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Gaining insight in the constraints of the monthly demand on a tyre production plant to improve production adherence

KONING TER HEEGE, S.

BSc Industrial Engineering and Management

Apollo Vredestein B.V., Enschede

UNIVERSITY OF TWENTE.

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Author	S. Koning ter Heege
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Graduation Committee

University of Twente	Dr.Ir. J.M.J. Schutten
	Faculty of Behavioural Management and Social Sciences
	Dr. E. Topan
	Faculty of Behavioural Management and Social Sciences
Apollo Vredestein B.V.	Ron Peeks

apollo VREDESTEIN

UNIVERSITY OF TWENTE.

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Sven Koning ter Heege

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Management summary

Apollo Vredestein B.V. (AVBV) is a tyre manufacturing company and is part of Apollo Tyres Ltd.. It has production sites in Hungary and Enschede. In Enschede, AVBV scaled down their production significantly during the last years, lowering its production from around 18,000 to around 11,250 tyres a day. Going from producing at maximum capacity to focusing on efficiency and cost reduction creates a whole new situation with new issues and challenges. It is important for AVBV to go through this transition in the best way possible; therefore the goal of this research is to contribute to this transition.

Due to decrease in demand and fierce competition, producing the right amount of tyres is important to make sure every tyre that can be sold is, and no tyres become stuck in inventory. In this research we focus on the Passenger Car Tyre product line within AVBV and the plant in Enschede. We decide to look into the difference between the planned production amount and the actual produced amount. This difference is measured in ticket adherence. Each month, AVBV decides how much it is going to produce in the next month. This list we call the monthly ticket. We see that there is insufficient insight in the impact of the monthly ticket on the plant. This is our core problem and it follows the main research question:

> *How can Apollo Vredestein B.V. gain more insight in the impact of the monthly ticket and its product mix on the plant to improve ticket adherence?*

Methodology

To answer the main research question and reach the goal to improve ticket adherence, we set three research objectives that we achieve in four stages. These objectives are: analysing the current situation, searching for insights that contribute to a better decision making process during the making of the production plan and finding a method to design a tool and use this method to design a tool that shows these insights.

The goal of the first stage is getting a better understanding of the current situation. We look at the production process of a Passenger Car Tyre, the processing of a monthly ticket and the stakeholders of this research. In the second stage we study the available literature to gain knowledge about several process improvement methods that theoretically support this research. Also, we use the literature to find a method to design a tool. In the third stage we combine the findings of stage one and two, together with knowledge from the stakeholders to find insights that contribute to an improvement of the ticket adherence. Also, we do a multi-criteria analysis to determine which insights are most useful and select some to implement. In the fourth stage we use the design method to design the tool and implement the selected insights found in stage three.

Results

By analysing the current situation we found that selling each tyre that AVBV can sell is important and that producing too much tyres that cannot be sold immediately or at a normal price results in inventory and costs. This means that having a good ticket adherence is important. We also found that AVBV takes some, but not all, relevant constraints into account when making the production plan. By engaging with the stakeholders and studying available literature we found a total of 8 insights that could contribute to an increase of ticket adherence. Due to limitations like decisions made during the scoping of the research and time we decide to implement a total of 4 insights.

By studying the available literature we found a method that can be used to design a tool, called the ICOV method. It goes through the design process in four steps: Identifying requirements (I), Characterising the design (C), Optimizing the design (O) and Validating the design (V). Also, using the Kano model in the first step proved useful because it categorises the requirements into three types: Must-be, One-dimensional and Attractive. This gives the requirements a prioritisation and an approach. We used this tool to start designing and developing the tool. We found a total of 9 customer requirements and translated them into 16 product requirements by consulting the available literature and engaging with stakeholders.

With these requirements and the 4 insights we made a tool that calculates and shows the following three implementations based upon the monthly ticket: Highlighting mergeable product series in the building department in the upcoming month, calculated the expected load on the automatic tyre building machines of the upcoming month and shows the expected load on the moulds of the Curing Department in the upcoming month. This tool is designed to be dynamic and could be updated and/or expanded in the future.

Recommendations

We recommend validating the tool before completely trusting it on its results. This is not extensively done yet. We recommend before implementing a new insight into the tool, justifying the insight with quantitative arguments when possible since it can be quite an effort to implement it. We recommend to use the customer and product requirements while improving or expanding the tool. Note that there might arise new requirements when updating or implementing new insights. Therefore, the list of requirements should be re-evaluated when making changes to the tool. We recommend to look into the possibility to gain more insights bases upon the curing plan, because the current analyses the monthly ticket. Next, we recommend to upload the monthly ticket to a central file location so that the tool can be used by anyone who has access. This way, no files need to be sent around. Lastly, we recommend to keep the source files up to date. When they are not, it can impact the accuracy of the results within the tool.

Abbreviations

APBM	Automatic building machines
AVBV	Apollo Vredestein B.V.
CTS	Critical-to-satisfaction
DBR	Drum Buffer Rope
DFSS	Design for Six Sigma
DMADV	Define, Measure, Analyse, Design and Verify
DMAIC	Define, Measure, Analyse, Improve and Control
GT	Greentyre
HAPBM	Semi-automatic building machines
ICOV	Identify, Characterise, Optimise and Validate
IE	Industrial Engineering
JIT	Just-In-Time
OE	Original Equipment
PCT	Passenger Car Tyres
PI	Product Industrialisation
SCM	Supply Chain Management
SKU	Stock Keeping Unit
TOC	Theory of Constraints
TQM	Total Quality Management

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1. Introduction

This chapter gives an introduction to Apollo Vredestein and describes the research approach. First, Section 1.1 introduces the company. Section 1.2 gives the motivation of this research and Section 1.3 gives a brief description of the project team. Next, Section 1.4 looks at what problems Apollo Vredestein experiences, how they are related and selects a core problem. Section 1.5 describes the research objective and Section 1.6 the general approach, research questions and the structure of this thesis.

1.1. About Apollo Vredestein

Vredestein was founded over 100 years ago in 1909 and has a long history of building tyres. Vredestein was originally producing tennis balls but started producing tyres instead. Over the years the Vredestein brand has achieved a premium status in the automotive industry. Nowadays Vredestein, called Apollo Vredestein B.V. (AVBV), is part of Apollo Tyres Ltd. which has its headquarters located in Gurgaon, India. Apollo Tyres Ltd. clocked a turnover of US$ 2.48 billion in the financial year 2019 with a workforce of approximately 17,200 employees. Apollo Tyres Ltd. has several manufacturing plants in India and Europe. Apollo has many sales offices around the world and sells Apollo and Vredestein tyres in more than 100 countries worldwide. The head office of AVBV is located in Amsterdam and represents the plants in Hungary and Enschede. AVBV manufactures and sells high quality and award-winning tyres across the globe. AVBV has a wide range of products existing of tyres for passenger cars, delivery trucks, bikes & scooters and agricultural & industrial applications.

The company serves two types of markets: The Original Equipment Manufacturers and the Replacement Market. The Original Equipment (OE) tyres are directly supplied to the car manufactures that are customer of AVBV. These tyres are mounted under the new cars that leave the factory. The tyres that are for the replacement market are sold for example to garages that do maintenance on cars. The majority of AVBV's production is purposed for the replacement market.

In Enschede, AVBV produces three different ranges of tyres; Passenger Car Tyres (PCT), Agricultural Tyres and Space Master Tyres. The type of tyres that are produced are very diverse, where tyres that are produced in the same sector can also have many differences. This product mix is highly variable during the year, partly because the production experiences seasonality by producing the winter tyres between week 23 and 49 and the summer tyres during the other weeks. However, the process steps that are done to produce a tyre are generally the same throughout the sectors. Figure 1 shows an overview of the 5 main process steps.

FIGURE 1: PRODUCTION PROCESS OF A TYRE

1.2. Research motivation

During the last couple of years AVBV had to downscale their production at plant Enschede by a significant amount. They went from a production of 18,000 to 11,250 tyres a day. They were used to produce at maximum capacity and to push out as many tyres as possible, since there was a demanding market. With a now saturated market combined with the fact that part of the production being moved because of high production costs, AVBV had to downscale and now faces challenges like dealing with smaller lot sizes, more changeovers, lack of flexibility amongst employees and inventory within the plant. Going from a way of working that is focused on maximizing output, to a way that focusses on minimalizing costs and working as efficiently as possible creates a whole new situation and issues that are to be dealt with. It is crucial for the plant to adapt to this situation to make sure the business stays profitable and can compete within the markets. This research contributes to the successful adaptation of plant Enschede.

1.3. Theory of Constraints

This research is done within a project team that is implementing the TOC management concept to execute continuous improvement. The TOC lives by the idea that in reality any system has very few constraints that limit the performance of it. A system's constraint is anything that limits a system from achieving higher performance versus its goal. This constraint is referred to as a bottleneck. The TOC addresses these constraints via a 5-step approach to reach higher performance levels. (Goldratt, 1990) How efficient the rest of the plant is aligned with the bottleneck is measured in flow performance. The goal of the TOC project team is to increase the bottleneck & flow performance levels of plant Enschede and with this, contribute to having a smaller difference between the planned and the actual production. Plant Enschede deliberately sets their Curing Department as bottleneck because this department can represent the actual bottleneck, the market, the best. Also its capacity can be easily adjusted by varying the amount of machines that are used within the department. Section 3.1.4 tells more about the TOC and the application of it within this research by the means of a literature review.

1.4. Problem definition

In this section we analyse the problems regarding the research objective that are present within the organisation and decide upon which is relevant to resolve, is considering the various limitations and decisions. Section 1.4.1 expounds the problems that AVBV faces by setting up a problem cluster to find the possible core problems. Section 1.4.2 derives and addresses the selected core problem and Section 1.4.3 sets the research scope.

1.4.1. Problem cluster

A problem cluster helps analysing the current situation by identifying the problems that occur and finding the causes. This eventually results in finding a problem that can be solved, which is called a core problem. Solving these so called core problems contributes or even solves the problem that it is linked with. The diagram in Figure 2 displays a rough sketch of the problem cluster within AVBV. Every part of the problem cluster has a number that relates to the explanation of it that is given in the remaining part of this section.

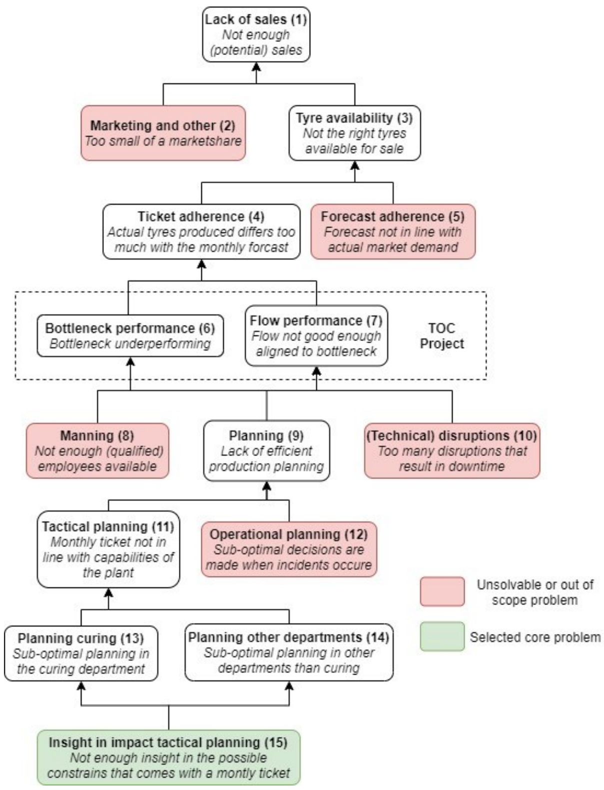

FIGURE 2: PROBLEM CLUSTER: PROBLEMS THAT AVBV FACES.

Lack of sales (1) – AVBV wants to increase its sales amount so that more tyres can be produced and sold so that the plant is utilised more than it is now. The company wants to achieve this mainly by increasing its market share so that more tyres can be sold. Producing should not be a problem since a new plant is opened in Hungary and there is overcapacity in both Enschede and Hungary.

Marketing and other (2) – Many factors influence the market share of AVBV and thus the amount of sales. Some of these factors are not within the power of plant Enschede to have influence on. Take for example marketing and Research and Development. AVBV does its marketing globally, and its head office is in Amsterdam. Research and Development is also done on another site in Enschede. Therefore these departments are out scope.

Tyre availability (3) – Tyre availability is a factor where plant Enschede can make a difference. Tyre availability is a percentage of the market demand (tyres that can be sold), that are available from stock. It means that when this number is 100% all orders from sales can be directly delivered. If not, that means that AVBV cannot sell every tyre possible, because they are not available, which might results in lost sales. Therefore, a higher tyre availability correlates in more sales.

Ticket (4) & forecast (5) adherence – Each month, AVBV decides upon what is to be produced during the next month in the plant. This is called the monthly ticket. The actual amount that is produced is compared to the expected amount. This is expressed as ticket adherence and Section 0 addresses this further. Forecast adherence reflects the alignment between forecast and the actual demand of the market. Both ticket & forecast adherence affect the tyre availability. Optimising of both the forecast and ticket adherence to 100% would result in less overproduction and more tyres that are available for sale. **(4)** Enschede has influence on adhering to the monthly ticket that is derived from the forecast, measured with ticket adherence, because it is responsible for its output. Currently, the tyres produced each month differ too much in comparison with the forecast. **(5)** The market demand is not the same every month, so there is always a forecast on what could be sold each month. This forecast is not made in Enschede and thus out of scope.

Bottleneck (6) & flow performance (7) – Bottleneck and flow performance are the two indicators that are linked with the ticket adherence. **(6)** Monthly tickets demand a certain amount of minimal bottleneck performance to make the tyres that are needed. When the actual performance does not meet the calculated expected performance, not all tyres can be produced and thus the ticket will not be adhered.

(7) The production processes that are around the bottleneck must be sufficiently aligned with it, which is measured in flow performance. Optimising the flow performance contributes to a better bottleneck & overall performance and thus the ticket adherence. Ideally the bottleneck is performing as expected and the flow is perfectly aligned with the bottleneck. The TOC project's main goal is to improve the bottleneck & flow performance.

Manning (8) and (technical) disruptions (10) – While the bottleneck & flow performance are two different indicators, a lot of the problems that lower the performance are the same. **(8)** When there are not enough (qualified) employees available on the bottleneck or any other machine, the performance will drop. This is becoming an increasing challenge since the downscale which comes with a lower amount of employees that are available. AVBV had to drop some of the temporary workers at the cost of flexibility. The workforce is being trained to be more versatile so that the flexibility will be better, which in the end will contribute to both the bottleneck & flow performance. So there are already ongoing projects that attend to this matter.

(10) Another problem that both indicators face are (technical) disruptions. These are events that happen which cannot always be prevented. AVBV has a relative old machine park, which requires a lot of technical support to keep it up and running.

Tactical (11) & operational (12) planning (9) – (9) Planning has a considerable impact on the flow and bottleneck performance. Decisions that are made within the planning determine the demand on the factory and it is crucial that it is done with good care. Planning at AVBV is done at two different levels: tactical and operational. Tactical planning is associated with the monthly ticket. The result of the tactical planning process is a plan which states which tyres are made that month. Operational planning is the daily planning of the plant.

(11) Operational planning is really dynamic and is continuously done by the shift planner to react on what is happening within the plant. The horizon of the operational planning, except for curing, is 24 hours. The curing plan is set fixed for the upcoming two weeks. A team of experienced employees puzzle around the clock to make the best decisions possible. Reactive decision-making and considering the limited amount of information available like real-time production data results in sub-optimal decisions.

(12) The tactical planning is done in the beginning of each month. Here the global plan for the upcoming month is determined and checked if the Curing Department can handle the demand. Not many indicators and factors other than the capacity of the Curing Department are considered while deciding whether or not the plant can handle the demand. There is insufficient information available to make good decisions for all processes on a tactical level.

Planning curing (13) and other departments (14) – **(13)** The planning in the Curing Department is done manually by the head planner. The IT Department is working on a project where the goal is to automatically generate a possible or a draft of the curing plan for the upcoming month. The goal of this project is to assist the head planner in making the monthly planning so that in the end planning will be less time consuming and/or more efficient.

(14) The plan for the processes prior to the Curing Department are based on the curing plan and is continually adjusted to react on the current situation (operational level). On a tactical level, not all processes are considered to determine if the monthly ticket is adherable by the plant. This comes with the problem that during the month problems arise, for example machines that are overloaded, that have a negative influence on both the flow and bottleneck performance.

Insight in impact tactical planning (15) – Gaining more insight in the impact of the tactical plan on the plant can give more anticipatory capacity and thus improving the overall quality of the tactical planning. Knowing the impact on the plant results in better decision making during the tactical planning which eventually results in less losses in other processes. Knowing the impact on some processes can also improve the decision-making at an operational level. Both these improvements result in a better overall planning. This is the selected core problem. Section 1.4.2 discusses this core problem.

1.4.2. Core problem

The core problem of having too little insight in the impact of the tactical planning on the plant is the result of the analysis which is found in Section 1.4.1. Solving this core problem results in an improved overall planning, which in turn contributes to improved performance and ticket adherence. The core problem is stated the following:

> There is insufficient insight in the impact of the monthly production plan on the plant.

Reality

Right now there is insufficient information available to measure the impact of a monthly ticket on the plant. Currently, the tactical planning is made so it fits the Curing Department. There is information available to check if the remainder of the processes are capable of handling the demand, but there are insufficient means to assess if the ticket is feasible for the other production processes within the plant. In the current situation, monthly tickets are being confirmed to go in production while not all constraints of it are taken into account since they are not available to see automatically. These constraints will arise during the month which will result in the ticket not being adhered to. Also, the impact resulting from the product mix of the ticket is not the same every month, since the demand varies throughout the year because for example seasonality and demand fluctuates. Now problems pop up during the month itself which potentially could be prevented if there was enough information available.

Norm

There should be enough information available to detect at least the most often appearing constraints or most critical production processes. With this information available AVBV can anticipate on the monthly ticket instead of reacting on the impact of the ticket during the month itself. This will contribute to an improved overall planning and thus bottleneck and flow performance.

1.4.3. Research scope

This section considers some of the limitations and scopes the research. Table 1 shows what is in and out of scope. Some of the decisions are made because they are not possible, while others are made because for example other limitations like available time that was reserved for this research.

Table 1: In- and out-scope of the research

In-scope	**Reason**
Passenger Car Tyres	Including other product lines is not possible during this research
Bottleneck & flow performance	Objective of TOC project and improvement goal of this research
Tactical planning	Decisions that are made in the handling of the monthly ticket are made on a tactical level
Out-scope	**Reason**
Agricultural and Space Master	Different planning and production process
Marketing and other	Not done at plant Enschede
Manning & disruptions	Already ongoing projects and not related to selected core problem
Operational planning	Due to time limitations

1.5. Research objective

The first objective of this research is to analyse the current situation and look in what ways we can improve the ticket adherence. The second goal is to find insights that provide a better understanding of the impact of the monthly demand on the plant, and help making better decisions during the planning process which results in better performance. The last goal is to find an implementation method that can be used to implement these insights and eventually implement some of the findings by using this method.

1.6. Research questions & approach

In this section we explain the steps of this research and the corresponding research questions that arise during those steps. Section 1.6.1 shows the steps of this research and they are summarised in Section 1.6.2.

1.6.1. Research steps & questions

In Sections 1.6.1.1 to 0 we discuss the four steps of this research. Each of the steps comes with several questions that, when answered, contribute to solving the core problem. Table 2 shows a summary of these questions. Considering the core problem the main research question states as the following:

- *How can Apollo Vredestein B.V. gain more insight in the impact of the monthly ticket and its product mix on the plant to improve ticket adherence?*

A summary of the research questions can be found in Table 2.

1.6.1.1. Stage 1: Current situation

To answer the main and the other research questions, knowledge of the current situation is required about the production process in order to understand the discussions and terminology that is used within AVBV. To analyse and understand the impact of the monthly ticket, we need to know how the monthly ticket is processed, to what extend it has influence on the plant and what is already taken into account considering the constraints. Lastly, we chart the stakeholders to gather all the involved parties and determine who should be closely managed during the research and where information and data can be gathered to answer the other questions. These points form the first set of research questions:

Research questions:

a. What are the production process steps of a Passenger Car Tyre?
b. How is a monthly ticket processed?
c. Who are the stakeholders?

1.6.1.2. Stage 2: Literature review

After knowing more about the current situation, we find out what is known by using literature about various process improvement methods like the Theory of Constraints. Also, we review the literature to find a method that can be followed to implement the findings of this research. This results in the second set of research questions:

Research questions:

d. What are known methods of process improvement?
e. What method can be used to implement the findings of this research?

1.6.1.3. Stage 3: Solutions

After having an understanding of the current situation and having the knowledge of the literature reviews at hand, we look for possible solutions that increase the insight of the impact of the monthly ticket and contribute to the improvement of the ticket adherence by entering discussions with the stakeholders and doing interviews. These possible solutions are then further analysed to figure out what is needed to implement them and how they contribute to the improvement of the ticket adherence. In this stage the following research question is answered:

Research question:

f. What solutions can contribute by gaining more insight to increase the ticket adherence?

1.6.1.4. Stage 4: Implementation

In the last stage we evaluate the found solutions and make a selection which solutions are possible to implement during this research considering the limitations. Before we implement, we need to consider the effect of the implementation. Also, in this phase, after the implementation, knowledge about the tool will be transferred so that AVBV can start implementing the other insights that were found in this research.

Research question:

g. *What solutions are feasible for implementation considering the limitations?*

By completing these steps, more insight is created in the impact of the monthly ticket and its product mix on the plant. Implementing the findings of this research should contribute to better decision making for some of the possible constraints regarding the monthly ticket. The end result is designed with and to be used by the stakeholders so that they can improve their decision making on both a tactical and operational level.

1.6.2. Thesis structure

Completing these steps creates an insight in some of the possible constraints regarding the monthly ticket that is designed to be used by the stakeholders so that they can improve their decision making on both a tactical and operational level. In Table 2 a summary of the research questions in each step is given and in what chapter they are answered.

Table 2: Overview of the stages and research questions within the problem solving approach		
Chapter 2	**Stage 1: Current situation**	
	a.	*What are the production process steps of a Passenger Car Tyre?*
	b.	*How is a monthly ticket processed?*
	c.	*Who are the stakeholders?*
Chapter 3	**Stage 2: Literature review**	
	d.	*What are known methods of process improvement?*
	e.	*What method can be used to implement the findings of this research?*
Chapter 4	**Stage 3: Insights**	
	f.	*What solutions can contribute by gaining more insight to increase the ticket adherence?*
Chapter 5	**Stage 4: Implementation and evaluation**	
	g.	*What solutions are feasible for implementation considering the limitations?*

2. Current situation

This chapter answers the first research question "What is the current situation?". The subjects that are addressed in this chapter contribute to a deeper understanding of the problems and the current situation. Section 2.1. explains the wide range of products that AVBV produces and the complexity that comes with it. Section 2.2. gives a more in-depth explanation about the production process of a PCT. Section 2.3. explains how the demand is processed throughout the organisational structure and how the ticket adherence is measured. Section 2.4. analyses the stakeholders that are relevant regarding this research.

2.1. Stock Keeping Units

AVBV produces lots of different tyres that are called Stock Keeping Units (SKUs). These SKUs each have a code associated with them which tells some of the specification the tyre has, like its inch-size and tread. These products vary from large to small sizes, and various properties like being a winter, summer or all-season tyre. The plant in Enschede, in comparison with the plant in Hungary, is more focused on the bigger and high performance tyres. These tyres are produced within smaller batches, which causes an increasing amount of complexity within the plant. On average, more than 200 different SKUs are demanded each month from the plant. Producing over 200 SKUs a month having a broad range of different specifications means having a high complexity that is caused for example by changeovers, intermediate stock and the alignment of the production flow.

2.2. Production process

The production process of a tyre consists of five general process steps. The mixing of rubber, manufacturing of semi-finished products, assembly into a greentyre (GT), curing and uniformity. Different characteristics of the tyre, like durability, performance comfort, etc., can be optimized by mixing various chemical components with rubber, allowing the tyre to fit its purpose perfectly. Since this research is scoped on PCT, Sections 2.2.1 to 2.2.4 address only the production process of this product line. Figure 3 shows a detailed overview of the production process of a PCT. (Apollo Vredestein B.V.)

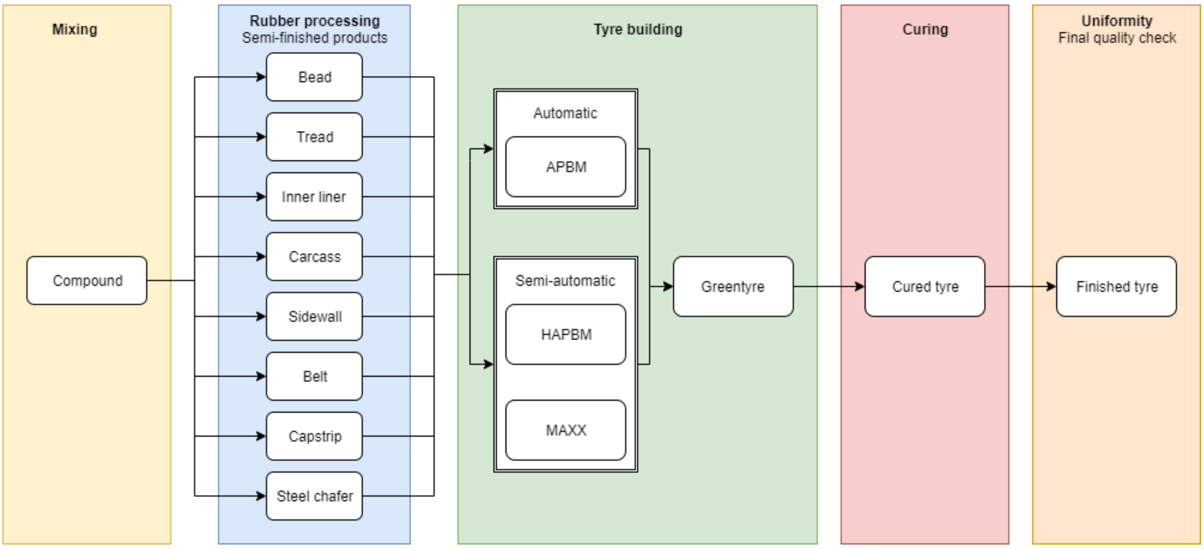

FIGURE 3: PRODUCTION PROCESS OF A PASSENGER CAR TYRE

2.2.1. Mixing

In the mixing process, rubbers are mixed with different chemicals. These raw materials are put in the mixer and brought on temperature (160-180°C) and kneaded by two rotating screws until it is a homogenous mix. In the next step, more chemical components are added in a different mixer, with a lower temperature. If these chemicals were added at the first stage, the mix would be an unworkable tough slab due to triggered chemical reactions, which are supposed to trigger in the curing process. These different rubber mixes are called compounds and are used as material for the semi-finished products.

2.2.2. Semi-finished products

Different compounds and raw materials are combined and used to make various semi-finished products that are needed to put together into a tyre. The semi-finished products can have various characteristics that are of influence the quality of the tyre. For example, treads, which generally are sturdy, have influence on matters like breaking distance, water drainage and wear, while the sidewalls, that generally are more elastic, are related to driving comfort. The greatest portion of the production plant is used for machinery that is making these semi-finished products.

2.2.3. Tyre building

In this process step, the requested semi-finished products are combined into a greentyre (GT). A GT has the shape of a tyre and is ready to be cured in the last process step. Plant Enschede currently has three types of building machines, differing from semi-automatic to automatic. These building machines each have a different set-up and machines specs. This results in the fact that not all GTs can be assembled on each of the machines. For example, certain machines can only assemble a certain range of inch sizes.

Plant Enschede has three types of building machines: automatic building machines (APBM) and the semi-automatic building machines (HAPBM & MAX). The MAX machines are the newest building machines in the plant. Within these three categories, there are several machines which often have different specs themselves, even within the same category. Figure 4 shows all the different building machines AVBV has in their machine park and which ones are not in use at the moment.

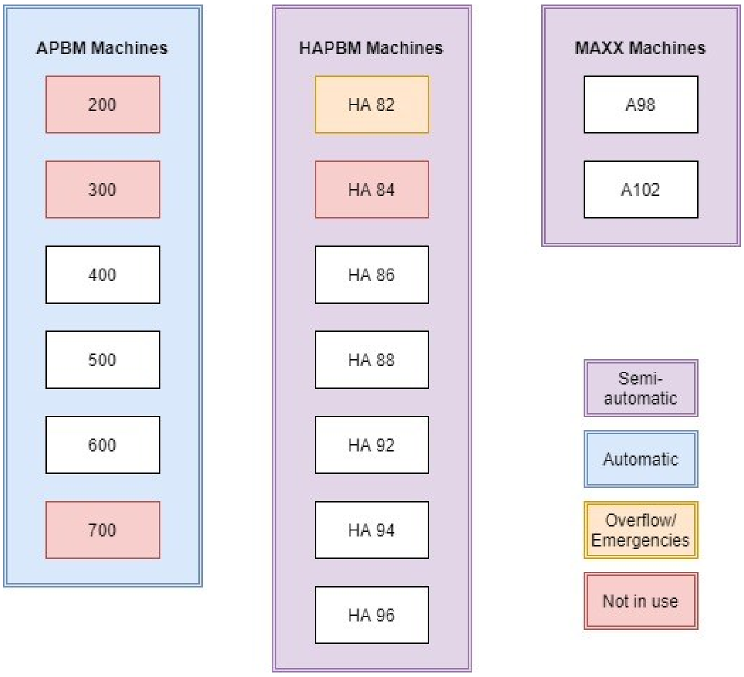

FIGURE 4: OVERVIEW OF TYRE BUILDING MACHINES IN PLANT ENSCHEDE

2.2.4. Curing & Uniformity

The GT has the shape of a tyre, but has no profile yet. In the Curing Department, the GTs are put into a press and are given a treatment that triggers a chemical reaction that changes the material properties of the rubber. The rubber changes from a plastic to an elastic material property. This happens under high pressure, a temperature of about 200°C and within 8 to 14 minutes. When the curing is complete the tyre is checked by the operator if there are any impurities. The final check happens in the Uniformity Department. Here the tyres are tested on high-tech machinery if its properties are within the allowed margin. When a tyre passes the tests, it is sent to storage and is ready for shipment.

2.3. Monthly ticket

AVBV walks through a Supply and Operations Planning cycle each month. Various departments like Production, Global Supply Chain, Industrial Engineering and Planning are involved. In this cycle the demand is reviewed and the production targets of the upcoming month are determined. This cycle starts with the demand planning. AVBV updates the market trend and forecasts the total demand for the upcoming 12 months. Supply Chain Management (SCM) then combines the expected demand and the current stock levels, together with the capacity of the plants to decide upon the demand for the two plants. As a result of this, plant Enschede knows what they will have to produce in the upcoming month. SCM takes this monthly demand and ranks the demand in various criteria. First, the demand is split in three types; Nett requirement, future requirement and stock. Nett requirement is the part of the demand that is to be produced in this month because customers have ordered it. Future requirement is the part of the demand that is needed in future months. The remaining part of the demand are the tyres that are expected to be sold, which will go to stock first. Within these three sections, the prioritisation of the demand is as follows: first OE tyres (tyres that are mounted on cars that come out of the factory), secondly are the all-season and current season tyres, and lastly are the off-season tyres. However, sometimes there comes a request to produce a tyre which has high priority. When this happens, it is put above all tyres in the priority ranking. These are called exceptions. Figure 5 visualises this prioritisation.

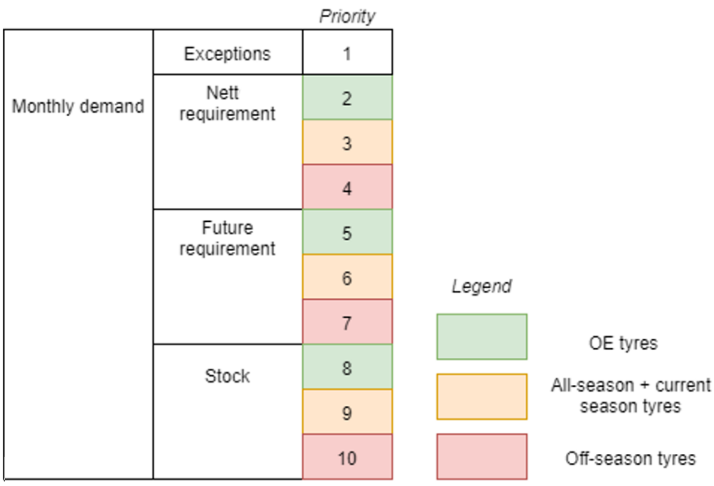

FIGURE 5: PRIORITISATION OF TYRES WITHIN THE MONTHLY DEMAND

Next, the Industrial Engineering Department runs these prioritised SKUs through a program which takes some of the capabilities and constraints of the plant into account. When this is done, they have a list of the expected production numbers of plant Enschede for the upcoming month. This list is called the confirmation. The confirmation is sent back to and reviewed by Supply Chain and applies final adjustments if needed.

The head of Planning makes the curing plan which is derived from the monthly confirmation. The curing plan is fixed for the upcoming two weeks. The two week window is a consideration of the pros and cons of having a shorter or longer fixed curing plan. While fixing it for a longer amount of time is better for the plant since more product series could be combined, it comes with the expense of flexibility. No adjustments can be made on the curing plan when unexpected events like breakdowns occur. Having the fixed window lower than two weeks gives more flexibility, but it can create more complexity because of it. This is due to more possible last minute changes of the plan which results in more changeovers. This can have a negative effect on the intermediate stock because some of the semi-finished products might already be produced and also causes more waste of materials because of the changeovers.

Ticket adherence gives an indication to how the planned production amount compares to the actual produced amount. A good ticket adherence became increasingly important since the scale down. This because it is important to sell every tyre that AVBV can sell, and not produce too much tyres because when they cannot be sold, they are likely to be stuck in inventory or have to be sold at a lower price. The goal is to only produce the tyres that are needed. Ticket adherence takes the sum of the absolute difference between the planned and actual amount of each of the SKUs and divides this by the total planned amount. The aim is to be as accurate as possible, meaning that the actual is the same as the planned amount. When this is the case, the ticket adherence is 100%. See the equation below on how the ticket adherence is measured. *n* is the total number of SKUs in a month and *i* is an individual SKU. Table 3 shows the historical data of the ticket adherence within plant Enschede.

$$Ticket\ adherence = \left(1 - \left(\frac{\sum_{i=1}^{n} |planned_i - actual_i|}{\sum_{i=1}^{n} planned_i}\right)\right) \times\ 100\%$$

Table 3: Ticket adherence

KPI	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Okt-19	Nov-19
Ticket adherence	62%	69%	76%	56%	84%	81%	84%	85%

In both the monthly confirmation of the demand and the making of the curing plan, not all constraints of the plant are taken into account. There are too much constraints within the plant to consider them all, so AVBV made a selection of which ones to include. However, there are still some constraints that are valuable to have insight in that need more research to be included that can contribute to a better ticket adherence.

2.4. Stakeholder analysis

This section identifies the various parties that this research involves and groups these people/teams/departments according to their level of participation, interest and power in the project. Having a stakeholder analysis provides knowledge about how to involve the different parties and how to communicate with them.

Each of these stakeholders has their own level of relevance in this research. Each stakeholder has their own level of interest and power within the research project. (MindTools Content Team, 2016) Figure 6 shows the interest and power of each of the stakeholders mentioned below, and gives us an indication on how to manage them. (Mendelow, 1981)

TOC Project Team – This project is part of the TOC Project Team. This team consists of employees of different production departments such as Industrial Engineering and Planning. The goal of this team is to improve the bottleneck and flow performance and introducing new methods of work and creating a support base.

Industrial Engineering Department (IE Department) – The IE Department is concerned with the optimisation of production processes, systems, capacity calculations, demand, budgeting and more. This department has most of the data that is required in this project available and has insight in what happens within the factory. The IE Department has several engineers that each are responsible for some part of the plant, so when specific questions arise or data is required of a certain part of the production process, the corresponding industrial engineer can be utilized.

Head Planning – The head of the Planning Department makes and adjusts the curing plan. A lot is dependent on how the curing plan is shaped. Head planning receives a list of SKUs that are demanded each month and plans these SKUs in the Curing Department taking various constraints into account. Since Head Planning has a good overview on what effect the curing plan has on the plant, it is a good information source on what problems are useful to solve and finding concrete examples on what could be organised better. Initially, Head Planning is the main user of the implementations.

Shift Planning – Each shift workforce at AVBV has their own shift planner. He does the operational planning of the production departments and manages it throughout the shift. He acts when things do not go as planned and can make last minute adjustments. He is responsible for the operational planning of the plant. This could be a good information source on where systematically things go wrong and how they could be fixed by making better decisions somewhere else.

Operations Manager – The Operations Manager is responsible for what happens in the whole plant and reports to the site manager of plant Enschede. He takes actions to ensure and improve the effectivity and efficiency of the plant. The Operations Manager has the highest power of the stakeholders and thus should be kept satisfied.

Business Team Managers – AVBV divides its big production process in smaller parts called Business Teams. Each of these Business Teams has several experts in different fields available to keep the machines of their business team running. They for example focus on maintenance and constantly improving the processed that are included within the business team. Every team is led by a Business Team Manager. These managers have an overview over what happens within that part of the production and can provide insights into problems that might be useful to address in this research.

Shift Managers – Where the Business Teams are responsible for keeping the production running, are the Shift Managers responsible for the manning and what happens during the shift itself. The Shift Managers makes decisions based on what happens within the plant with the goal to keep the flow performance as high as possible.

Product Industrialisation (PI) – PI investigates the consequences of the introduction of a new SKU and is concerned with the overall complexity within the plant. PI has information available on what machines are capable of, which can be useful to know during this project.

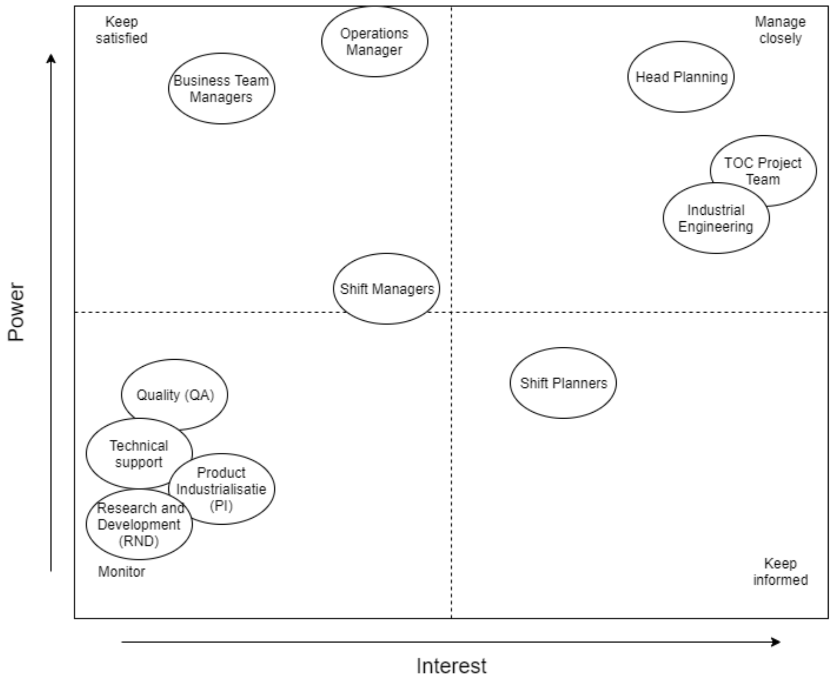

FIGURE 6: OVERVIEW OF STAKEHOLDERS CLASSIFIED BY POWER AND INTEREST (MENDELOW, 1981)

3. Literature review

This chapter discusses the most relevant findings in the available literature. Section 3.1. explains various process improvement methods, including the one used within AVBV called the Theory of Constraints. Section 3.2 presents the results of a systematic literature review about design and implementation methods. This research uses one of these methods to develop a tool. Section 3.3. gives a more in depth literature review about one of the models that is used in the selected method, the Kano model.

3.1. Process improvement methods

This section explains some of the more well-known process improvement methods that are used since the 1970s. Often, there is not one perfect method to tackle the subject of process improvement, thus studying varying methods helps understanding the subject and makes combination of best practises possible. Often best practises of multiple methods are used within an organisation or one method makes the other one whole.

3.1.1. Total Quality Management

Total Quality Management (TQM) is one of the more sophisticated methods that originated out of the 80s. TQM makes a few assumptions where its principles are based upon. The first one is about quality. TQM assumes that the cost of high quality is less expensive than of poor labour and products. This means that the costs of scrap, rework, inspection, loss of customers, etc. are higher than the costs that come with developing and producing a high quality product. The second one is that employees care about their quality of work. As long they are provided with the tools and training to execute quality improvement, they will come up with ideas and initiatives to increase the quality of their product. The third assumption is that businesses consist of very interdependent parts and face central problems that arch over various functional lines. The last assumption is about management. It is the responsibility of the managers that create the organizational systems to commit to and provide the means to improve the quality of the systems. (Wageman & Hackman, 1995) TQM focuses on 4 major areas (Gershon, n.d.):

1. Managerial responsibility for continuous improvement
2. Focus on the work processes to achieve improvements
3. Use of statistics to measure process performance
4. Employee involvement and empowerment

3.1.2. Just-In-Time

Just-In-Time (JIT), or the Toyota Production System, originates from the Japanese car industry and was developed in the 1960s and 1970s. The Toyota productions plants were the firsts ones to implement this method. JIT has 3 main goals (Cheng & Podolsky, 1996):

1. Increasing the organization's ability to compete with rival firms and remain competitive over the long run
2. Increasing the degree of efficiency within the production process
3. Reducing the level of wasted materials, time and effort involved in the production process

JIT is a policy that follows the way how orders are placed at the exact moment they are needed, thus creating an environment which has zero-inventory. Having a zero-inventory policy means that there is no safety stock available to fall back on when any reliability and variability issues occur. This means that the success of the whole production process, especially the links between process steps, relies on its reliability and variability. This is why TQM in addition with JIT can work well, since the dependence on reliability and variability within JIT is addressed by following TQM.

3.1.3. Six Sigma

Six Sigma is a business improvement approach 'that seeks to find and eliminate causes of defects or mistakes in business processes by focussing on process outputs which are critical to the eyes of the customer.' (Antony, Snee, & Hoerl, 2016) The Six Sigma approach is statistically based and very much data driven. This idea comes from the assumption that true customer satisfaction is only achieved when delivered with no errors, high quality, good service and on time. Six Sigma was developed by Motorola in the 1980s. Design for Six Sigma (DFSS), which is further elaborated upon in Section 3.2.3, is derived from the Six Sigma methodology and has its objective set on 'designing it right the first time', meaning minimal design flaws. (Yang & El-Haik, 2003)

3.1.4. Theory of Constraints

As mentioned in Section 1.3, this research is part of a project team that is using the TOC management concept to have a form of continuous improvement. The TOC lives by the idea that a system has very few constraints that limit the performance of it. The TOC provides a 5-step approach to reach higher performance levels. (Trojanowska & Dostatni, 2017) The first step is the identification of the systems component which negatively affects the global performance, the bottleneck. The second step is the exploitation of this process. The running of the bottleneck must be ensured, because every moment it is not running, results in losses that cannot be recovered. The third step is subordinating of everything that is related to the bottleneck. This means aligning the other processes with the bottleneck. This decreases work-in-progress inventory which means more costs. Step four is taken when the bottleneck still persists after the first three steps. This includes increasing the productivity of the bottleneck by for example investing.

The Drum Buffer Rope (DBR) is a planning and scheduling solution derived from the TOC. (Woeppel, 2008) The DBR, like the TOC, assumes that there is a very limited number of processes that control the output of the process. This process is called the Drum. To maximise the output of the system, all efforts should be focussed on exploiting the Drum. This can be done by protecting it against disruptions by the use of a Buffer, which protects the drum's resource from upstream disturbances so that the global output is not affected. The extra capacity of the non-drums contributes to the recover capabilities in such cases. The Rope stands for how new work is released. In the ideal situation, the whole production process is producing at the level the Drum. If other processes work harder, work piles up and inventory between process steps rises.

Because AVBV produces less tyres than they used to, a lot of processes have overcapacity. To manage things, AVBV has put their bottleneck on the last step, the Curing Department. This is partly because they can turn the presses on and off, and it can reflect the real current bottleneck, the demand of the market. According to the DBR and TOC, most efforts should go to the planning and execution of the Drum, which means the Curing Department in this case.

3.2. Design and Implementation method

The findings of this section provides a method of implementing the results of this research. The following sections discuss three different implementation methods found in the literature. Each section explains how the method works and in what situation it is best used in. Section 3.2.4 discusses these methods and selects one that fits this research best.

3.2.1. DMAIC (Define, Measure, Analyse, Improve and Control)

The DMAIC-cycle is a data driven approach to Six Sigma projects for improving processes. This method is generally used throughout the Apollo Vredestein organisation to structure projects. It is often used to improve existing processes by analysing the possible benefits of the project and justifying it through defining the process and making it measurable. (Sokovic, Pavletic, & Kern Pipan, 2010) "*DMAIC is great for streamlining existing processes – taking out the bugs and translation problems between divisions – without too much cost or disruption.*" (Chowdhury, 2003). DMAIC works best when the process is flexible, because then it is possible to eliminate unproductive or adjust existing steps.

3.2.2. DMADV (Define, Measure, Analyse, Design and Verify)

The DMADV is used when a client or customer requires product improvement, adjustments to it or a whole new product or service. The application of the DMADV is aimed at creating a high-quality product while keeping in mind the customer requirements during the whole design process. This process consist of five steps. In the Define step, project leaders identify what according to them is most important to the customer through for example historic information and customer feedback. In the second phase are the data collection methods defined and how they are used to drive the rest of the process. In third phase, everything is put together and analysed to set up a solution and make the final adjustments. In the design phase, the solutions found in the previous step are tested and compared with the set customer requirements. The last phase is an ongoing process of listening to the customer feedback and reviews. These can be used to make improved version of the product. (Selvi & Majumdar, 2014)

3.2.3. ICOV (Identify, Characterise, Optimise, Validate)

The ICOV method are the steps out of the Design for Six Sigma philosophy. The ICOV provides several steps within phases that relates to designing a product, process, tool or solution, like identifying the customer, gathering a voice-of-customer list, translating this list into a variety of requirements, design and performance analysis, design tools and other. In the following section addresses the phases and steps in the ICOV method, as described by Yang & El-Haik. (Yang & El-Haik, 2003)

Phase 1: Identify requirements (I) – This phase consist of two steps. The first step analysing the current situation and the general field of work. This has many similarities as most other first steps in methods, like scoping and identifying stakeholders. The second step is identifying the customer and business requirements. In this step the customers are identified and their needs and wishes collected. These needs and wished then need to be analysed to determine the set of critical-to-satisfaction (CTS) or the customer requirements. The Kano Model is a possible tool to use in this step, which is discussed in Section 3.3.

Phase 2: Characterize design (C) – This phase consist of a total of three steps. The first step is translating the CTSs into product/process functional requirements. The CTSs give idea about what the customer wants, but they cannot be used directly as requirements for the product or process that is to be designed. The second step is generating design alternatives. After the determination of the functional requirements, several design should be made that fulfils these requirements as best as possible. The last step is evaluating these designs and determine with what design we continue to the next phase.

Phase 3: Optimize the design (O) – In this phase the selected design is optimized and tuned so that it fits all the functional requirements, and thus the CTSs that were set by the customers. Computer simulation or hardware testing or other methods can help optimizing designs.

Phase 4: Validate the design (V) – The last phase consists of three steps. The first step is pilot testing and refining. No product or service should be immediately used. It should be tested for possible mishaps and evaluate the real-life performance. The next step is validation and process control. The end result is validated in this step to make sure it meets the design requirements. The last step is the rollout and transfer of ownership. Since the design is validated and ready for use, it is time to transfer ownership and knowledge of the project to the users in the last step.

3.2.4. Discussion

All of the three methods mentioned above have several steps to create or improve various products, processes or solutions. The DMAIC is more focused on improving existing processes, which is not very relatable to this research since here we look for new insights that can be implemented. Both the DMADV and ICOV use steps to develop a new product, process or solution. Not much of the DMADV can be found in the existing literature, whereas Yang & El-Haik provide a clear overview of the method, which is summarised above. We recommend using the ICOV method to implement the insights.

Throughout this research we will use the ICOV in two different ways. The first one is during the general design of the tool and the other is during the design and implementation of the separate insights that will be added to the tool. In the general design we walk through the first two stages of the method. These requirements and design is taken into account when designing and implementing the separate insights into the tool. For each individual insight, we walk through the first three stages of the ICOV before starting to implement the next insight. We keep validating the existing insights of the tool throughout the project and after since this important to find possible bugs and make necessary adjustments.

3.3. Kano model

In the second step of the first stage of the ICOV, the customer requirements are gathered. Customer satisfaction was used to be seen as a mostly one-dimensional construction; the amount of quality of the product results in the amount of customer satisfaction. However, fulfilling the individual product requirements to an extensive level does not necessarily go hand in hand with a high customer satisfaction. The type of the requirement also has influence on the perceived product quality and thus the customer satisfaction. The Kano model distinguishes three different kind of customer requirements; Must-be, One-dimensional, and Attractive requirements (Sauerwein, Bailom, Matzler, & Hinterhuber, 1996). Below we discuss each of these requirements and their impact on the customer satisfaction. Figure 7 give a summary and a visual representation of the impact of the different requirements.

Must-be requirements – These are the basic requirements of the product. If these requirements are not fulfilled, the customer will be extremely dissatisfied. The fulfilment of these requirements does not lead to an increase of satisfaction. The customer takes these requirements for granted and does not explicitly ask for them. If these criteria are not met, the customer will not be interested in the product at all.

One-dimensional requirements – With these type of requirements, the customer satisfaction is proportional to the level of fulfilment. The higher level of fulfilment, the higher the customer satisfaction. These requirements are often explicitly demanded by the customer.

Attractive requirements - These requirements are the ones which have the greatest influence on how satisfied a customer will be with a certain product. These requirements are often not explicitly requested nor expected by the customer. Fulfilling these requirements will result in a more than proportional satisfaction of the customer. Not having these requirements does not causes any dissatisfaction.

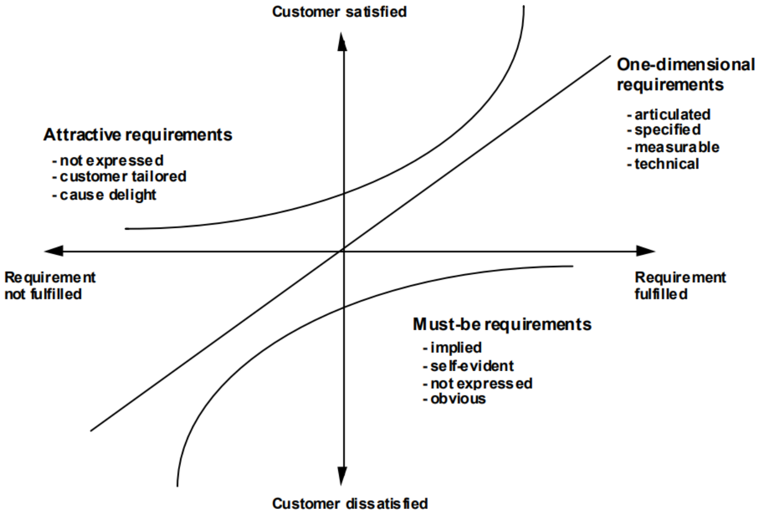

FIGURE 7: RELATION OF FULFILMENT VS SATISFACTION OF THE THREE REQUIREMENT TYPES (SAUERWEIN, BAILOM, MATZLER, & HINTERHUBER, 1996)

Some of the main advantages of using the Kano model are; ability to set priorities during product development, requirements that are better understood and it can provide help during trade-off situations. It is more easy to prioritise requirements during development. For example, it does not have much use to develop an already sufficiently implemented 'Must-be' requirement while there are several Attractive requirements on the list that are not yet started. Also, each of the requirements are analysed more thoroughly and this creates a better understanding of the individual requirements and what they are supposed to add to the product. Lastly, using a Kano model can help when trade-off situations arise. For example, when two requirements cannot be met simultaneously due to some reason, the designer can look at the results of the Kano model to determine which of the two has the most impact on the customer satisfaction which result in making the correct decision.

4. Insights

In this chapter we discuss insights that are required by the stakeholders. Firstly, a rough list of possible insights that were found is presented. In the following section we set up various criteria that will grade them. These are analysed and graded on various criteria resulting in a list of prioritized insights. These insights are also addressed individually on aspects like data availability and complexity. This list of insights is used in the following chapters where the visualization/dashboard/setup is described and in the implementation of these insights.

4.1. Gathering insights

In Section 3.1.4 we discussed the Theory of Constraints and specifically the Drum Buffer Rope solution and the fact that AVBV has the Curing Department as their current bottleneck, the Drum. As discussed before, there are several ways to improve the overall performance of the system. The DBR states that the planning should focuses on exploiting the Drum. With the research scope on the planning, we looked for insights that can be used during the planning process to increase its quality. We looked for insights that had a possible effect on the capacity of the Drum, the Buffer and the Rope of the system.

Table 4 shows a collection of insights that are the result of engaging with the stakeholders and doing interviews with them. Having these insights during the planning process of the Curing Department should have a possible effect on the Drum, Buffer and/or Rope. The sections below the table further explain these insights. Insights that are related to manning are left out, since this is not within the scope of this research. One of the goals is to improve the quality of the plan, where then in turn the manning is based on.

Table 4: Possible valuable insights

Number	Insight
1	Merging production series in Building Department
2	Intermediate stocking resources
3	Load on Building Department resulting from the monthly ticket
4	Distribution of load on bead machines
5	Difference between calculated and recent machine performance
6	Availability equipment for building machines
7	Impact curing time of a tyre on Building Department
8	Mould usage Curing Department

Below are the individual insights generally explained. The explanation addresses how the insights work, what they add, and how they have a positive effect on the Drum, Buffer and/or Rope.

(1) Merging production series in the Building Department – In the Building Department, all the semi-finished products are brought together to make a greentyre. Next, the greentyre is sent to the Curing Department, where it is cured in a hot mould. Some of the SKUs that come out of the Curing Department and have *different* moulds, have the *same* greentyre. This means that while they are planned as a different SKU in the system, the building of the tyre is exactly the same. Planning these SKUs with the same greentyre together, decreases the load on the building machines, since they can keep producing the same greentyre for a longer amount of time, which saves changeovers and increases the productivity. This also has a positive effect on the Buffer, since it decreases the load on the process before the Drum.

(2) Intermediate stocking resources – To use and store semi-finished products, various kinds of stocking resources like racks and cassettes are used throughout the plant. Many of these stocking resources are abundant since the downscale of production, however some of them are not and need close management to prevent disturbances. Right now, the curing plan is checked if it does not overload some of these resources. When it does, the plan is changed. Having and accurate insight in what stocking resources are available to use and what the expected load on these resources is with a certain monthly ticket prevents unnecessary disturbances because lack of storage possibilities. This has a positive effect on each process of the system.

(3) Load on Building Department resulting from the monthly ticket – The Building Department, which is the process step that produces the Buffer, has an overall overcapacity. However, if the product mix of a monthly ticket is balanced in such a way that certain machines are over requested, it cannot deal with the demand. This recently became more relevant since more machines are being shutdown, which reduces the overall capacity and makes the department even more susceptible to the impact of the monthly ticket and the planning of it. This insight has a positive effect on the Buffer.

(4) Distribution of load on bead machines – There are two bead machines which have, like the building machines, different specs. Now, it occurs that during one period of the month, one of the machines produces at its max capacity and the other is not, while during another period within the same month, the roles are reversed. Taking the load on the bead machines into account during planning helps by distributing the load evenly throughout the month, and thus being less susceptible for disturbances that can lead to loss of Buffer.

(5) Difference between calculated and recent machine performance – Each of the machine within AVBV has a calculated performance. These are used to determine if a certain machine can handle the demand, and what time is needed to meet it. However, sometimes this differs from the performance the machine recently has achieved. Knowing the difference between these two decreases the risk of taking the wrong decisions, especially on an operational level.

(6) Availability equipment for building machines – Building machines need various equipment to be able to produce. Some of this equipment is not available at all times, for example when it needs maintenance. Knowing what equipment is available or not in the planning process, prevents unalignments between production and planning. This means a better alignment between the plan of the Drum and the rest of the plan, and improving the Rope.

(7) Impact curing time of a tyre on Building Department – Each type of SKU has his own curing time. Bigger tyres take longer to fully cure than smaller ones do. This means that having a batch of tyres that has a relative low curing time, puts a higher load on the Building Department than tyres with a relative high curing time. This difference in curing time can lead to either a bigger than necessary, or a critical buffer. Having the impact of the curing time of the tyres within the plan increases the quality of the buffer and helps managing the rope.

(8) Mould usage in Curing Department – The Curing Department uses moulds to cure the GTs into finished tyres. Some SKUs, which have different GTs, use the same mould during the curing process. This means that if not planned correctly, SKUs have to 'wait' until the mould it is supposed to be cured in is free to use. Having an overview of SKUs which share moulds and the required utilisation of a mould during the month, assists decision making and can increase the capacity of the Drum, since there is less risk of overlap. This also improves ticket adherence because it can decrease the amount of difference between the produced and planned amount.

4.2. Prioritizing insights

The insights need prioritisation, as a selection is needed because not all of them can be implemented without taking actions first. It is best to start with implementing the most valuable insight, which is determined by finding out which ones are the most 'efficient', which means weighing up the impact versus the effort. The higher the impact and lower the effort, the more attractive the insight is to implement. These insights are prioritised by an in total of three criteria. The criteria that are used in this case are discussed and agreed upon by talking to the most important few stakeholders of the project. The criteria used are the following; Data availability, complexity and impact.

Data availability is considered in this process, because it affects the implementation of the insight a lot. Ideally, the data is already available and only the data has to be linked. In other cases, the data might not be available yet, which could be a lot of effort to gather, or not possible in the current state of the company. The next criterium is complexity. The complexity is based on the combined presentiment of the stakeholders and the individual analysis of each insight. When the complexity is low, less effort is needed to implement the insight than when the complexity is high. Next, the impact of having the insight implemented is considered. This reflects how 'useful' it is to have the insight implemented and how high the expected impact is on improving the performance and ticket adherence, based on prior experiences where the insights were not available and not considered in the decision-making. Lastly, there is one criterium which is a show-stopper. A showstopper is an obstacle to further progress. This means that when the insight meets the criterium, it cannot be implemented within this research. This means that the insight is based on the curing plan instead of the monthly ticket. The tool will analyse the monthly ticket, and not the curing plan during the month. Thus having insights that rely on the plan, cannot be further pursued in this research. Note that this does not mean the insight is not valuable.

Table 5 shows how the insights are grades according to the previous mentioned criteria. Each of the criteria can be graded with a **1**, **2, 3, 4** or **5**, where the 5 means that its good for the acceptability of the insight, and a 1 means it is bad. For example, a **5** at complexity means that it is not that complex, thus it is good for the 'efficiency' of implementing the insight. **3** at data availability means the data is somewhat easy accessible, but needs some work and a **5** at impact mean it has a high impact on the overall goal. Data availability and complexity both have a weight of 1 with respect to the total score, where impact is weighed as 1,5. This is because impact is seen as more important than the other two criteria in the eyes of the stakeholders. The value true in the show stop column means that the according insight cannot be implemented in this research because of the previous mentioned reason.

Table 5: Prioritization of insights

Number	Data availability	Complexity	Impact	Score	ShowStop
Weight	**1**	**1**	**1,5**	**Total**	
1	**1**	**4**	**5**	12,5	FALSE
2	**3**	**5**	**2**	11,0	TRUE
3	**3**	**5**	**4**	14,0	FALSE
4	**4**	**4**	**3**	12,5	TRUE
5	**1**	**3**	**5**	11,5	FALSE
6	**2**	**3**	**4**	11,0	FALSE
7	**5**	**4**	**3**	13,5	FALSE
8	**3**	**2**	**5**	12,5	FALSE

4.3. Individual analysis of insights

Table 5 shows the insights that are possible to implement considering the scope and their individual score. Due to mainly time limitations, not all of the insights can be implemented. This is why we make a selection of three implementations based upon which insights score the highest and on a consultation with the more important stakeholders. In this consultation we decided that the main goal of the tool is supporting the Head Planner in the making of the curing plan. Therefore, we choose the insights that are specifically relevant for the main user, the Head Planner. Section 4.3.1 to 4.3.3 describe three implementations and their according insights in more detail and how the Head Planner can use it to optimize the curing plan.

4.3.1. Merging of product series in the Building Department (insight 1)

As mentioned in the small description of the insight, there are SKUs that use the same greentyre. There is a high chance that there are different SKUs listed in the monthly demand that use the same greentyre as another in the same month. Usually, each of the SKUs are planned individually, which means that it is possible that the same greentyre is produced in different times of the month. Especially when it is produced in small amounts makes this an inconvenience because the same tyre is built during different times within the month. Planning these SKUs in the same time window in the curing plan, reduced the load on the Building Department because unnecessary changeovers are evaded. This even has a positive effect on the load of the machines that produce the semi-finished products, since the orders can also be clustered, to decrease load. Presenting SKUs that can be clustered to the Head Planner during the making of the curing plan, he then can decide to act and possibly make a better plan that lowers the load on the Building Department. Table 6 shows how many different SKUs have more than one other SKU that has the same greentyre, and in how many greentyre groups these SKUs could be clustered in during the past four months.

Table 6: Overview possible changeover savings by clustering productseries

Month	Dec-19	Jan-20	Feb-20	Mar-20
Number of SKUs	53	25	33	29
Number of possible GT clusters	25	12	16	14

To implement this insight, we need the following information: what greentyre a SKU uses and the SKUs which are needed to be produced in the upcoming month. The demand is available on a monthly basis. The greentyres used in the SKUs are also available in the bill of materials which is kept up to date regularly.

4.3.2. Load on the Building Department (insight 3)

The Building Department is the step in the process which makes the Buffer for the curing department. In this department, all the semi-finished products are combined into a greentyre. AVBV has many different SKUs within its assortment that can differ a lot from each other. For example, the inch size of a tyre produced at the plant in Enschede can vary from 14 to 24 inch. The Building Department has three type of machines: automatic, semi-automatic and MAX.. Figure 4 in Section 2.2.3 gives an overview of the machines that AVBV has and uses. MAX. machines are also semi-automatic building machines, but are more modern and produce more efficiently. The most productive machines are the automatic ones. However, these can only produce 13 to 16 inch tyres, where the 13 inch tyres are not made in plant Enschede anymore. Due to the decrease in production, and the movement to producing more bigger inch tyres, AVBV recently decided to stop the usage of the automatic building machines that were located on a premises close to plant Enschede. Now the overcapacity is drastically reduced and no transport of semi-finished products, greentyres and others between the plant and the premises is needed. However, due to the reduction of machines, it becomes more important to align the Building with the Curing Department to prevent overloading the Building Department and take the product mix of the monthly ticket in account during the planning process.

To gain more insight in the effect of the monthly ticket on the Building Department, we can link the specs of the building machines to the product mix. Due to time limitations, we look at the load on the automatic building machines. It is ideal to know the whole load of the product mix on all the building machines. However, this becomes rather complex since in some inch-size groups, there is a lot of overlap between the possible building machines.

AVBV currently has 3 automatic building machines in use, where two of them are close to identical. It is useful to know what is expected of these machines during the month, based upon the product mix of the demand. This can be compared with what is the standard performance and even the recent performance. Having this information helps with the decision making in the planning.

4.3.3. Load on moulds in Curing Department (insight 7 & 8)

Each month there are many different SKUs that are demanded each month. Some SKUs are needed in large quantities (10,000+) and some are demanded by the lowest production amount, which is currently set on 600. When the quantity is large, the tyres are in production for a long time. Each SKU has one or more moulds available where the green tyre can be cured in. Often there are more moulds of the same type, so several curing presses could produce the same tyre. The current policy is that normally, each mould that is available is used at the same time to cure the tyres. This is to minimize the number of SKUs that are in production at a time. However, there are SKUs that use the same mould. This has to be taken into account while planning, so no more moulds are planned than that can be used. The idea of the monthly ticket is that all the SKUs are produced within the upcoming month. It is not intended to schedule a SKU for production late in the month, while it needs a lot of production time. This results in not having the targeted amount at the end of the month. This is why it is useful to have insight in how many tyres of individual SKUs could be produced in a certain amount of time. Having this information indicates the minimum amount of time needed to have the SKU in production to reach the target amount.

The data needed to implement this is: knowing what SKUs are made in which moulds, how many of each mould group is available, the average curing time per SKU and possible interference between SKUs and available moulds. This data is available. Also, a list of moulds that are currently out of use is needed to make sure no moulds are taken into account in the calculation while they are not available. However, this data is not immediately available. This makes it a point of interest to make it available to create a more accurate calculation of the load on the moulds.

4.4. Conclusions

In this chapter we found a total of 8 possible insights that can contribute to getting a better understanding of the impact of the monthly ticket on the plant Enschede. 6 of these insights are feasible for implementation in the tool considering its purpose. However, due to mainly time limitations we chose to start implementing 4 insights processed into 3 separate implementations. We found these 8 insights by analysing the current situation and by consulting various stakeholders. We then made a prioritisation of these insights to determine what insights are feasible for implementations and give an indication on the implementation order considering the data availability, complexity and impact. These results are based upon the in-depth analysis of the individual of the insights and consultation with key-stakeholders. In this session we decided that the main user of the tool will be the head of planning. This because making better decisions during planning results in better flow performance what results in a better ticket adherence. The 4 selected insights, which can be divided under 3 implementations, are further explained by looking what is needed to implement them and how they can be used to improve the curing plan. Table 7 gives an overview of the findings of Chapter 4.

Table 7: Findings overview of Chapter 4

Insight Nr	Insight	ShowStop	Score
3	Load on Building Department resulting from the monthly ticket	FALSE	14,0
7	Impact curing time of a tyre on Building Department	FALSE	13,5
4	Distribution of load on bead machines	TRUE	12,5
8	Mould usage Curing Department	FALSE	12,5
1	Merging production series in building department	FALSE	11,5
5	Difference between calculated and recent machine performance	FALSE	11,5
2	Intermediate stocking resources	TRUE	11,0
6	Availability equipment for building machines	FALSE	11,0
Impl. Nr	**Implementation**	**Insight Nr**	
1	Merging of product series in the Building Department	1	
2	Load on the Building Department	3	
3	Load on moulds in Curing Department	7 & 8	

5. General design of the tool

This chapter walks through the first three steps of the ICOV method described in Section 3.2.3 to design the tool that contains the three implementations of Chapter 4. Section 5.1 explains the first step where we look for customer requirements using the Kano model. In Section 5.2 we turn these customer requirements into product requirements and Section 5.3 shows the results by showing and briefly explaining screenshots of the design of the tool. Section 5.4 summarises and concludes this chapter.

5.1. Identifying requirements (I)

The first step, drawing the project charter, of this stage of the ICOV is already executed which is the stakeholder analysis and the scoping of the project. The stakeholder analysis found in Section 2.4 and the scoping of the project in Section 1.4.3. Combining these two and the research objective, we know the general goal of the tool. After consulting the most important stakeholders and (potential) users by means of interviews and discussions we come up with a set of CTSs that are found in Table 8. The section below the table explains each of the CTSs. Having the set of CTSs concludes the first stage of the ICOV and we continue with the second stage.

Table 8: Customer requirements tool

Nr.	Customer requirement (CTSs)	Type of requirement
1	Results of the tool	Must-be
2	Usability within organisation	Must-be
3	Amount of errors	Must-be
4	Simplicity of the tool	One-dimensional
5	User-friendly	One-dimensional
6	Level of automation	One-dimensional
7	Layout	Attractive
8	Waiting time tool	Attractive
9	Maintainability	Attractive

5.2. Characterising the design (C)

In this stage we try finding the product requirements that positively contribute to the customer requirements by engaging with various stakeholders and researching available sources. First, we discussed the customer requirements and brainstormed to find the most important product requirements during a workshop with some of the stakeholders. Not all of the customer requirements are directly applicable on the function of the tool, so the sections below each address one of the CTSs individually and explains the product requirements. Table 9 gives a summary of the product requirements of the tool.

(1) Results of the tool – The results that come out of the tool is the most important requirement and is therefore of the type Must-be. The three implementations of Section 4.3 are expected by the stakeholders to be implemented in the first working version of the tool.

(2) Usability within organisation – The next Must-be requirement is that the tool must be usable throughout the organisation. This means that the user can understand the tool and the tool must fit in the IT landscape AVBV currently has. This customer requirement can be fulfilled by the following three product requirements. The first one is having a connection with the AVBV database. AVBV has a database with a lot of different data like SKU specs, lead times, etc. This data is regularly updated, which means that when the tool is run, it should update the source data to make sure that the results are most accurate. The next product requirement is that the terminology within the tool should match the one that is used within the organisation. This contributes to the understandability and results in less effort needed to create an understanding of the tool. The last product requirement that fits within this CTS is that the tool should be made in Excel and VBA. The main users of the tool use Excel a lot and the source data that is required is easily accessible using Excel. Making the tool in another program is unnecessary since the possibilities of Excel fit with the purpose of the tool.

(3) Amount of errors – The tool must have no run errors. Especially since the tool is not used by the person that makes it. It is hard to fix errors within code that is written by someone else.

(4) Simplicity of the tool – The tool should be simple to use and require low effort to work. It should give clear insights that can contribute to better decision making during the planning process. This can be achieved by having a minimalistic design with minimal distractions and having purely necessary info presented. Also having graphical aid in the form of graphs or colours helps with having a quick understanding of the results.

(5) User-friendly – The tool should be user-friendly which means that it should be easy to use. This mainly strikes the interface of the tool. The following four common attributes are often found in user-friendly interfaces: simple, clean, intuitive and reliable. (TechTerms, 2014) Concretely this means that the interface should not contain any unnecessary information, have a brief explanation and make sense to the user by making it like the other tools AVBV uses.

(6) Level of automation – Since the goal of the tool is to help during the decision making during the planning process, it should provide the users with valuable insights while needing minimal input from the user. Having a high level of automation lowers the threshold to use the tool and lowers the amount of time needed from the user that he then can use on other things like making the planning itself. The user should only fill in the necessary variables and press one button to make the tool work.

(7) Layout – Having a good layout is an attractive requirement since it does not contribute to the results of the tool, but it can create a delightful effect and it should be customer tailored, meaning it should fit the house-style of AVBV. (Sauerwein, Bailom, Matzler, & Hinterhuber, 1996) AVBV already has a lot of tools where the layout can be taken from.

(8) Waiting time tool – The tool needs time to make the calculations since it has to handle a lot of rows of data within multiple sheets. However, through smart programming we can limit the run time needed. (Hans, 2019) Also, according to the Microsoft Design Guidelines a progress bar should be shown during processes that take more than two seconds so users are aware of response times longer than one second. (Microsoft, 2018) Progress bars should be implemented even when the representation of the bar does not perfectly represent the real progress. The Nielsen Norman Group, a group that does research on user-based experiences, states that when the waiting time is longer than 10 seconds, the progress bar should be supported with percentual or textual explanation of the progress. (Sherwin, 2014) Because the tool might run longer than 10 seconds, a progress bar with textual explanation fits the tool perfectly since it can track in which stage the tool is for example loading source files or writing down the results.

(9) Maintainability – The tool is supposed to be designed that it can be updated and more insights can be added to after this research. Therefore, making the back end of the tool tangible and clear for others so it can be easily expanded. Martin Fowler, a software developer, states that "Good programmers write code that humans can understand.". (Fowler, Beck, Brant, Opdyke, & Roberts, 1999) Various things can be done to achieve this like: Using the same definitions throughout the code making it uniform and re-usable and making explanations & comments on how various parts of the code work.

Table 9: Product requirements	
CTS NR	**Program requirement**
1	Implementing the three described insights
2	Connection between AVBV database
2	Terminology of AVBV
2	In Excel and VBA
3	No errors while running tool
4	Minimalistic design
4	Graphical
5	Few buttons
5	User instructions
6	Minimal input needed from user
7	Design in Apollo house style
8	Efficient code
8	Progress bar
9	Clear definitions in code
9	Re-useable code
9	Explanation how code works

5.3. Optimize the design (O)

In this section we try combining and implementing these product requirements in the tool. We choose to use one sheet per implementation to show the results and one dashboard in the tool. This means having a total of four sheets that are usable. There are other sheets in the tool, but they are required for doing the calculations. In the following sections we address each of the four sheets briefly. Note that most of the numbers are whitened out or dummy data is used because of confidentiality.

Sheet 1 – Dashboard The first sheet in the tool is the dashboard. Figure 8 shows the design of the dashboard. The dashboard contains roughly three different points of interest. The first one is the general description of the tool and how it works. The second part is the input section. Here the user can select the month that is to be analysed and adjust the input variables if necessary. The last part gives a very brief summary of the monthly ticket about some interesting values like the distribution over the inch sizes. This dashboard is designed in a way that takes point 5 and 7 of Section 5.2 into account. This design is simple, as there are no unnecessary distractions and uses the colours of AVBV.

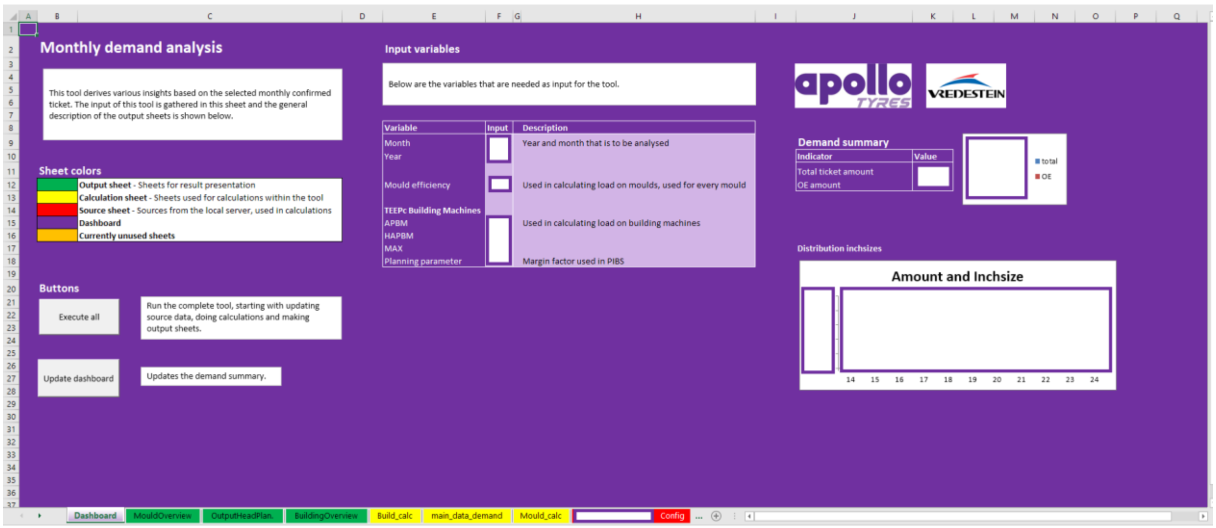

FIGURE 8: TOOL: DASHBOARD

Sheet 2 – Overview Mould Capacity The second sheet gives a rough estimate of the load on the different moulds that can be used in the Curing Department during the upcoming month. This sheet refers to the insight of Section 4.3.3. Figure 9 shows the overview of the mould Capacity. This table does not perfectly represent the capacity of each mould because often several SKUs can be cured. This means that often SKUs can be re-allocated amongst different moulds to make the plan fit within the month. However, having this rough estimate provides an overview of the moulds that can be critical or need special attention during the planning. Note the red bar, which indicates the moulds that might need special attention. The orange bar gives an representation of time that the mould is in use during the month. Pressing on the + buttons shows the SKUs that are can be cured in that mould. Having this feature enables seeing what SKUs can be shuffled around which help making the curing plan fit within the used timeframe.

Row Labels	SKU	Values Sum of dem/nr.m	Sum of Capacity
			115,8811004
			115,8811004
			108,5190939
			102,0776517
			102,0776517
			97,43833017
			96,44366719
			96,29146526
			96,29146526
			94,0875
			92,67117249
			92,00608319
			92,00608319
			92,00608319
			92,00608319
			89,99456327
			89,99456327
			86,78870339
			86,78870339
			84,76347512
			84,18221013
			82,92657068
			77,89547755
			73,41417038
			73,12713057
			73,12713057
			72,48546047
			69,60697071
			69,60697071
			69,09023917
			66,47551365
			65,33172017
			64,15910425
			64,15910425
			63,77694086
			61,04357379

FIGURE 9: TOOL: OVERVIEW MOULD CAPACITY

Sheet 3 – Overview mergeable product series The third sheet is an overview of the monthly demand and the SKUs that use the same greentyre, meaning that they could be clustered to reduce load on the building department. This sheet refers to the insight of Section 4.3.1. Figure 10 shows this sheet. These groups that possibly can be clustered, are put in a greentyre group and highlighted next to the demand overview. This sheet is designed this way because it reflects the sheet the Head Planner is working in and makes notes in. This way, the usual way of business is minimally affected, making it user-friendly, and still provides information. For example, there is still room for notes next to the demand.

FGCode	last deployed dat	Demai	Greentyre Grp.			Greentyre Grp.	Frequent coccuring GTs	Total Demand GT	SKU1	SKU2	SKU3
SKU1		10000	1			1	GT1	19000	SKU1	SKU5	SKU24
SKU2		9000				2	GT2	11000	SKU8	SKU18	
SKU3		8000				3	GT3	9000	SKU9	SKU21	
SKU4		8000				4	GT4	8500	SKU13	SKU25	
SKU5		8000	1								
SKU6		8000									
SKU7		8000									
SKU8		8000	2								
SKU9		8000	3								
SKU10		7500									
SKU11		7500									
SKU12		7500									
SKU13		7500	4								
SKU14		3000									
SKU15		3000									
SKU16		3000									
SKU17		3000									
SKU18		3000	2								
SKU19		3000									
SKU20		1000									
SKU21		1000	3								
SKU22		1000									
SKU23		1000									
SKU24		1000	1								
SKU25		1000	4								

FIGURE 10: TOOL: MERGEABLE PRODUCT SERIES

Sheet 4 – Overview load on automatic building machines (APBM)

The last sheets gives an overview of the estimated load on the automatic building machines. This sheet refers to the insight of Section 4.3.2. With this information available, AVBV can act on it by for example giving more attention to increase the output when necessary, or even decide to shut the machine down for a portion of the month when the load is low. Figure 11 shows the last information containing sheet of the tool.

	A	B	C	D	E
1		14 inch	15 inch	16 inch	Total
2	Load	30000	25000	23000	78000
3	Capacity	35000	30000	30000	95000
4					
5					
6					
7	Total use APBM	82%			

FIGURE 11: TOOL: LOAD ON BUILDING MACHINES

5.4. Conclusions

In this chapter we used the ICOV method, with support from the Kano model, to design a tool that can be used to make better decisions during the planning process by providing various insights that can be derived from the monthly ticket. First, we found a total of 9 customer requirements and classified them according to the Kano model into three type of requirements: Must-be, One-dimensional and Attractive. Using the Kano model turned out to be quiet useful because it clarifies the approach that needs to be taken to meet the requirement and gives them an order of importance. Also, using this method to develop a tool gives a structure to the developing process. Then, by having a discussion with stakeholders and consulting the available sources, we turned these customer requirements into product requirements. By knowing these product requirements and the three implementation that are discussed in Section 4.3, we designed a tool that is ready for the last step of the ICOV method, the Validation, which is not extensively done in this research. Note that the tool in its current state is subject to change during and after the validation. In the future, some of the calculations can be changed, the design improved and more insights added.

6. Conclusion

In this chapter we conclude and reflect upon this research. Section 6.1 covers the main conclusions made throughout this research. Section 6.2 addresses the limitations of this research and Section 6.3 shows the recommendations resulting from the experiences and results.

6.1. Conclusions

To improve ticket adherence, we developed a tool that shows relevant insights based on the monthly ticket that contribute to better decision making. To achieve this, we set a total of three research objectives. In this section we answer the main research question:

> *How can Apollo Vredestein B.V. gain more insight in the impact of the monthly ticket and its product mix on the plant to improve ticket adherence?*

The first objective was to analyse the current situation and how the ticket adherence could be improved. We found that during the confirmation of the monthly ticket and making of the curing plan information was missing to make optimal decisions. Most of the constraints were taken into account in these processes, but there was room for improvement. We came to the conclusion that developing a tool that provides its users with information that contributes to better decision making during these processes eventually improves ticket adherence.

The next objective was to find insights that ought to be useful to have that were not taken into account during the planning and confirmation process before. We found a total of 8 possible insights that can contribute to a better ticket adherence, and decided to start implementing 4 of them. We used our knowledge about various process improvement methods, especially the Theory of Constraints and its Drum Buffer Rope concept, and consultation with the stakeholders to find, describe and justify these insights.

The last objective was to find a method to develop a tool that can be used to use these insights and use this method to make a tool that can be expanded and improved after this research. We used the ICOV method with the assistance of the Kano model to find customer requirements and turn these into product requirements of the tool, as explained in Section 3.2 and 3.3. We learned that using this method to develop a tool creates structure in the design process and assists in the prioritisation and approach of the customer & product requirements.

6.2. Limitations

This section explains the limitations of this research. Recommendations that come with these limitations are discussed in Section 6.3. A limitation of this research is the fact that most of the information about the insights is gathered in a qualitative way. A lot is based on experiences of various employees and is not much quantitatively supported. This can be a limitation because a stakeholder can say an insight has a very high impact, but in reality the impact is not as high. To minimalize the risk to start implementation on something that has limited impact, we discussed it with other stakeholders as well.

The first limitation of the tool is that it currently looks at the monthly ticket and not the curing plan. Therefore, some of the insights that seemed interesting could not be implemented. Another limitation of the tool in its current state is only validated to some extent. This means that there could still be some bugs in it and it can have design flaws because it is not extensively used yet. One more limitation of the tool is the maintainability. Although effort was put into the maintainability of the tool because it was a customer requirement, it is still hard for others to build upon others programming work. This could interfere with the intentions of it being a dynamical tool which can be continuously improved.

6.3. Recommendations

In this section we present an overview of the recommendations of this research. We categorize the recommendations in three sets. The first set being the recommendations that are directly related to the results of this research.

- We recommend using the tool made in this research to gain extra information during the planning process to improve decision making. Especially when the planning is made by an employee who has less experience with regard to making the curing plan, like a substitute. This is because the tool can show insights that can be overlooked while making the plan. This can help evening out the load on the plant and creating an improved alignment between the Curing and Building Department.
- We recommend taking the customer & product requirements as shown in Sections 5.1 and 5.2 into account when updating and/or expanding the tool. However, when adding new insight or functionalities to the tool, new customer and/or product requirements may arise. So it is important to keep this list up to date to ensure the quality and usability of the tool.

The second set of recommendations originate out the limitations of this research and contains some recommendations for future work.

- We recommend before implementing a new insight, to justify it with some kind of quantitative arguments when possible. Fully implementing an insight can take up a considerable amount of work, and it would be a dismay when the impact turned out to be lower than expected.
- We recommend to validate the tool before completely trusting on its results. Bugs within the code can occur and inaccuracies within the calculation can be present. Note that the tool is useable as it is, but the results should not mindlessly be adopted for they might be incorrect or incomplete.
- Currently, the tool looks at the impact of the monthly ticket that is why we recommend looking into the possibility of developing a way to analyse the curing plan. We found some insights in Section 4.1 and 4.2 that seem interesting, however could not be implemented in this tool. There might be more interesting information that can be derived from the curing plan.

The third set of recommendations contains additional recommendations that we gathered throughout this research.

- We recommend looking into if the source files can be kept up to date. During the development of the tool we found that some of the source files were not up to date, for example a SKU was in the monthly ticket, however was not added to the bill of materials yet.
- We recommend uploading the monthly ticket onto the central file server, like the source files, to make sure that employees who are interested can use the tool. We also recommend using the explained format since it does not interfere with the IT department, who also uses the monthly ticket for PIBS, and the tool itself.

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