is mostly tactical based	

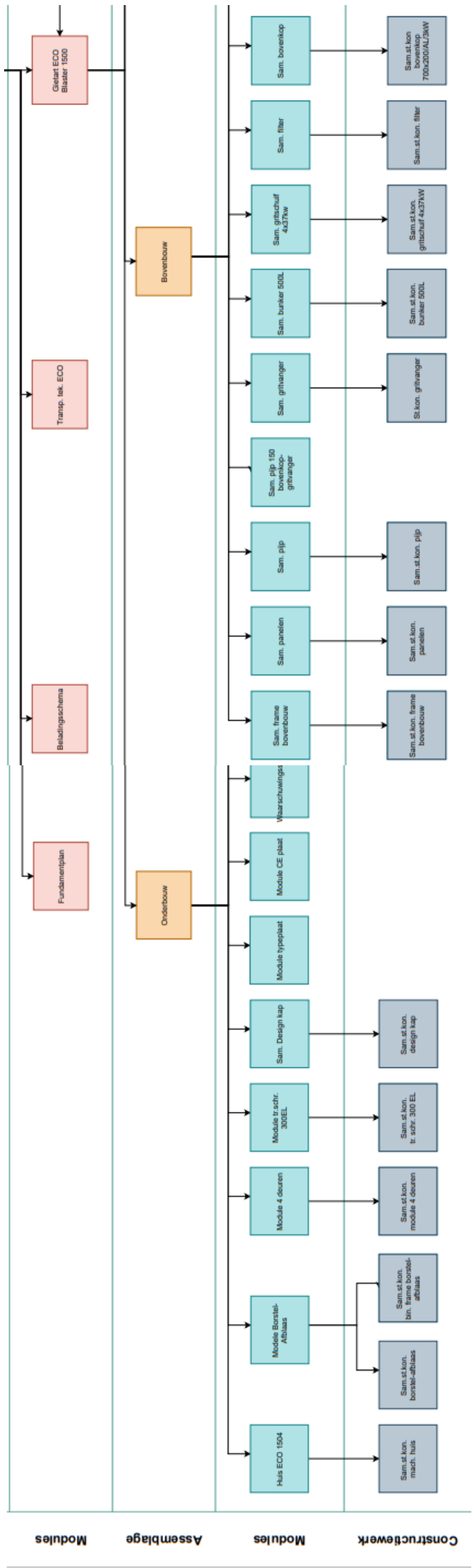
Opportunities

MS Project	MS Excel
• MS Project has the possibility of a multi-project view → a master-sheet where all the projects can be viewed	• Desired changes in the layout within the ERP system can be used directly with an export to MS Excel
• Resources can be allocated to different modules of a project, resulting in capacity control within MS Project (RCCP/CRP)	• Perfectioning the connection between the ERP system and MS Excel (goal of the research)
	• POs from ERP can be easily monitored by MS Excel, updated data on POs in ERP can be exported and updated in MS Excel

Threats

MS Project	MS Excel
• Difficult to align on a repetitive basis the ERP system with the production planning: manual implementation from scratch needed when a new order comes in	• Directly implementing lead times and working hours from the ERP system. Own lead times and hours are needed to iteratively see how the hours from the ERP system correspond with reality
• PDCA-cycles are not straightforward to update the data from the ERP system. The production planning in MS Project will be updated, but there is a threat of losing sight of the working hours of the source – the ERP system	• User-friendliness of the visualization. To visualize the data in MS Excel, macro programming will be needed to convert the data. Possible threat will be dependency on the programmer.

Appendix 3: Layered production scheme example



Appendix 4: VBA-codes with pseudo code elaboration

Appendix 4.1: Macro programming used in MS VBA for the data conversion

(Algemeen) Fill

```
Sub Clear()
Dim i As Integer
Dim n As Long
'Remove the tasks connected to engineering, only production task remain
For i = 1 To 5000
    If Cells(i, 4) = "100" Or Cells(i, 4) = "500" Or Cells(i, 4) = "550" Or Cells(i, 4) = "900" Then
    Range(Cells(i, 1), Cells(i, 11)).ClearContents
    End If
    Next i
   n = Cells(rows.Count, "B").End(xlUp).Row + 1
   Cells(n, "B").Value = Cells(1, 2)
End Sub
Sub Fill()

Dim rownr As Integer
Dim startRow As Integer
Dim endrow As Integer
Dim rng As Range, cell As Range
Dim lng As Range

rownr = 1
startRow = 1
endrow = 1
Set lng = [B1]
Set rng = Range(lng, Cells(rows.Count, lng.Column).End(xlUp))
For Each cell In rng
'Set parameters rownr and endrow for the array to copy
If Cells(rownr, 2).Value = "Taak" Then
    startRow = rownr
ElseIf Cells(rownr, 2).Value = Cells(1, 2).Value Then
    endrow = rownr
End If
'Copy the array with usable content to a new sheet --> finishing first part cleaning
If rownr > startRow And rownr = endrow Then
Sheets("Data Converteren").Range(Cells(startRow + 2, 2), Cells(endrow - 1, 5)).Copy Worksheets("Data Converteren").Cells(startRow + 2, 16)
Sheets("Data converteren").Range(Cells(startRow + 2, 8), Cells(endrow - 1, 11)).Copy Worksheets("Data Converteren").Cells(startRow + 2, 20)
End If
rownr = rownr + 1
startRow = startRow
endrow = endrow
Next cell

Sheets("Data Converteren").Range("P1:W5000").Copy (Sheets("Data Output").Range("B2"))
End Sub
```

(Algemeen) Info

```
Sub Info()
'Add specific information to the copied array
Dim i As Integer
Dim j As Integer
Dim k As Integer
Dim l As Integer
For i = 1 To 5000
'Copy the production order number to every row
    If Cells(i, 1) = "Prod.order :" And Cells(i + 6, 1) <> "" Then
    Sheets("Data Output").Cells(i, 1) = Cells(i, 3)
    End If
    If Cells(i, 1) = "Prod.order :" And Cells(i + 6, 1) <> "" Then
    Sheets("Data Output").Cells(i, 3) = Cells(i + 2, 5)
    End If
Next i

For j = 1 To 5000
'Add project name to the description row (upper bold row) of a PO
    If Cells(j, 1) = "Project :" And Cells(j + 5, 1) <> "" Then
    Sheets("Data Output").Cells(j - 1, 2) = Cells(j, 5)
    End If
Next j

For k = 1 To 5000
'Add the status of a PO to the description row (upper bold row) of a PO
    If Cells(k, 1) = "Project :" And Cells(k + 5, 1) <> "" Then
    Sheets("Data Output").Cells(k - 1, 10) = Cells(k - 1, 5)
    End If
Next k

End Sub
```

```
(Algemeen)                                                    SumFormat
Sub SumFormat()
'Add extra contents to the conversion sheet
    Worksheets("Data Output").Activate
Dim ar As Range, cell As Range, LastrowC As Long, j As Integer, g As Integer, lastrowG As Long
Dim ak As Range, lastrow As Long, endr As Integer, startr As Integer, i As Integer
'Sum booked and planned hours to the description row of the PO, showing total hours
  For Each ar In Range("F2:F" & Range("F" & rows.Count).End(xlUp).Row).SpecialCells(xlCellTypeConstants).Areas
    ar.Offset(-1).Resize(1).Value = WorksheetFunction.Sum(ar)
  Next
   For Each ak In Range("G2:G" & Range("G" & rows.Count).End(xlUp).Row).SpecialCells(xlCellTypeConstants).Areas
    ak.Offset(-1).Resize(1).Value = WorksheetFunction.Sum(ak)
  Next
lastrow = Cells(rows.Count, "B").End(xlUp).Row
endr = lastrow
'Make the PO description lines bold for an overview
For Each cell In Range("A1:A1000")
     If Cells(cell.Row, 4).Value = "" Then
            cell.EntireRow.Font.Bold = True
        End If
End Sub
```

Appendix 4.2: Macro programming used in MS VBA to create the master-sheet

```
(Algemeen)                                                    Create_Summary
Sub Create_Summary()
Dim sh As Worksheet, sumSht As Worksheet
Dim i As Long, last_row As Long, lr As Long, j As Long, lastrow As Long, k As Long, m As Long, n As Integer

Set sumSht = Sheets("Master")
sumSht.Move after:=Worksheets(Worksheets.Count)
'Copying all projects (from different worksheets) to the master-sheet
For i = 4 To Worksheets.Count - 1
lr = Worksheets(i).Cells(rows.Count, "B").End(xlUp).Row
last_row = sumSht.Cells(rows.Count, "B").End(xlUp).Row
Worksheets(i).Range("A1:H" & lr).Copy
sumSht.Cells(last_row + 1, "A").PasteSpecial xlPasteValues
Application.CutCopyMode = False
Next i

'Deleting empty rows under every copied project
lastrow = Sheets("Master").Cells(rows.Count, "B").End(xlUp).Row
For j = 2 To lastrow
If Cells(j, 1) = "Prod. Order" Then
Range(Cells(j, 1), Cells(j, 9)).Delete
End If
Next j
'Keeping formatting of bold rows in the master-sheet available
For k = 2 To lastrow
If Cells(k, 4) = "" Then
Range(Cells(k, 1), Cells(k, 9)).Font.Bold = True
End If
Next k
Cells(2, 12) = "Start"
Cells(3, 12) = "Eind"
Range(Cells(2, 12), Cells(3, 12)).Font.Bold = True
'Sort the POs on start date and overarching PO
Range("A:I").Columns.Sort key1:=Columns("F"), Order1:=xlAscending, Key2:=Columns("A"), Order2:=xlAscending, Header:=xlYes

End Sub
```

(Algemeen) | Interval

```vba
Sub IntervalToepassen()
Dim m As Long, n As Integer, lastrow As Long, o As Integer, p As Long
'Adding days to the 'days within interval' column if it falls within the interval
lastrow = Sheets("Master").Cells(rows.Count, "B").End(xlUp).Row
For m = 2 To lastrow
    For n = 2 To 6
If Cells(n, 20) >= Cells(m, 6) And Cells(n, 20) <= Cells(m, 7) Then
    Cells(m, 9) = Cells(m, 9) + 1
End If
    Next n
Next m
For o = 2 To lastrow
If Cells(o, 9) = "" Then
Cells(o, 9) = 0
End If
Next o
'Calculate 'hours within interval' based on total hours divided by total networkdays multiplied by days within interval
For p = 2 To lastrow
Cells(p, 10).Value = (Cells(p, 8).Value / Application.WorksheetFunction.NetworkDays_Intl(Range(Cells(p, 6), Cells(p, 6)), Range(Cells(p, 7), Cells(p, 7))) _
* Cells(p, 9).Value)
Next p

End Sub
Sub Interval()
Dim i As Integer, lastrow As Long
'Delete all POs that do not cover the interval, resulting in OP
lastrow = Sheets("Master").Cells(rows.Count, "B").End(xlUp).Row
For i = lastrow To 2 Step -1
If Cells(i, 6) > Cells(3, 13) Then
Range(Cells(i, 1), Cells(i, 10)).Delete
ElseIf Cells(i, 7) < Cells(2, 13) Then
Range(Cells(i, 1), Cells(i, 10)).Delete
End If

Next i
End Sub
```