# Improving the alignment of the AGRI production process at Apollo Tyres Ltd.

Bachelor Thesis



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APOLLO TYRES LTD | UNIVERSITY OF TWENTE.

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Bachelor thesis

This report is written as bachelor thesis of the study Industrial Engineering & Management at the University of Twente.

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# PREFACE

Dear Reader,

This bachelor thesis "Improving the alignment of the AGRI production process at Apollo Tyres Ltd." concludes my bachelor in Industrial Engineering and Management at the University of Twente. From February until August 2023 I conducted this research at the Industrial Engineering department of Apollo Tyres Ltd. to find a way to improve the alignment of the AGRI production process. This assignment was very interesting and provided good insight into the role of an industrial engineer in a production environment.

I would like to thank Apollo Tyres Ltd. for giving me the opportunity to cooperate with them and their willingness to support and guide me during the performance of this research. I want to thank all my colleagues at the Industrial Engineering department and Planning department for their continuous collaboration and support in gathering the necessary information. More specifically, I want to thank Mark Horselenberg, Martin Zuiddam, and Gijs Noordman, for always finding the time to guide me and to provide feedback on my work.

Furthermore, I would like to express my gratitude to my supervisors, Dr.Ir. Schutten and Dr.ir. Van der Wegen, from the University of Twente. Their feedback challenged me and pushed the quality of my research to a higher level. Most importantly, I am thankful for their belief in my abilities.

Lastly, I want to thank my friends and family, who have been a reliable source of support. I am grateful for their encouragement and genuine interest.

I hope you enjoy reading my bachelor thesis!

Carmen Boekee

*Enschede, August 2023*

# MANAGEMENT SUMMARY

## Introduction

We perform this research at the Industrial Engineering department of Apollo Tyres Ltd. As a bachelor assignment of the study Industrial Engineering & Management at the University of Twente. Apollo Tyres Ltd. is a leader in the tyre manufacturing industry. This research concentrates on optimizing the AGRI production process, the process that produces tyres for agricultural applications. The AGRI production process consists of 6 sequential sub-processes. Within this research, we focus on the last 3 sub-processes: carcass building, orbitread, and curing. According to the Theory of Constraints, Apollo Tyres Ltd. identified that the bottleneck of the AGRI production process is the curing department as this department is not reaching its target output. The main reason for this is that the curing department can often not continue production, because there are no green tyres available as input. The downtime due to this is expressed in the NGT percentage (No Green Tyres). Currently, the NGT percentage is 7% while the corporates target is 2%. The too-high NGT percentage is caused by a sub-optimal alignment of carcass building and orbitread department on the demand of the curing department. Therefore, this research investigates the following main research question:

*"How can the alignment of the three sub-processes of carcass building, orbitread, and curing be improved to decrease the NGT percentage?"*

The research objective hereby is to create insight into the alignment problems and provide a solution for the most constraining alignment problems.

## Approach

First, we analyse the current situation at the AGRI production process by observing it and interviewing several stakeholders working in the management, the Industrial Engineering department, the Planning department, and the production floor. Next, we review the literature on improvement theories. Considering the characteristics of the AGRI production process and the found literature, we develop an improvement framework to support the identification and improvement of the alignment problems. The improvement framework applies step 3 of the TOC cycle with the goal to "Subordinate the process to the curing department". Within this step we perform 3 phases. First, we identify the alignment problems by performing a Gemba Walk. Second, we prioritize the alignment problems by applying an adjusted FMEA that assesses the alignment problems on occurrence and severity. Lastly, we provide solutions for the 5 most constraining alignment problems.

## Results

This research resulted in 7 alignment problems. The alignment problems with high priority are:

- **"Lack of production sequence in orbitread plan"**
  The orbitread production plan does not contain a production sequence. Hence the operators determine the sequence by communicating with operators of other production phases. This leads to several efficiency losses. We expect this problem to account for 16% of the NGTs.
- **"Mismatch effective capacity of carcass building machine and curing presses"**
  The current market trend of an increase in demand for larger-sized tyres limits the production of the carcass building machine Farrel 51, designed for smaller-sized tyres. Due to the constant under-utilisation of this machine, the carcass building department is not able to meet the required internal demand of the curing presses anymore. We expect this problem to cause 17% of the NGTs.

The alignment problems with a medium priority are:

- **“Orbitread production plan exceeds capacity of certain positions”**
  The orbitread machine consists of four work positions. The production planning does not consider the capacity of these individual positions, which leads to overloading certain positions. We estimate the impact of this problem on the NGTs to be 12%
- **“Unreliable inventory”**
  Manual counting mistakes are leading to an unreliable insight into inventory levels and unreliable production plans. We estimate this problem to be responsible for 9% of the NGTs.
- **“Too late arrival of new shift plan”**
  The new shift plan arrives 1.5 hour after the start of the shift, causing misalignments at the orbitread machine between the new plan and the operations in the first 1.5 hour. We estimate this problem to account for 11% of the NGTs.

The alignment problems with a low priority are:

- **“Unrealistic norm times”**
  The norm time refers to the time in which a certain machine should be able to produce a certain SKU. At Apollo Tyres Ltd. these are used in the capacity calculations and production planning. As the norm times were lastly measured in 2017, some became unrealistic due to recent developments. This causes a somewhat unrealistic production planning.
- **“Production plan exceeds inventory capacity”**
  The capacity of the inventory locations is not considered in the production planning, which causes downtime due to full inventory locations.

We estimate the high and medium priority alignment problems to account for 65% of the NGTs and thus expect solving these alignment problems reduces the NGT percentage from 7% to 2.5%.

## Recommendations

Regarding the problems with a high priority, we recommend implementing all solutions that this research discusses. As a short-term solution Apollo Tyres Ltd. can improve problem 6 “lack of production sequence in orbitread plan” by developing a prioritization tool that creates a prioritized sequence. On the long term we recommend Apollo Tyres Ltd. to integrate prioritization into Apollo’s new AMES planning system. To solve problem 2 “Mismatch effective capacity of carcass building machine and curing presses” in the short-term, we recommend Apollo Tyres Ltd. to set-up an improvement project on the performance of the VMI 53 and Mesnac 55. For the long term, we recommend Apollo Tyres Ltd. to investigate the options for buying a new carcass building machine that can handle larger sized tyres. Hereby, we stress that considering the market trend and the improvement project on the curing presses, this problem is getting worse.

Regarding the problems with a medium priority, we recommend implementing a selection of solutions. Concerning problem 5 “Orbitread production plan exceeds capacity of certain positions” we recommend not implementing the provided solutions as Apollo Tyres Ltd. is planning on buying a new orbitread machine for which this problem does not necessarily apply. We do recommend Apollo Tyres Ltd. to investigate how to avoid this problem in the new situation. Regarding problem 3 “Unreliable inventory” and problem 7 “Too late arrival of new shift plan”, we recommend solving these on the long-term by developing a track and trace system and base the inventory counting and the new shift plan on the inventory levels from the track and trace system. As short-term solutions, we recommend tackling problem 3 by developing a counting procedure and problem 7 by developing a communication procedure and prioritizing the AGRI planning in the planning process.

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# GLOSSARY OF TERMS

| | |
|---|---|
| **AGRI** | Agricultural applications |
| **Alignment** | The match of the planning and activities of the carcass building & orbitread machine on the demand of the curing machines |
| **Carcass** | The framework of a tyre |
| **Green Tyre** | A tyre without a profile that is input for the curing machines |
| **KPI** | Key Performance Indicator |
| **NGT** | No Green Tyre |
| **Norm time** | The norm time is the time in which a certain machine should be able to produce a certain SKU. |
| **PCR** | Tyres for passenger cars |
| **SKU** | Stock Keeping Unit |
| **SM** | Space master tyres |
| **TOC** | Theory of Constraints |
| **WIP** | Work in progress |

# 1. INTRODUCTION

We perform this research at Apollo Tyres Ltd as part of the bachelor thesis of the study Industrial Engineering & Management at the University of Twente. This chapter introduces the research assignment. Section 1.1 introduces the company and Section 1.2 provides some general information about the AGRI production process. Section 1.3 motivates the research. Next, Section 1.4 formulates the problem statement on which Section 1.5 follows with a description of the research objective. Section 1.6 describes the scope of this research. Finally, Section 1.7 explains the research question of this research and Section 1.8 provides an overview of the structure of this report.

## 1.1 ABOUT APOLLO TYRES LTD.

Apollo Tyres Ltd. is an international leader in the tyre manufacturing industry. In 2009 the originally Dutch company Vredestein Banden B.V. has been acquired by an Indian company Apollo Tyres Ltd. Since then, it has been producing high quality tyres under the premium brands “Apollo” and “Vredestein”. Nowadays, these brands are sold all over the world and the production is spread over seven manufacturing facilities across Europe and India. The main office of Apollo Tyres Ltd. is in Amsterdam and the production facility is located in Enschede. We perform this research at the production facility in Enschede. Apollo Tyres’ production consists of three different product lines: passenger car tyres (PCR), tyres for agricultural applications (AGRI), and space master tyres (SM). This research focuses on the production of tyres for agricultural applications, hereafter called AGRI tyres.

## 1.2 AGRI PRODUCTION PROCESS

As this research focuses on the AGRI production process, this section first provides some general information about this process. The AGRI production process characterizes itself as a process with a lot of variation as it produces a wide range of stock keeping units (SKUs) with a relative low quantity of tyres per SKU. A SKU refers to the type of AGRI tyre. Each SKU has different specifications regarding tyre size, width, profile, etc. As there is so much variation in the AGRI production process, all machines in the process are semi-automated, meaning that they require at least one operator.

Figure 1.1 visualizes the general AGRI production process. At Apollo Tyres Ltd. the environment of the production process is a hybrid flow shop. The production process consists of 6 sequential steps. The focus of this research is on step 3 Carcass building, step 4 Orbitread, and step 5 Curing. Within these steps, two sub-assemblies are produced: the carcass and the green tyre. The first sub-assembly is the carcass. The carcass forms the framework of the tyre. Step 3 builds the carcasses. After that, the operators store the carcasses in the ‘carcass inventory’, from where they move to the orbitread (step 4). In step 4, the orbitread machine uses the carcasses to build the second sub-assembly ‘the green tyre’. The green tyre is a fully built-up tyre without profile. The operators store the finished green tyres in the ‘green tyre inventory’, from where they move to the curing presses (step 5). Section 2.1 provides more detailed information about the structure of an AGRI tyre. Furthermore, Section 2.2 explains all steps in the AGRI production process in more detail.

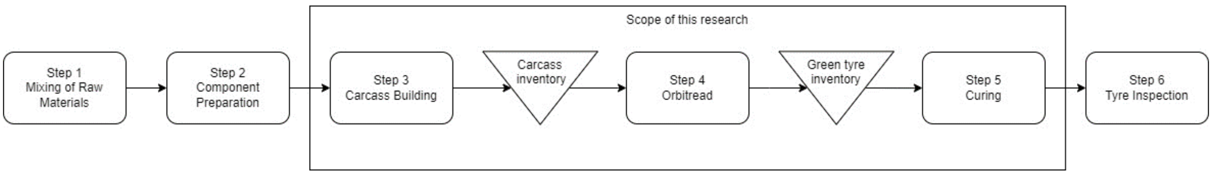



*Figure 1.1 General AGRI production process*

## 1.3 RESEARCH MOTIVATION

For Apollo Tyres Ltd. the agricultural sector is becoming more and more important. This is mainly because producing AGRI tyres in the Netherlands is more profitable compared to producing PCR tyres, since the conversion costs for AGRI tyres are lower. The conversion cost is a key performance indicator (KPI) that the management uses to indicate how much it costs to transform 1 kg natural rubber into saleable rubber. For AGRI tyres these costs are relatively low. The reason for this is that the average size of the AGRI tyres is larger and therefore more kilogram saleable rubber is produced per labour hour. Next to this, the market for AGRI tyres is quite large around the Netherlands. Producing AGRI tyres in the Netherlands is thus closer to the client, which reduces the transportation costs. This is very beneficial since these costs are relatively high for AGRI tyres. Because of all these reasons Apollo Tyres Ltd. (Enschede) has shifted focus from PCR tyres to AGRI tyres over the past years. Consequently, they are currently downscaling the production of PCR and focusing on optimizing the production process of AGRI tyres.

For optimizing the AGRI production process, the company follows the philosophy "Theory of Constraints Method (TOC)". According to this method there is always at least one constraint in the process. This constraint is the weakest point in the process and consequently determines the production pace. TOC focuses on identifying this constraint and resolving it by a 4-step approach (Goldratt & Cox, 2012):

1. Identify the constraint
2. Exploit the constraint
3. Subordinate the process to the constraint
4. Elevate the constraint

Apollo Tyres Ltd. performed step 1 and concluded that the constraint is at the curing phase of the production process, step 5 in Figure 1.1. Currently, the curing department is not reaching its target output. Therefore, the focus of this research is to optimize the AGRI production process considering the curing phase as constraint of the process.

## 1.4 PROBLEM STATEMENT

To identify the main problem of why the curing department is not reaching its production output, we perform a root cause analysis. Appendix A shows a detailed explanation of the root cause analysis. Apollo Tyres Ltd. is not reaching its target output at the curing phase as this department can too often not produce due to starvation. The input for the curing presses are green tyres. When the green tyres of the required SKU are not available in inventory, the curing presses cannot continue production. Apollo Tyres Ltd. measures all downtime caused by a lack of green tyre availability of the required SKU, by the percentage of NGT (No Green Tyres). The NGT percentage shows the downtime due to NGT as percentage of the total scheduled production time. Currently, this percentage is too high. The average NGT percentage of 2022-2023 is about 7% while it should be below the corporate target of 2% The NGTs mostly occur due to a sub-optimal production planning and a sub-optimal execution of the production plan. Both the production planning and the execution are sub-optimal because they result in mismatches of the planning and activities of the carcass building and orbitread machines on the demand of the curing machines. As a consequence of this, the carcass building and orbitread machines produce less or more than the curing presses demand. When this happens the product mix is not balanced correctly which leads to NGTs. To put these problems in other words, there is a sub-optimal alignment between the three production phases.

From this we formulate the core problem as follows:

*"At Apollo Tyres Ltd. there is a sub-optimal alignment of the carcass building, orbitread, and curing phase causing a too high NGT percentage."*

## 1.5 Research objective

This research focuses on optimizing the AGRI production process. Hereby, the goal of this research is to improve the alignment of the carcass building, orbitread, and curing phase so that the number of NGTs decreases. We do this by creating insight into the alignment problems and providing solutions for the most constraining alignment problems.

We reflect this in the following research objective:

*"To create insight into the alignment problems between the carcass building, orbitread, and curing phase, and provide a solution for the most constraining alignment problems. "*

## 1.6 Research scope

As we have limited time for the performance of this research, we set some boundaries. Apollo Tyres Ltd. is a big international company. This research only focuses on the manufacturing plant located in Enschede. This means that all company activities executed at other locations are considered out of scope. At the production plant in Enschede there are three product lines. This research only focuses on the production process of AGRI tyres. More specifically, we narrow this research down to the carcass building, orbitread and curing phase of the production process, because those phases are impacting the number of NGTs the most. We only discuss the other production phases to obtain a better understanding of the three main phases. Within these three main phases, this research focuses on improving the alignment problems. Alignment refers to matching the planning and activities of the carcass building and orbitread machines on the demand of the curing machines. Since alignment is a broad concept, this research focuses on improving the match of the production plans of the three phases.

## 1.7 Research questions

From the research motivation, problem statement, and research objectives, we formulate the following main research question:

*"How can the alignment of the three sub-processes of carcass building, orbitread and curing be improved to decrease the NGT percentage?"*

To answer the main research question, we define research questions and describe these per chapter.

**Chapter 2 The Current Situation**

The goal of Chapter 2 is to create a better understanding of the core problem and the issues related to it. To understand the core problem, it is crucial to know what the current situation on the AGRI production line is like. Hence the first question investigates what the characteristics of an AGRI tyre are, what the current product flow is, how the current production plan is made, and how the inventory level and mix of moving products are currently controlled. To gather this information, we perform observations of the AGRI production process and conduct interviews with several stakeholders like the operators, the planners, and the industrial engineers.

Research question:

1. *What is the current situation at the AGRI production line at Apollo Tyres Ltd.?*
    a) *What are the characteristics of an AGRI tyre?*
    b) *How do the products currently flow through the AGRI production process?*
    c) *How is the current production plan for AGRI tyres made?*
    d) *How are the inventory level and mix of moving products currently controlled?*

**Chapter 3 Literature Review**

Chapter 3 aims to generate knowledge that can contribute to improving the alignment problems in the AGRI production process. This chapter investigates what methods exist to support the identification and improvement of alignment problems. Hereby, this chapter distinguishes between improvement approaches, techniques, and tools. An improvement approach is the philosophy of how improvements should be achieved. An improvement approach makes use of improvement techniques and tools. Hereby, the techniques refer to a set of tools and the tools refer to the practical means to perform specific tasks. As Section 1.3 explains, Apollo Tyres Ltd. uses the TOC philosophy as improvement approach. With this literature review, we investigate whether TOC is also the right improvement approach for this research or whether other improvement approaches fit better. Furthermore, we investigate what combination of improvement techniques and tools can be used the best to identify and improve the alignment problems at Apollo Tyres Ltd.

Research question:

2. *What methods are known to identify and improve alignment problems in the AGRI production process?*
    a) *What approaches are known to improve production processes?*
    b) *What improvement techniques do these approaches use?*
    c) *What improvement tools do these approaches use?*

**Chapter 4 Identification of alignment problems**

This chapter aims to identify the most constraining alignment problems in the AGRI production process. First, this chapter creates an improvement framework by selecting a combination of improvement approaches, techniques and tools that support the identification and improvement of the alignment problems at the AGRI production process the best. Second, this chapter identifies the most constraining alignment problems by assessing all alignment problems and prioritizing them.

Research question:

3. *What approach, techniques, and tools can be used the best to improve the AGRI production process at Apollo Tyres Ltd.?*
4. *What are the most constraining alignment problems?*

**Chapter 5 Improvement of most constraining alignment problems**

This chapter aims to develop an improvement plan for the most constraining alignment problems in the AGRI production process. Therefore, this chapter investigates multiple solutions per alignment problems.

5. *How can Apollo Tyres Ltd. improve the most constraining alignment problems?*

**Chapter 6 Conclusion and Recommendations**

This research completes by concluding the findings and providing recommendations. Furthermore, this chapter discusses the limitations of the research and suggests topics for further research.

## 1.8 Thesis Structure

Table 1.1 summarizes the structure of this thesis.

| Chapter number | Chapter Title | Research questions |
|---|---|---|
| Chapter 2 | The Current Situation | 1a - 1d |
| Chapter 3 | Literature Review | 2a - 2c |
| Chapter 4 | Identification of alignment problems | 3 - 4 |
| Chapter 5 | Improvement of most constraining alignment problems | 5 |
| Chapter 6 | Conclusion & Recommendations | |

*Table 1.1 Thesis Structure*

# 2. CURRENT SITUATION

This chapter answers the first *question "What is the current situation at the AGRI production line at Apollo Tyres Ltd.?".* The goal of this chapter is to get a deeper understanding of the AGRI tyre production and gain insight into the complexity of the process. Hence, Section 2.1 explains the product characteristics and Section 2.2 explains the production process. Based on this information, Section 2.3 visualizes the product flow. Next, Section 2.4 explains the planning procedure and Section 2.5 explains how Apollo Tyres Ltd. monitors and controls the inventory level and mix. Lastly, Section 2.6 concludes this chapter.

## 2.1 PRODUCT CHARACTERISTICS

Apollo Tyres Ltd. produces on average around 2800 AGRI Tyres per month. In total they produce 81 different SKUs. The wide range of product specifications cause complexity in the production process. Due to the different tyre sizes, machine set-up changes are necessary. Furthermore, not every machine or storage equipment is able to handle every type of SKU. This forms restrictions for the production process and planning.

An AGRI Tyre consists of 8 components and two sub-assemblies (Apollo Tyres Ltd., 2015). The first sub-assembly is the carcass. As Section 1.2 explains, the carcass forms the framework of the AGRI tyre. The carcass consists of the following components:

1. **Chafer,** a rubber line that strengthens the tyre and prevents the rim and tyre from chafing.
2. **Inner liner**, a thin sheet of rubber that is applied to the ply layer to ensure the tyre is airtight.
3. **Body Ply**, the main part of tyre that consists of layered polyester, nylon, or ryon sheets with rubber liner. Its function is to support the thread and form the tyre into a specific shape.
4. **Beads**, rubber-coated steel wire to ensure correct attachment of the tyre to the wheel rim.
5. **RC strips**, rim cushions that protect the tyre against the rim.
6. **Side walls**, the side walls ensure stability, air tightness, and protection of the body plies.

The second sub-assembly is the green tyre. The green tyre is a fully built-up tyre without profile. The green tyre consists of the carcass and the following components:

7. **Breaker,** a layer consisting of polyester, nylon, or rayon that is placed between carcass and thread.
8. **Thread**, the top layer of the tyre that is contacting the road surface.

Figure 2.1 visualizes the structure of the AGRI tyre.

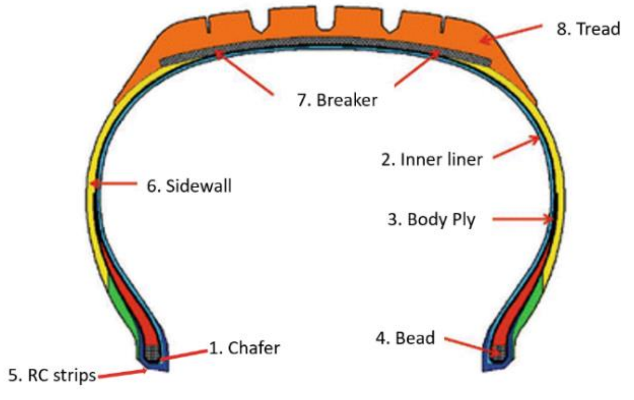



*Figure 2.1 Agri tyre structure*

## 2.2 PRODUCTION PROCESS

As Section 1.1. explains, the AGRI production process consists of 6 phases. By observing the production process and conducting interviews with operators, shift managers, and management, we create a better understanding of the production phases and the complexity involved. Furthermore, we retrieve information from “The Unofficial Global Manufacturing Trainee Survival Book” (Apollo Tyres Ltd., 2015).

**Phase 1 Mixing of raw materials**

This phase consists of three steps: mixing the pre-mix, mixing the final mix, and quality testing. Every component requires a different mix of chemicals. Hence, this phase starts with weighting all chemicals to create bags with the correct amounts of the required chemicals. The chemical bags and rubber are the input for the pre-mixing machines. At Apollo Tyres Ltd. there are two of these machines, Mixer 6 and Mixer 8. The operators store the pre-mixed rubber at the “pre-mix inventory”. From there it goes to the final-mixing machines. These machines mix the rubber with sulphur, decelerators, and accelerators and extrude the rubber into a “slab”, a long rubber sheet. At Apollo Tyres Ltd. there are two final-mixing machines, Mixer 4 and Mixer 5. After mixing, the operators test the quality of the rubber. If the quality is good, the operators store the rubber at the “rubber inventory”.

**Phase 2 Component preparation**

The second phase prepares all components except for the thread. In general, there are four processes involved with the preparation of components: extrusion, calendaring, cutting, and bead-making.

1. Extrusion
   An extruder heats the rubber and forces it through a die, to shape a layer of rubber into a specific form. The RC strips, sidewalls, and beads are produced by extrusion.
2. Calendaring
   This is the process of rubberizing fabric like polyester, nylon, or rayon. The inner liner, chafer, body ply, and breakers are produced by calendaring.
3. Cutting
   There are 2 types of cutting processes: Bias cutting and Orion cutting. Bias cutting cuts the rubber at an angle, turns the cut strips, and sticks them together. The chafer, body ply, and breaker require bias cutting. In addition to this, the chafers also require Orion cutting. This type of cutting slits the chafer layers to the required width.
4. Bead making
   This process starts with creating the bead core by wrapping bead wires around each other. Next, an extruder rubberizes the bead core, and the “Flipper” machine applies a bead filler.

**Phase 3 Carcass building**

In the third phase, the process of building the AGRI tyre starts by building the carcass. The carcasses are built at carcass building machines. In total there are 3 carcass building machines, the 51 Farrel, 53 Mesnac, and 55 VMI. The 51 Farrel is an old machine that can only be used for the smaller AGRI tyres. All carcass-building machines are not automated and require operators. The operators build up the carcasses by executing the steps that Figure 2.2 shows. When the carcasses are finished, the operators store them on T-trucks in the carcass inventory. A T-truck is a long rack on which a carcass hangs. On each T-truck one carcass fits. As each carcass SKU has a different size there are small and large T-trucks.

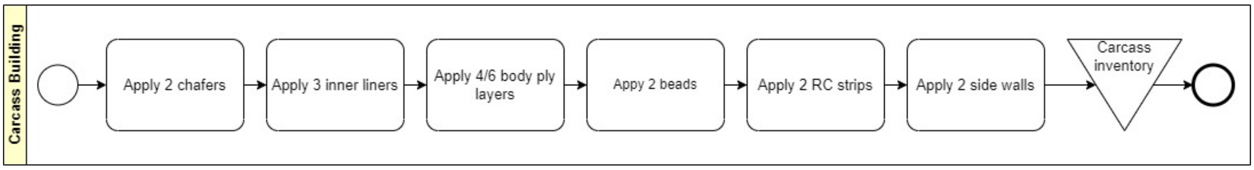



*Figure 2.2 Carcass building process*

**Phase 4 Orbitread**

In the fourth phase the green tyre is built up. This is done by operators using the orbitread machine. At Apollo Tyres Ltd. there is one orbitread machine. Figure 2.3 shows the set-up of this machine. In total there are 4 working positions: A, B, C, and D. There are 2 positions per turntable and each turntable has one operator. Both operators place a carcass on the outside position of their turntable (A and D) and apply the breaker layers. At the same time the extruder applies the thread layer to position B or C. If the extruder finishes on one of these positions the turntable of that position turns. Then the operator of that position removes the finished tyre and starts a new tyre, while the extruder applies thread to the position at the other turntable. The extruder limits the performance of the orbitread machine because only 1 thread can be applied to a tyre at a time, while 2 tyres can be built up on the outside positions at the same time.

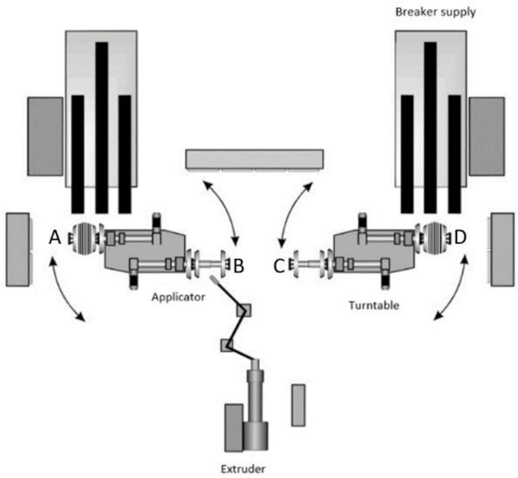



*Figure 2.3 Orbitread machine (Apollo Tyres Ltd., n.d.)*

When the operators finish a tyre on the orbitread machine, another operator moves this tyre to the paint cabin. After the paint cabin the operators store the finished green tyres on cones. Cones are coned-shaped platforms on which a green tyre lies on its side. As there is a wide range of green tyre SKUs with different sizes, there are small and large cones. On the cones, the green tyres need to rest for 4 hours before they can be further processed. The advantage of storing green tyres in cones is that they can be stacked up in racks in the warehouse. Figure 2.4 visualizes all steps that the operators need to perform in this phase.

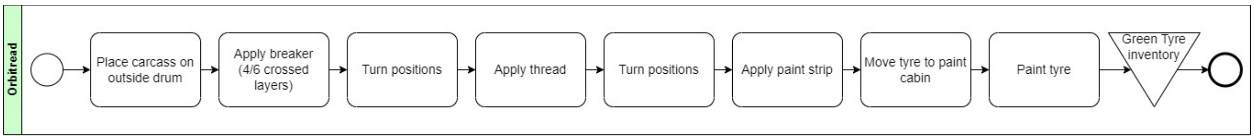



*Figure 2.4 Orbitread process*

**Phase 5 Curing**

In the fifth phase, the green tyres are cured to convert them into road-worthy tyres. In this vulcanization process, the operators place the green tyre on a loading device. This loading device places the tyres in the curing mould, where great heat and pressure transform the tyre. At Apollo Tyres Ltd. there are 10 curing presses. However, each SKU requires a different mould, hence mould changes are sometimes necessary. The vulcanization process takes about 1.5 to 3 hours. When the tyres are cured, the operators place them under extractor hoods where they can evaporate.

**Phase 6 Inspection**
The last phase inspects the finished AGRI tyres. The inspection is done by operators that assess the tyres.

## 2.3 Product flow

Knowing all production phases, we visualize the total product flow in Figure 2.6. This figure shows the relationship between the different production phases and provides insight into the flow of resources. Although the focus of this research is on improving the alignment of phases 3, 4, and 5, the flowchart also includes the other phases as those phases impact or are impacted by phases 3, 4, and 5.

## 2.4 Planning

Within Apollo Tyres Ltd. multiple departments are involved in the production planning process. The main stakeholders are the Supply Chain department, the Industrial Engineering department, the Planning department, and the shift managers. We conduct interviews with these stakeholders to create a better understanding of the planning process and its complexity.

### 2.4.1 Planning process

Apollo Tyres Ltd. creates a production plan with a monthly horizon. They create the monthly production plan using backward scheduling. The planning process starts in the Supply Chain department. Based on market predictions the Supply Chain department provides a monthly demand forecast. This is called the monthly ticket. The Supply Chain department communicates this monthly ticket with the Industrial Engineering Department (IE department), who check whether the demand matches the capacity of the plant. Next, the Industrial Engineering department sends the checked monthly ticket to the Planning department. This department is responsible for creating the production plan. They do this with the help of PIBS, the production information and operating system of Apollo Tyres Ltd. The company uses this system to manage several production processes including the production planning. PIBS supports the Planning department by determining all production plans. The Planning department first creates the curing plan (phase 5) and sends this to the Industrial Engineering department so that they can confirm the monthly ticket. Second, the Planning department creates the carcass building plan (phase 3) and third the orbitread plan (phase 4). Lastly, they create the component plan and mixing plan (phases 2 and 1). The Planning department thus schedules everything backwards, except for the orbitread plan. Figure 2.5 visualizes the planning process.

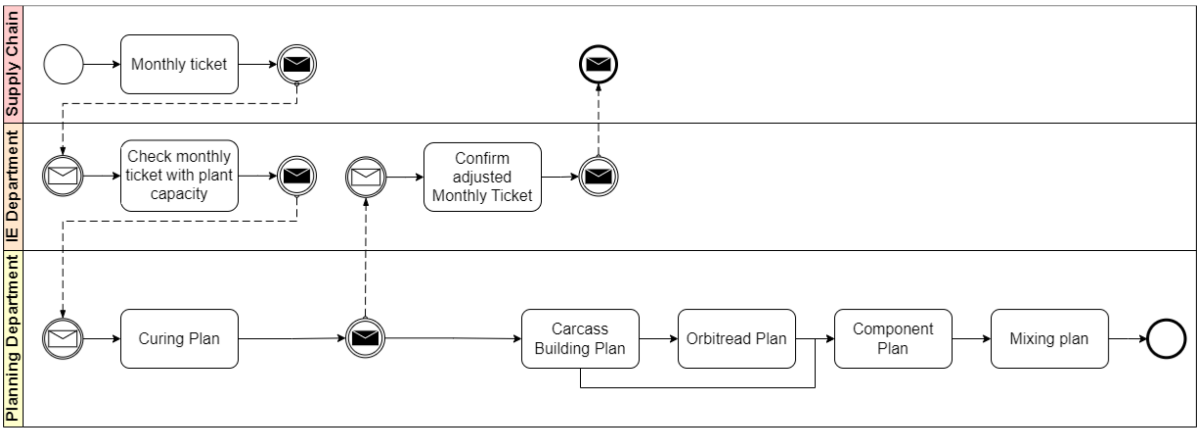



*Figure 2.5 The planning process*

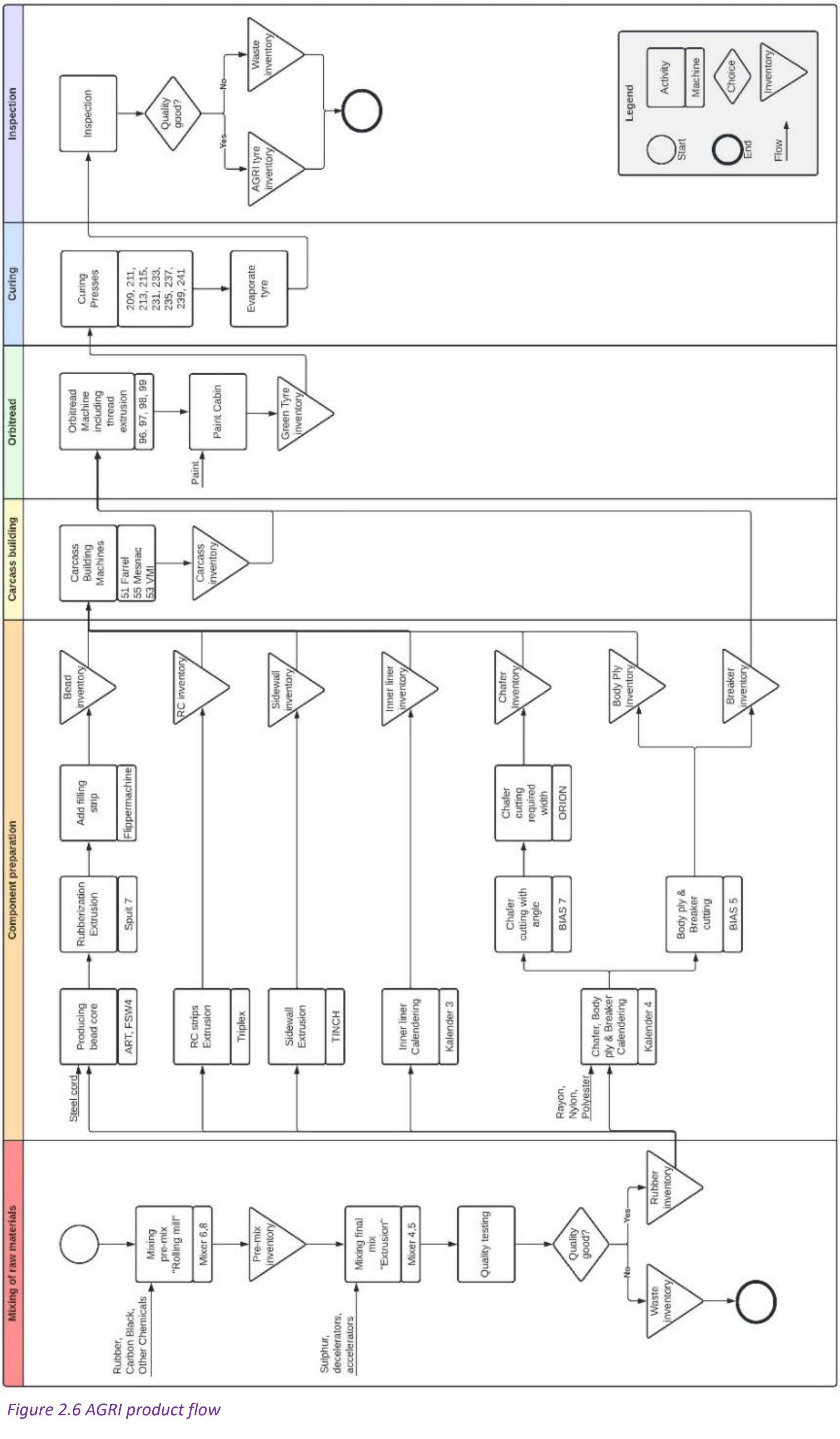



*Figure 2.6 AGRI product flow*

### 2.4.2 Planning activities

To create a better understanding of the planning activities in the planning process, this section explains the main activities.

**Monthly ticket**

The main input for the production planning is the monthly ticket that the Supply Chain department delivers. The monthly ticket defines the demand per SKU for one month. The Supply Chain department already tries to balance the demand in such a way that it fits the capacity of the plant. The Industrial Engineering department receives the monthly ticket and checks whether the monthly ticket actually fits the plant capacity.

The calculation of the plant capacity considers the capacity of the curing presses and the capacity of the carcass building machines. The calculation of the plant capacity does not consider the capacity of the orbitread machine and paint cabin since the capacity of these machines is higher than the capacity of the carcass building machine. The Industrial Engineering department checks the press capacity by comparing the total time available with the norm time required for the monthly ticket. The norm time is the time in which the plant should be able to produce a certain SKU on a certain machine. Each SKU has different characteristics, and each press has different capabilities, therefore the norm time differs per SKU per machine. Multiplying the monthly ticket with the norm time per SKU per press results in the required total norm time for the monthly ticket. The norm time for the monthly ticket includes a correction rate to compensate for unexpected delay. The Industrial Engineering department checks whether the total norm time does not exceed the available time. For checking the carcass capacity, the Industrial Engineering department follows a different approach. For each carcass building machine there is a maximum number of tyres that can be produced per day. The Industrial Engineering department translates the demand per month to an average daily demand per carcass machine. Next, they compare whether this does not exceed the maximum number of tyres that can be produced per day per carcass building machine.

After the Industrial Engineering department has checked the monthly ticket, they send it to the Planning department.

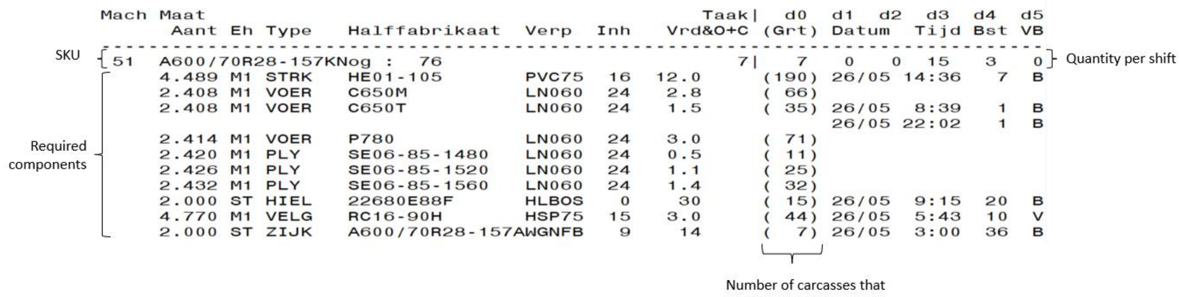
**Curing plan**

The Planning Department starts the planning process by creating a production plan for the curing presses. The curing plan is a monthly plan that shows per press which SKUs and how much tyres of that SKU should be cured. Next to this, it shows on which day and shift a mould changeover should take place. The curing plan is created in PIBS. PIBS uses the monthly ticket as main input. Furthermore, it considers other inputs like which SKUs can be produced on which presses, the norm time per SKU per press, and the expected efficiency per press. To minimize the number of mould changeovers, the batch size of each SKU equals the monthly demand of that SKU. This means that all tyres of a certain SKU are cured in one sequence on one press. Furthermore, based on the norm time per SKU per press and the expected efficiency per press PIBS determines the time it should take to produce the total demanded quantity per SKU on that press. With this information PIBS plans the day and shift on which mould changeovers should take place. Appendix B.1 shows an example of a monthly curing production plan.

**Carcass building plan**

Next, the Planning department creates the carcass building plan. As input for determining the carcass building plan, PIBS uses the curing plan and the start-inventory that consists of the number of carcasses plus the number of green tyres available at the start. Based on these inputs, the shift planner determines the number of carcasses to be produced per SKU per carcass building machine, by creating a master production schedule (MPS). Appendix B.2 shows an example of the MPS of carcass building. During the creation of the MPS, PIBS shows a notification when the shift planner exceeds the machine capacity. PIBS calculates the utilization of the machine by taking the sum of the norm times of the planned SKUs. This results in the total time it takes to produce the carcass plan of that machine. When this time exceeds the total available time, PIBS warns the planner. Hereby PIBS also considers the number of operators available.

After the creation of the MPS, PIBS translates the MPS to a carcass building plan that can be used on the work floor. This carcass building plan has a horizon of 6 shifts. It shows per machine per SKU how much carcasses should be produced per shift. Hereby, the plan specifies the required components and shows how much carcasses can be produced with the current component inventory. Furthermore, the order in which the SKUs should be produced equals the order in which the SKUs are visualized in the plan (from top to the bottom). Figure 2.7 shows an example of a part of the carcass building plan. It shows the carcass building plan for machine 51 and displays the plan for one SKU.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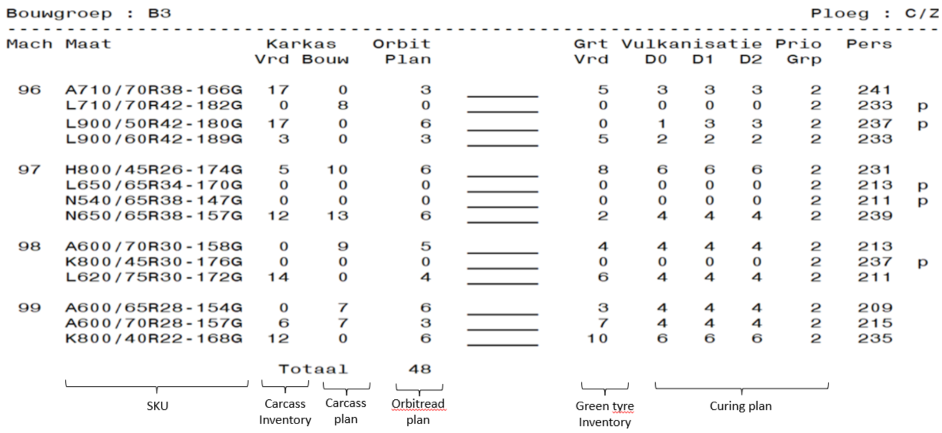
Mach Maat                                                  Taak|   d0   d1   d2   d3   d4   d5
      Aant  Eh Type    Halffabrikaat      Verp   Inh   Vrd&O+C (Grt) Datum    Tijd Bst  VB
-----------------------------------------------------------------------------------------------
51    A600/70R28-157KNog :   76                                7|    7    0    0   15    3    0
      4.489 M1 STRK    HE01-105           PVC75   16    12.0   (190) 26/05 14:36    7    B
      2.408 M1 VOER    C650M              LN060   24     2.8   ( 66)
      2.408 M1 VOER    C650T              LN060   24     1.5   ( 35) 26/05  8:39    1    B
                                                                     26/05 22:02    1    B
      2.414 M1 VOER    P780               LN060   24     3.0   ( 71)
      2.420 M1 PLY     SE06-85-1480       LN060   24     0.5   ( 11)
      2.426 M1 PLY     SE06-85-1520       LN060   24     1.1   ( 25)
      2.432 M1 PLY     SE06-85-1560       LN060   24     1.4   ( 32)
      2.000 ST HIEL    22680E88F          HLBOS    0      30   ( 15) 26/05  9:15   20    B
      4.770 M1 VELG    RC16-90H           HSP75   15     3.0   ( 44) 26/05  5:43   10    V
      2.000 ST ZIJK    A600/70R28-157AWGNFB    9      14   (  7) 26/05  3:00   36    B
```


*Figure 2.7 Example of carcass building plan*

**Orbitread plan**

The Planning department creates a production plan for the orbitread machine based on the carcass building plan. The planning approach is like the approach for the carcass building, first a MPS is made and second the MPS is translated into an orbitread plan that can be used on the workfloor. As input for the MPS PIBS uses the start-inventory of green tyres, the start-inventory of carcasses, the curing plan, and the carcass building plan. Appendix B.3 shows an example of a MPS for the orbitread. During the creation of the MPS, PIBS does not notify the planner if he exceeds the capacity of the orbitread machine. However, PIBS does show the total utilization of the orbitread machine against the total available time. Hereby, the utilization of the individual positions of the orbitread is not considered.
When the planners finish the MPS, PIBS translates the orbitread MPS into an orbitread plan that can be used at the workfloor. The orbitread plan looks different than the carcass building plan. The orbitread plan has a horizon of 1 shift. Per SKU it shows the start-inventory of carcasses, the curing plan, the quantity to be built on the orbitread, the start-inventory of green tyres, and the curing plan for the coming 3 shifts. The orbitread plan does not specify the order in which the SKUs need to be produced. Hence, the operators need to decide the order by communicating well with the operators of the other phases and considering the demand from curing, the start- inventory of carcasses and the start-inventory of green tyres. Furthermore, they also need to consider the start-inventory of the breaker supply which the orbitread plan does not show. Figure 2.8 shows an example of an orbitread plan.



Bouwgroep : B3 Ploeg : C/Z

| Mach | Maat | Karkas Vrd | Karkas Bouw | Orbit Plan | Grt Vrd | Vulkanisatie D0 | Vulkanisatie D1 | Vulkanisatie D2 | Prio Grp | Pers | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 96 | A710/70R38-166G | 17 | 0 | 3 | 5 | 3 | 3 | 3 | 2 | 241 | |
| | L710/70R42-182G | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 2 | 233 | p |
| | L900/50R42-180G | 17 | 0 | 6 | 0 | 1 | 3 | 3 | 2 | 237 | p |
| | L900/60R42-189G | 3 | 0 | 3 | 5 | 2 | 2 | 2 | 2 | 233 | |
| 97 | H800/45R26-174G | 5 | 10 | 6 | 8 | 6 | 6 | 6 | 2 | 231 | |
| | L650/65R34-170G | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 213 | p |
| | N540/65R38-147G | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 211 | p |
| | N650/65R38-157G | 12 | 13 | 6 | 2 | 4 | 4 | 4 | 2 | 239 | |
| 98 | A600/70R30-158G | 0 | 9 | 5 | 4 | 4 | 4 | 4 | 2 | 213 | |
| | K800/45R30-176G | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 237 | p |
| | L620/75R30-172G | 14 | 0 | 4 | 6 | 4 | 4 | 4 | 2 | 211 | |
| 99 | A600/65R28-154G | 0 | 7 | 6 | 3 | 4 | 4 | 4 | 2 | 209 | |
| | A600/70R28-157G | 6 | 7 | 3 | 7 | 4 | 4 | 4 | 2 | 215 | |
| | K800/40R22-168G | 12 | 0 | 6 | 10 | 6 | 6 | 6 | 2 | 235 | |
| | | Totaal | | 48 | | | | | | | |



*Figure 2.8 Example of orbitread plan*

Section 2.2 explains that there is also a paint cabin in the orbitread phase, for this machine there is no planning. The orbitread plan also functions as production plan for the paint cabin. This means that all tyres that need to be built on the orbitread also need to be painted in that shift.

**Component and mixing plan**

The Planning department creates a list of all components and raw materials that are required using the carcass building and orbitread plan as input. Based on this, they create a component plan and mixing plan.

## 2.5 INVENTORY CONTROL

At Apollo Tyres Ltd. there are two options for in-between inventory. In-between inventory can either be directly stored in a machine or at a physical location in front of a machine. Two important storage locations within the scope of this research are the carcass inventory and the green tyre inventory. The carcass inventory is in front of the orbitread machine. The operators store the carcasses on T-trucks. In total, there are 36 small T-trucks and 42 large T-trucks. The number of T-trucks available limit the capacity of the carcass inventory. The green tyres are stored in a warehouse in front of the curing presses. The operators place the green tyres on cones that are stacked in racks in the warehouse. In total, there are 42 small cones and 54 large cones. The number of storage locations in the racks limits the capacity of the green tyre inventory. Within the production planning the inventory capacity is not considered as constraint.

The inventory levels at Apollo Tyres Ltd. are determined as the stored inventory plus the work in progress (WIP). So, the carcass inventory is the total of the number of stored carcasses plus the WIP of the orbitread machine and the green tyre inventory is the sum of the number of stored green tyres and the WIP of the curing presses. To control the inventory level and mix Apollo Tyres Ltd. strives for a green tyre inventory level and mix that is sufficient to supply the curing demand for the next 12 hours (1.5 shift). As Section 2.4 explains the Planning department creates a curing plan based on the monthly ticket. The production plans of the other phases should supply the curing department in such a way that all 10 curing presses have a constant supply of the required SKU. Therefore, the Planning department strives to have a green tyre inventory level and mix that fulfils the demand of the Curing department for the next 12 hours (1.5 shift). This could be considered the norm for the level and mix of the green tyre inventory. This norm is not used as a constraint in PIBS for determining the production plans. Rather this norm is used by the Planning department to support the decision-making process when creating the production plans.

To track the inventory level and mix Apollo Tyres Ltd. uses a manual tracking system. At the start of each shift the operators count all components, carcasses, and green tyres that are in inventory. Next, they communicate these start-inventory levels with the shift manager who registers them in PIBS. Based on the deviating inventory levels the Planning department adjusts the production plans. Slightly before the end of the shift the shift manager takes stock of how many tyres the operators think they can finish in the shift. Based on this prediction, the shift manager registers in PIBS how much carcasses and green tyres are built and how much green tyres are cured during the shift. Using this information PIBS determines the new inventory levels. Next, the Planning department updates the production plans based on the new inventory levels. This tracking process repeats every shift. Although tracking the inventory levels is useful for updating the production plans, the current tracking system does cause complexity to the accuracy of the production planning process. The production planning is based on the inventory levels. However, since the inventory levels are tracked manually errors are likely to occur.

## 2.6 Conclusion

This chapter discussed the current situation at the AGRI production process at Apollo Tyres Ltd. The AGRI production process characterizes itself as a production process that produces a wide range of SKUs. Section 2.1 provided insight into the structure of an AGRI tyre. An AGRI tyre consists of 2 sub-assemblies: the carcass and the green tyre. Section 2.2 explained all steps of the AGRI production process. This research focuses on the carcass building, orbitread, and curing phase. To provide a good overview of all steps in the AGRI production process, Section 2.3 visualized the process in a flowchart. For the AGRI production process to function well, the Planning department creates a planning every month. Section 2.4 explains the planning process. The planning process starts with the creation of the curing plan based on the monthly ticket. Next, the planners create the carcass building plan after which they create the orbitread plan. Based on these, the planners make the production plans for the components. To create the production plans the planners use PIBS. PIBS is the production information and operating system of Apollo Tyres Ltd. that supports several processes including the planning. In PIBS the planners create a MPS for each machine. Next PIBS translates these into workable production plans for the production floor. Section 2.5 explains how Apollo Tyres Ltd. controls the inventory in the AGRI production process. Currently, Apollo Tyres Ltd. uses a manual tracking system.

# 3. LITERATURE REVIEW

This chapter integrates the outcomes of a systematic literature review by answering the knowledge question "*What methods are known to identify and improve alignment problems in the AGRI production process?"* Section 3.1 introduces the concept of process improvement and explains the theoretical perspective regarding this concept. Next, Section 3.2 provides an overview of all improvement approaches, Section 3.3 of all improvement techniques, and Section 3.4 of all improvement tools. This chapter finishes with a conclusion in Section 3.5.

## 3.1 INTRODUCTION TO PROCESS IMPROVEMENT

Approaches for performing improvement processes can be applied at Apollo Tyres Ltd. to detect and solve the constraining alignment problems. Within the literature many authors use the terms "improvement approach", "improvement techniques", and "improvement tools" interchangeably. Slack and Brandon-Jones (2019) define an approach as the set of underlying beliefs. An improvement approach is the philosophy of how improvement should be achieved. Hence an improvement approach makes use of improvement techniques and tools. Hereby, tools can be defined as "practical methods, skills, means, or mechanisms that can be applied to a particular task", whereas techniques have a larger scope and can consist of many tools (Tickle et al., 2015). In this research, we use these definitions to differentiate between improvement approaches, techniques, and tools. Although we follow these specific definitions, it is important to recognize that the improvement techniques and tools do not exclusively belong to one improvement approach. Hence, the goal is to provide an overview of all approaches, techniques, and tools that could potentially function as a guide to improve the alignment at the AGRI production process at Apollo Tyres Ltd.

## 3.2 IMPROVEMENT APPROACHES

The literature discusses multiple improvement approaches. Section 3.2.1 explains improvement approaches that are the most well-known, as indicated by several researches (Ahuja & Khamba, 2008; Aichouni et al., 2021; Jevgeni et al., 2015; Muthiah & Huang, 2006; Purba et al., 2021; Slack & Brandon-Jones, 2019; Tickle et al., 2015). In addition to this, Section 3.2.2 discusses the similarities and differences between the approaches.

### 3.2.1 Overview of improvement approaches

**Business Process Reengineering (BPR)**

BPR is an approach that emerged in the 1990s. During this period technologies were developing fast and a trend for automation arose. BPR emerged as a countermovement, "don't automate, obliterate". The objective of this approach is to examine all activities in a process on whether they add value for the customer. If an activity is identified that does not add value, the process should be redesigned to eliminate the activity (Slack & Brandon-Jones, 2019). This approach is unique in its radicality (Muthiah & Huang, 2006). The main principles are to rethink the whole process and strive for dramatic improvement by redesigning the process. Hereby it is checked whether activities can be made independent, not depending on other activities to supply them. BPR often makes use of process flow charts visualizing the design of the process (Slack & Brandon-Jones, 2019).

**Total Quality Management (TQM)**

The key objective of this improvement approach is obtaining "total quality" in the process. The philosophy is that "long-term success can be booked by benefiting all members of the organization and ensuring customer satisfaction" (Muthiah & Huang, 2006). TQM stresses that quality improvements should be made considering the 'totality' of the process. This is reflected by five key aspects. First, performing an improvement process should involve all individuals of an organization. All knowledge and skills should be bundled to establish improvement. Second, improvement should be established through the whole process. Hence, teams can be created that focus on establishing an improvement at a certain sub-process. Third, all quality costs should be considered. Fourth, the focus should be put on meeting the needs and expectations of the customers. Lastly, TQM aims to do things right the first time (Muthiah & Huang, 2006; Slack & Brandon-Jones, 2019).

**Total Productive Maintenance (TPM)**

TPM was developed by Nakajima (1988) as a practical application of the TQM approach. TPM combines the practices of productive maintenance with those of TQM. The objectives of TPM are to optimize the Overall Equipment Effectiveness (OEE), eliminate breakdowns, and promote autonomous maintenance (Cheah et al., 2020; Ahuja & Khamba, 2008). As in the TQM approach, TPM also stresses that the improvements should involve all people and levels of the organization by using improvement teams. To establish its objectives TPM introduces an eight-pillar implementation plan, see Figure 3.1.

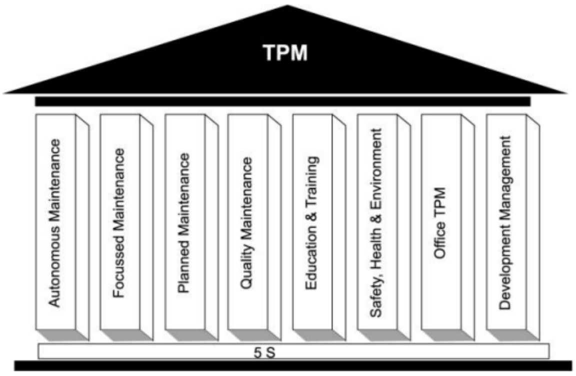



*Figure 3.1 Eight pillars of TPM (Ahuja & Khamba, 2008)*

**Theory of Constraints (TOC)**

TOC is an approach originally described by Goldratt (2012). He beliefs that a process consists of several interdependent sub-processes that are working together towards an overall goal. Each process has a constraint, the weakest sub-process. The performance of the whole process is determined by the performance of the constraint (Jevgeni et al., 2015). TOC explains this with the "Drum, Buffer, Rope" concept. The drum refers to the sub-process of the constraint, "beating the pace" of the production. All production lost at the constraint impacts the loss of the whole process. Therefore, inventory "the buffer" should be kept before the constraint, to ensure the constraint can work all the time. If all sub-processes other than the constraint would work to full capacity, this work would flow along the process until it would stack at the constraint. Therefore, there should be communication between the constraint and the sub-processes that supply the constraint. This is reflected by the rope (Slack & Brandon-Jones, 2019). The TOC focuses on improving the constraint by balancing the flow and reducing variation to increase throughput time and process reliability (Jevgeni et al., 2015; Muthiah & Huang, 2006; Slack & Brandon-Jones, 2019).

This is done by a five-step repeated cycle:

1. Identify system's constraint
2. Decide how to exploit the system's constraint
3. Subordinate everything else to the above decision
4. Elevate the system's constraint
5. If in the previous step a bottleneck has been broken, go back to step one, but do not allow inertia to cause a bottleneck (Goldratt & Cox, 2012).

**Lean**

The Lean approach originates from the Japanese manufacturer Toyota. Initially it was an approach designed to be exclusively used at manufacturing companies. However, nowadays it is widely applied. The Lean approach aims to exactly meet the customer demands with perfect quality and to eliminate waste (Muthiah & Huang, 2006). To achieve this exactly in time, the process should be managed with a "pull system". Lean proposes to identify wastes by reducing inventory. When there is no inventory there are no buffers, hence the operational problems will be exposed. The approach identifies 4 categories of wastes: wastes from irregular flow, inexact supply, inflexible response, and variability. All these wastes occur because of three main causes. First *muda*, which are all non-value-added activities due to poor communication. Second *mura*, which are inconsistencies of the system. Third *muri*, which are unnecessary/unreasonable demands of the process. To eliminate these wastes and their causes Lean makes use of several visual techniques. Next to this it emphasizes to include all individuals of the organization to achieve continuous improvement (Slack & Brandon-Jones, 2019).

**Six Sigma**

The Six Sigma approach was developed by the Motorola company (Jevgeni et al., 2015). It is an approach aimed at establishing 'total customer satisfaction'. According to Six Sigma the customer is satisfied when "the product is delivered when promised, without any defects or failures in the early life stage or service"). Therefore, this approach focuses on eliminating defects by using strict design specifications and increasing the process capability (sigma level) (Slack & Brandon-Jones, 2019). The capability of a process can be improved by reducing the process variation. Six Sigma does this in a data-driven way using multiple statistical tools. In addition to this, it uses a five-step plan called "DMAIC": 1. Define, 2. Measure, 3. Analyse, 4. Improve, 5. Control (Jevgeni et al., 2015; Purba et al., 2021; Aichouni et al., 2021).

### 3.2.2 Discussion

All approaches show differences and similarities. This section discusses these differences and similarities based on three aspects. First, the approaches differ in whether they improve by making one radical change or by continuously making incremental changes. Second, they differ in emphasis. Some approaches put the emphasis on how to improve and others on what to improve (Slack and Brandon-Jones, 2019). Thirdly, they differ on focus. In general, the approaches focus either on the customer, quality, or bottleneck.

First, we discuss the differences and similarities in the way of improvement. Where BPR beliefs improvements should be made by making radical design changes, the other approaches follow a more continuous path of incremental changes. Regarding emphasis, TPM, TQM, and Six Sigma put the emphasis on how improvements should be made. They make use of quantitative techniques and improve according to cycles and frameworks like the DMAIC cycle and the eight pillars. On the other side, BPR and Lean put the emphasis on what should be changed. BPR emphasizes that improvements should be made by redesigning the whole end-to-end process and Lean emphasizes that improvements should be made by reducing inventory and eliminating waste. TOC puts the emphasis on both the "what" and "how" of improvement, stating that processes should be improved by improving the constraint according to a 5-step approach. Lastly, the approaches differ from focus. BPR focuses on the customer by identifying added value and non-added value activities. TQM and Six Sigma are also focused on satisfying the customer, but they do this by improving the quality. TPM throws down the customer focus and only focuses on quality, by doing preventive maintenance. Lastly, TOC and Lean differentiate themselves by having the focus on identifying the bottleneck, in the form of searching for constraints or wastes. Hereby, Lean also focuses on the customer and TOC doesn't.

Not one of the approaches for process improvement is considered the best. However, some approaches are more suitable to function as a guide for improving the alignment at the AGRI production process at Apollo Tyres Ltd. than others. Table 3.1 summarizes all differences and similarities and visualizes the suitability of the approaches for application in this research. The approaches that make use of continuous improvement are more suitable to function as a guide since the alignment problems cannot be changed by one radical change. Rather several smaller changes should be made over time to improve the overall alignment. In addition to this, the aim of this research is to identify and solve the most constraining alignment problems. This is like identifying a bottleneck which is the focus of the Lean and TOC approach. Since these approaches also follow a continuous way of improvement, these approaches are the most suitable for this research.

| Improvement Approach | Way of improvement | Emphasis | Focus |
|---|---|---|---|
| BPR | Radical | What | Customer |
| TQM | Continuous | How | Quality, Customer |
| TPM | Continuous | How | Quality |
| TOC | Continuous | Both | Bottleneck |
| Lean | Continuous | What | Bottleneck, Customer |
| Six Sigma | Continuous | How | Quality, Customer |

*Table 3.1 Overview of improvement approaches*

## 3.3 Improvement Techniques

The improvement approaches from Section 3.2 make use of several improvement techniques. Section 3.3.1 provides an overview of the most well-known improvement techniques as stated by several researches (Ahuja & Khamba, 2008; Cheah et al., 2020; Jevgeni et al., 2015; Kumar et al., 2021; Muthiah & Huang, 2006; et al., 2017; Slack & Brandon-Jones, 2019). In addition to this, Section 3.3.2 provides a discussion of the improvement techniques.

### 3.3.1 Overview of improvement techniques

**Gemba Walk**

A Gemba walk refers to a walk through the production plant to search for improvement opportunities. It identifies areas to improve by observing the process, taking notes, and gaining feedback and complaints of the operators. An advantage of this technique is that it shows the gap between theory and practice (Slack & Brandon-Jones, 2019).

**Statistical Process Control**

Statistical process control (SPC) is a technique used to control processes. It uses multiple statistical tools to track the performance of a process over a period of time. Tracking the performance of a process enables detection and prevention of failures (Jevgeni et al., 2015; Slack & Brandon-Jones, 2019).

**Overall Equipment Effectiveness**

Overall equipment effectiveness (OEE) is a technique used to analyse the performance of a process. This technique makes sure that every step of the production process can be monitored. Hereby, it constantly analyses the data of the process and responds when the data deviates from the norm (Radej et al., 2017). It measures the degree of waste by examining all losses in three categories: availability (A), performance efficiency (P), and quality (Q). Next the OEE is calculated by multiplying all category losses. Figure 3.2 shows an overview of the OEE technique and the six greatest losses as identified by Nakijima(1988).

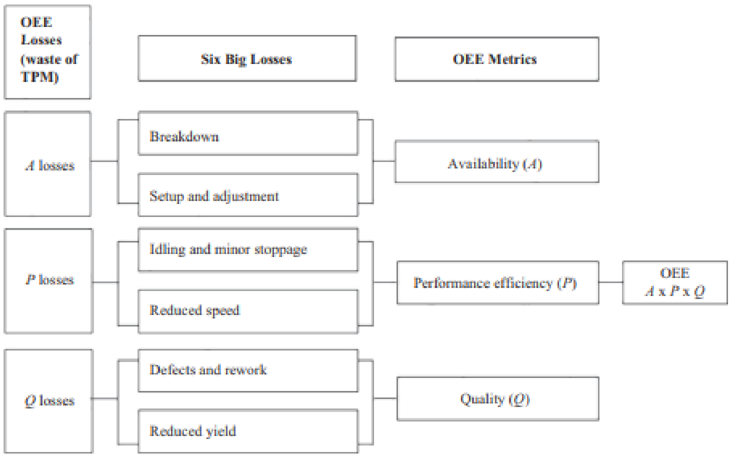



*Figure 3.2 Overview of OEE (Nakijima,1988)*

**Failure Mode and Effect Analysis**

The failure mode and effect analysis (FMEA) is a technique that aims to prevent failures from occurring. Once potential failures are identified, this technique prioritizes the failures by determining a risk priority number (RPN) for each failure. Next, it focuses on preventing the highest-priority failures (Jevgeni et al., 2015; Slack & Brandon-Jones, 2019). To determine the RPN the following three factors should be rated:

- Occurrence, rating the likelihood or frequency of a failure occurring
- Severity, rating the impact of the consequences of the failure
- Detection, rating the likeliness of the failure to be detected before it affects the process

Multiplying these ratings results in the RPN (Jevgeni et al., 2015).

**5S**

5S, also known as the 'housekeeping rules, aim to eliminate waste by standardizing the workplace and keeping it clear and clean. 5S stands for: sort, straighten, shine, standardize, and sustain (Ahuja & Khamba, 2008).

**Poka Yoke**

Poka Yoke is a mistake-proofing technique. Its goal is to prevent failures by designing processes/products in such a way that it is not possible for mistakes to occur.

**Single Minute Exchange of Dies**

This is a technique used to eliminate waste by minimizing the time it takes to change the set-up of a machine. This technique focuses on separating the external and internal activities of the changeover. Internal activities refer to the activities that can only be done when the process is paused. External activities are the activities that can be done during the process.

**Kanban**

Kanban is a technique that makes use of a visual supports that can be used on the work floor to match the internal supply and demand of sequential processes. By using 'kanban's', cards, or signals, an internal customer can demand new supplies hereby supporting a pull system. Kanban can be created either in physical form using coloured cards or stock locations or in digital form using electronic point of sales (EPOS).

### 3.3.2 Discussion

All improvement techniques are relevant for a manufacturing environment. However, they differ in applicability regarding stage of the improvement process. The literature shows some generals stages in process improvement: problem identification, prioritization, and problem solving (Aichouni et al., 2021; Cheah et al., 2020; Kumar et al., 2021). Some improvement techniques like the Gemba walk and SPC are very useful for identifying the bottleneck. Whereas the Gemba walk is a rather qualitative technique that focuses on identifying improvement areas, SPC is a quantitative approach that searches the bottleneck by analysing data. OEE also focuses on identifying the bottleneck by categorizing the losses and additionally it prioritizes the categories based on the OEE percentage. Another technique that is very useful for prioritizing problems is FMEA. FMEA prioritizes the problems on an RPN that consists of a percentage of occurrence, severity, and detection. Finally, 5S, Poka Yoke, SMED, and Kanban are applicable for solving the problem. 5S improves problems by organizing the workplace and standardizing it. SMED and Poka Yoke improve problems by redesigning processes and Kanban focuses on improving the match of internal supply and demand. Table 3.2 provides an overview of the improvement techniques and their applicability to the stages of the process Improvement process.

| Improvement Technique | Focus |
|---|---|
| Gemba walk | Problem identification |
| SPC | Problem identification |
| OEE | Problem identification & prioritization |
| FMEA | Problem Prioritization |
| 5 S | Problem solving |
| Poka Yoke | Problem solving |
| SMED | Problem solving |
| Kanban | Problem solving |

*Table 3.2 Overview of improvement techniques*

## 3.4 IMPROVEMENT TOOLS

There exist several process improvement tools. Within the literature, multiple researchers especially highlight the seven basic tools for process improvement (Aichouni et al., 2021; Radej et al., 2017; Ahuja & Khamba, 2008; Purba et al., 2021). Ishikawa (1976), an expert in the field of process improvement, introduces these seven tools. Section 3.4.1 explains all seven tools and Section 3.4.2 discusses the strengths and weaknesses of the tools.

### 3.4.1 Overview of improvement tools

**1. Cause-and-effect diagram**

Cause-and-effect diagrams are especially useful to find the root causes of a problem. It is also known as a fishbone diagram because of its shape. It shows categories in which root causes of a specific problem/effect are visualized (Slack & Brandon-Jones, 2019). An advantage of this method is that it shows the relationships between the causes and effects. However, a disadvantage is that the tool does not show the occurrence probabilities of the causes nor possible solutions (Radej et al., 2017). Figure 3.4. shows a framework of the diagram.

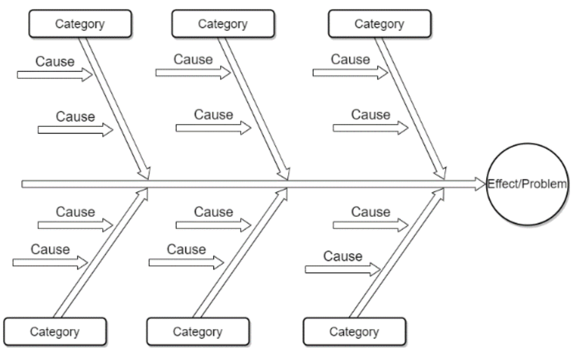



*Figure 3.3 Cause-and-effect diagram, interpreted from Slack & Brandon-Jones (2019)*

**2. Flow chart**

A flowchart is a visual representation of a process. It shows the order of the process steps and the decisions that must be made. Flowcharts come in several forms like swim line diagrams or value stream maps (Lean). The advantage of this tool is that it highlights the areas where there is no clear procedure, and it helps analysing the context of a problem (Slack & Brandon-Jones, 2019). Radej et al. (2017) mentions that a disadvantage of a flow chart is that it needs to be redesigned every time the process changes, which is a waste of time.

**3. Control table**

Control tables, also known as check sheets, are used to structurally collect and analyze data. It could be used to track causes of problems over time, for example to discover the frequency of occurrence.

**4. Control chart**

A control chart is a graphical representation of the data. Ishikawa (1976) states "the purpose of a control chart is to determine whether each of the points on the graph is normal or abnormal, and thus know the changes in the process from which the data has been collected." It thus detects trends and shows whether the deviations are within the control limits or not.

**5. Histogram**

A histogram can be used to visualize the variation of one specification in a process. It shows the frequency range, the amount of variation, the relationship of the process variation to the specification, and the shape of variation. A disadvantage is that this tool is hard to use when comparing multiple specifications of a process (Radej et al., 2017).

**6. Pareto analysis**

The pareto analysis is a tool commonly used to prioritize the causes of a problem. It is a bar diagram showing the frequency of occurrence of all causes in descending order. The tool emphasizes that a few causes can explain most of the problem. It does this by showing a cumulative line that highlights how much percent of the problem is affected by a certain cause. Radej et al. (2017) argues that disadvantages of this tool are that it focuses on the past and that prioritizing causes only on frequency of occurrence might be inaccurate.

**7. Scatter diagram**

Scatter diagrams can be used to show a relationship between two data sets. Hereby a scatter diagram visualizes whether the relationship is positive, negative, linear, or non-linear. Slack and Brandon-Jones (2019) stress that a scatter diagram only identifies relationships. Therefore, the relationship does not necessarily need to be a cause-effect relationship. Furthermore, they stress that a scatter diagram does not prove the relationship since it does not perform any statistical tests.

### 3.4.2 Discussion

All seven tools are useful in each stage of process improvement. Each tool has its own strengths and weaknesses that should be considered. Table 3.3 summarises these.

| **Improvement Tools** | **Strengths** | **Weaknesses** |
|---|---|---|
| Cause-and-effect diagram | - Shows relation between cause and effect | - Does not show any quantification of causes or effects |
| Flow chart | - Provides insight into process<br>- Highlights areas that lack of clear procedure | - Not easily adjustable, when process changes |
| Control table | - Overview of data | - No data processing so it does not provide clear information |
| Control chart | - Clear visualization of data<br>- Detects trends and deviations | - Does not show the cause of process deviations<br>- Requires knowledge to correctly interpret the chart |
| Histogram | - Visualizes the frequency and variation of a process | - Hard to use when comparing multiple specifications of a process |
| Pareto analysis | - Highlights how much percent of problem is affected by cause<br>- Useful for prioritizing problems | - Focuses on past<br>- Only prioritizes on frequency of occurence |
| Scatter diagram | - Identifies potential relationships<br>- Useful with different sets of data | - Does not statistically prove the relationship |

*Table 3.3 Overview of improvement tools*

## 3.5 CONCLUSION

Chapter 3 discussed the existing knowledge on process improvement.

Section 3.1 introduced the concept of process improvement, by explaining the difference between improvement approaches, techniques, and tools. Improvement approaches refer to the philosophies on how processes should be improved. Improvement techniques narrow this down to a set of tools that can be used to for improvement. The tools are the actual practical means or mechanisms that can used to perform specific tasks. Although this distinction is made, this section recognizes that the improvement techniques and tools do not exclusively belong to one improvement approach. Rather this research should use a combination of approaches, techniques, and tools to develop an improvement approach that suits the situation at Apollo Tyres Ltd.

Section 3.2 explained and discussed the improvement approaches. This includes BPR, TQM, TPM, TOC, Lean, and Six Sigma. From these approaches Lean and TOC are the most suitable for this research as these approaches focus on identifying bottlenecks, which is like identifying alignment problems. Furthermore, these approaches make use of continuous improvement which more suitable compared to radical improvement approaches.

Section 3.3 explained the improvement techniques, this includes the Gemba Walk, SPC, OEE, FMEA, 5S, Poka Yoke, SMED, and Kanban. The Gemba Walk, SPC, and OEE are useful for problem identification. OEE and FMEA are valuable for prioritizing problems and 5S, Poka Yoke, SMED, and Kanban are applicable for problem solving.

Section 3.4 explained the most well-known improvement tools, the seven improvement tools of Ishikawa. These consists of a cause-and-effect diagram, a flow chart, a control table, a control chart, a histogram, a pareto analysis, and a scatter diagram. We conclude that all tools are useful in each stage of the improvement process, but each stool has it strengths and weaknesses.

Figure 3.4 summarizes this chapter by providing an overview of all improvement approaches, techniques, and tools that could potentially function as a guide for improving the alignment at the AGRI production process at Apollo Tyres Ltd.

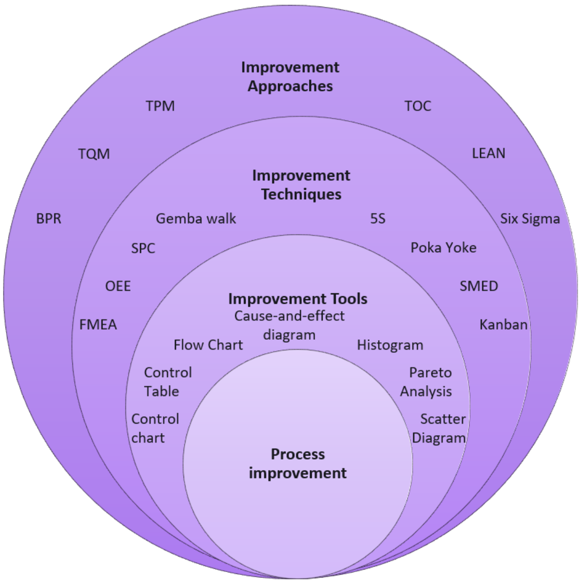



*Figure 3.4 Overview process improvement*

# 4. IDENTIFICATION OF THE ALIGNMENT PROBLEMS

This chapter identifies the alignment problems in the carcass building, orbitread, and curing phase of the AGRI production process. Section 4.1 develops an improvement framework that supports the identification and improvement of the alignment problems. The next sections of chapter 4 perform the phases of the improvement framework related to the identification of the alignment problems and Chapter 5 performs the phase related to the improvement of the alignment problems. Section 4.2 identifies the alignment problems, Section 4.3 prioritizes the alignment problems, and Section 4.4 discusses the impact of the alignment problems. Finally, this chapter finishes with a conclusion in Section 4.5.

## 4.1 IMPROVEMENT FRAMEWORK

This section selects the most suitable improvement approach to improve the alignment of the three sub-processes in the AGRI production process at Apollo Tyres Ltd. The improvement approach is the philosophy on how improvements should be made. Therefore, the improvement approach places this research in a greater perspective. In addition to this, this section provides an improvement framework summarizing the phases, techniques, and tools for this research.

As Section 1.3 explains, TOC is the philosophy that Apollo Tyres Ltd. generally follows for monitoring and improving their production processes. Section 3.1 explains that for this research Lean and TOC are the most relevant potential approaches. Whereas Lean focuses on eliminating wastes to add value to the customer, TOC focuses on improving constraints to increase throughput. The objective of the TOC approach fits better to the objective of this research. Furthermore, this research fits well into the 4-step improvement cycle of TOC. Therefore, we select TOC as improvement approach for this research and place our research in the context of the 4-step TOC cycle. The first step is "identifying the bottleneck". Part of the motivation for this research is that Apollo Tyres Ltd. identified the curing department to be the constraint of the AGRI production process. The second step, "exploiting the bottleneck", is out of scope for this research as Apollo Tyres Ltd. is already working on this. The third step is "Subordinate the process to the bottleneck". This step aligns the processes before the constraint to limit the starvation time at the constraint. Translating this to the situation at Apollo tyres Ltd, this step improves the alignment of the carcass building and orbitread phase to decrease the downtime due to NGTs at the curing phase. As this is exactly the goal of this research, this research fits into the step 3 of the TOC cycle. Within step 3, the TOC approach does not offer clear techniques and tools that can be used to perform this step. Therefore, we select TOC solely as improvement approach and we follow the general improvement phases that Section 3.3. explains: Identify problems, prioritize problems, and solve problems. To perform the phases, this research uses a combination of techniques and tools from multiple approaches.

**Phase 1: Identify the alignment problems**

Phase 1 identifies the alignment problems. Section 3.3 provides three possible techniques for this: Gemba Walk, SPC, and OEE. Whereas the Gemba Walk is a qualitative approach, SPC and OEE are quantitative approaches. Apollo Tyres Ltd. collects a lot of data regarding downtimes. The Industrial Engineering department constantly analyses this data. Hereby they use the SPC and OEE techniques. From their analysis they conclude that the greatest causes of NGTs are 'production delay' and 'efficiency losses'. Nevertheless, since there is no track and trace system at the AGRI production process, it is hard to find the root causes of 'production delay' and 'efficiency losses' through quantitative analysis. Next to this, the downtime data of the orbitread machine is unreliable as operators often double register the downtimes. Therefore, the qualitative Gemba Walk approach is more suitable for this research. An advantage of the Gemba Walk is that it reveals the gap between theory and practice. This insight is very useful to identify the misalignment between the theoretical planning and the practice. Section 3.4 explains that the cause-and-effect diagram is a useful tool to visualize causes and effects. Therefore, we visualize the alignment problems that result from the Gemba Walk in a cause-and-effect diagram.

**Phase 2: Prioritize the alignment problems**

Phase 2 prioritizes the alignment problems. Section 3.3 provides 2 techniques for this: OEE and FMEA. Where OEE focuses on categorizing the problems and prioritizing the categories, FMEA focuses on assessing and prioritizing all individual problems. As this research aims to identify "individual" alignment problems rather than problematic categories, the FMEA technique is more suitable. Therefore, we prioritize the problems using the FMEA technique. As Section 3.3 explains the FMEA technique prioritizes the problems by determining an RPN for each problem. The FMEA technique rates the problems on three criteria: occurrence, severity, and detection. It then, multiplies these ratings to determine the RPN. The detection criterion rates the problems on the likelihood of being detected before the problem occurs. This is not relevant for this research, as alignment problems are persistent problems that should be detected and solved once rather than continuously being detected and prevented during the production process. Hence, we modify the FMEA technique and only assess the problems on occurrence and severity. Due to time limitations, we cannot investigate solutions for all alignment problems. Hence, this phase selects the most constraining alignment problems based on the prioritization. We only investigate possible solutions for the most constraining alignment problems.

**Phase 3: Improve the alignment problems**

To solve the most constraining alignment problems Section 3.3 provides 4 techniques: 5S, Poka Yoke, SMED, and Kanban. Phase 3 does not specifically apply these techniques as the alignment problems require specific solutions and we do not want to limit the solution possibilities. However, we do use the techniques as a guide to explore possible solutions.

Figure 4.1 summarizes this section in an improvement framework. It shows the improvement phases, techniques, and tools that this research uses. Section 4.2 performs phase 1, Section 4.3 phase 2 and Chapter 5 performs phase 3.

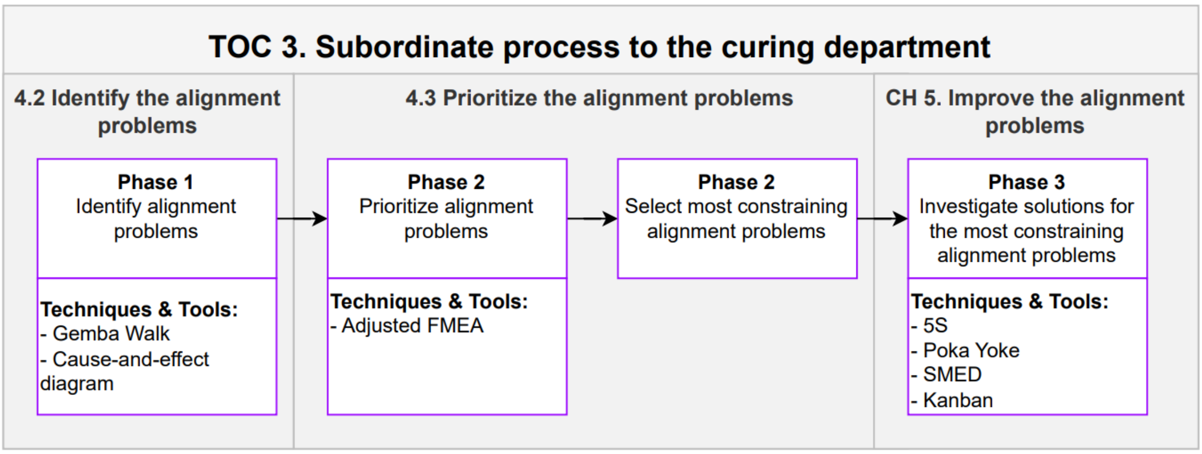



*Figure 4.1 Improvement Framework*

## 4.2 IDENTIFY THE ALIGNMENT PROBLEMS

This section performs phase 1 of the improvement framework in Figure 4.1. This section identifies the alignment problems by performing a Gemba walk and showing the results in a cause-and-effect diagram.

We perform the Gemba Walk at the Planning department and the AGRI production process. During the Gemba Walk we focus on identifying alignment problems that cause NGTs, hereby we especially focus on alignment problems related to the production planning. First, we observe the entire AGRI production process twice. Then, we conduct two observations on the operations at the orbitread machine to further investigate the alignment problems specific to that phase. Finally, we observe the planning process twice. In total we observe 4 of the 5 operating teams and 2 of the 5 shift planners, to get a broad perspective on the alignment problems and make sure the alignment problems cover most of the causes of NGTs.

Figure 4.2 shows a cause-and-effect diagram with all alignment problems resulting from the Gemba Walk. The cause-and-effect diagram consists of three problem categories. The first category is “Input for planning”. This category shows all problems that cause incorrect or unreliable inputs for the planning. Unreliable inputs for the planning result in an unreliable planning, which leads to alignment problems. The second category is “Planning”, this category shows all problems that occur within the planning procedure. The third category is “Planning process”. This category shows the problems that occur because of the role that the planning currently has in the larger production process.

In total the Gemba Walk resulted in 7 alignment problems. We describe all problems per category to explain their causes and their effects on the number of NGTs. To increase the understandability of the problems, we leave out some complexities as they do not affect the severity of the problems.

First, we discuss problems 1, 2, and 3 that occur in the category “Input of Planning”.

**1. Unrealistic norm times**

Section 2.4 explains that the planning department uses the norm times to create the production plans. The problem is that the current norm times are not up to date with the recent changes in the production process. Apollo Tyres Ltd. measured the norm times for the last time in 2017. However, recently Apollo Tyres Ltd. implemented some new safety measures. Due to this the operations at the carcass building machine and the orbitread machine take more time. This extra time is not considered in the current norm times. These unrealistic norm times lead to an unrealistic planning, eventually this causes production delay and NGTs.

**2. Mismatch effective capacity of carcass building machine and curing presses**

At Apollo Tyres Ltd. there is a trend towards producing more tyres with a larger size. Because of this, over the past months the product mix in the monthly ticket shifted towards a greater percentage of larger tyres. All curing machines can handle these larger tyres, so they can be fully utilized. However, for the carcass building machines this is not the case. One carcass building machine, Farrel 51, can only handle the tyres with smaller sizes. Because of this, the low demand for smaller sized tyres limits the utilization of this machine. Figure 4.3 shows the impact of the market trend on the utilization of the carcass building machines. It shows the division of production load on the three carcass building machines per month over the period 2019-2023. The figure shows a clear downward trend on the load on the Farrel 51 and an upward trend on the load on the VMI 53 and the Mesnac 55.

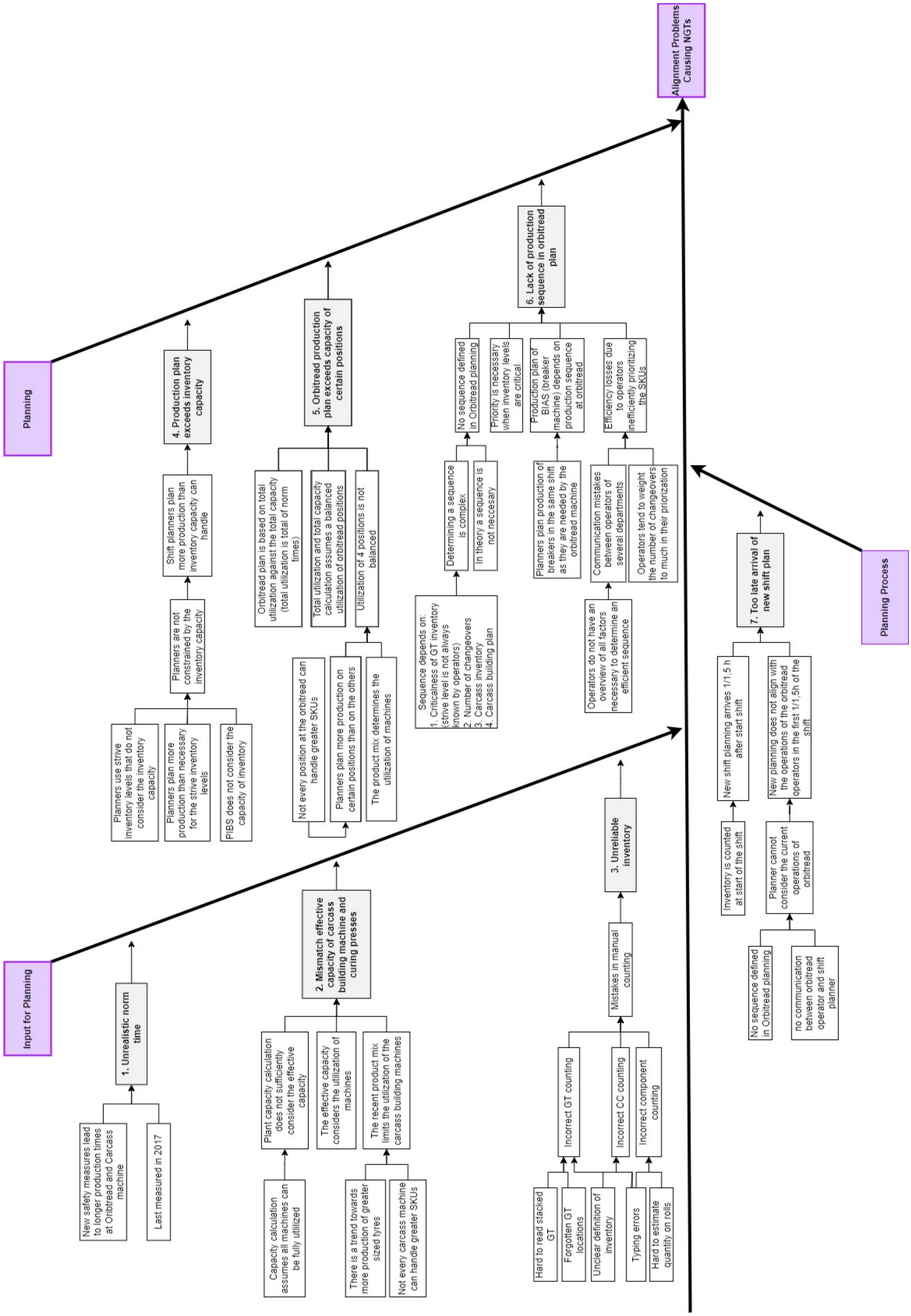



*Figure 4.2 Cause-and-effect diagram*

As the demand constantly limits the load on the Farrel 51, this machine is constantly under-utilized. Its capacity is constantly not used. Hence, its effective capacity is lower. The effective capacity is the capacity that is left considering the expected utilization and performance of a machine. So, as the effective capacity of the Farrel 51 is decreasing due to the low demand of small tyres, the VMI 53 and Mesnac 55 are compensating for this. The problem that occurs here is that the VMI 53 and Mesnac 55 have a limited capacity as well. The effective capacity of these machines is limited by their expected performance. With the current performance of the machine 53 and 55, the carcass building department is not able to meet the required demand of the curing department. So, the total effective capacity of the carcass building machines does not match with the curing demand anymore.

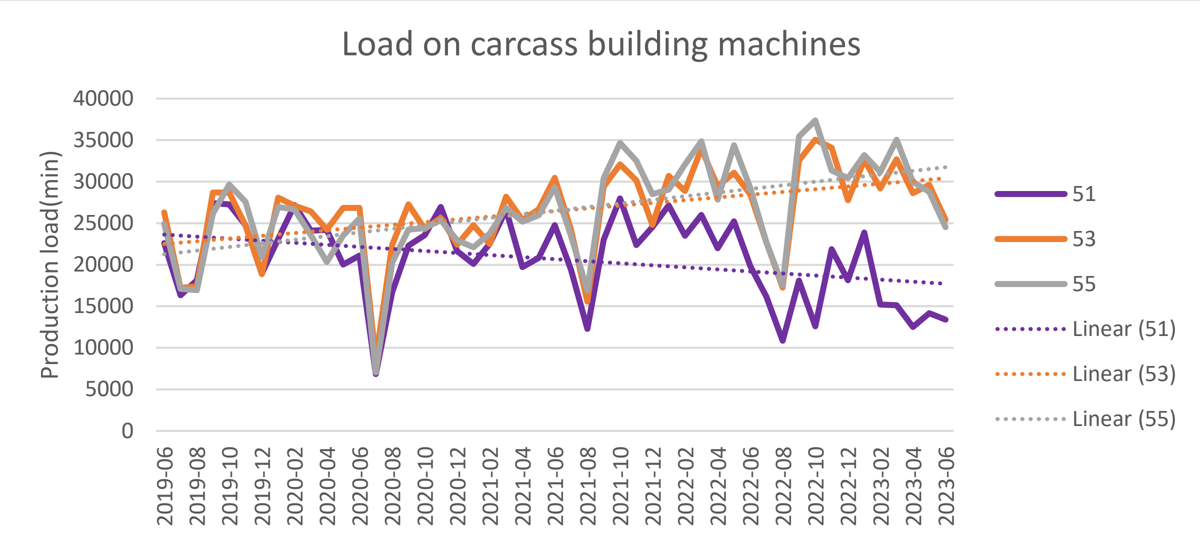



*Figure 4.3 Monthly load on carcass building machines in the period of 2019-2023*

To show the effect of this mismatch Figure 4.4 shows for the first weeks of July 2023 the utilization of carcass building machines that is required to meet the demand of the curing presses. We assign all required demand that can be produced on the Farrel 51 to that machine and all other demand to VMI 53 and Mesnac 55. We determine the required utilization by dividing the production time on the carcass machines required to meet the curing demand by the total available time. The figure shows the average utilization rate of 2022 based on realized performance and the utilization target of 2023 based on expected performance to provide an indication of a realistic utilization rate. The required utilization is often higher than the average utilization of 2022 and at the end of the month even higher than the target rate of 2023. Every time the required utilization cannot be met, there is a mismatch between the output of the carcass machines and the demand of the curing machines, which directly results in NGT. We acknowledge that the month July is an extreme example and the mismatch in other months is relatively smaller. However, we can still conclude that effect of this problem on the number of NGTs is significant. Machine 51 contributes very little to the overall output and machines 53 and 55 produce with their current performance against their maximum effective capacity and can regularly not meet the required demand, which results in NGTs. In addition to this, 2 factors reinforce this problem. First, the market trend reinforces the problem as we expect the demand for larger tyres to keep increasing which keeps increasing the load on machine 53 and 55. Second Apollo Tyres Ltd. is currently performing an improvement project on the performance of the curing presses. Because of this, they expect an increase in throughput of the curing presses and thus an increase in internal demand of the curing presses, which increases the load on machine 53 and 55.

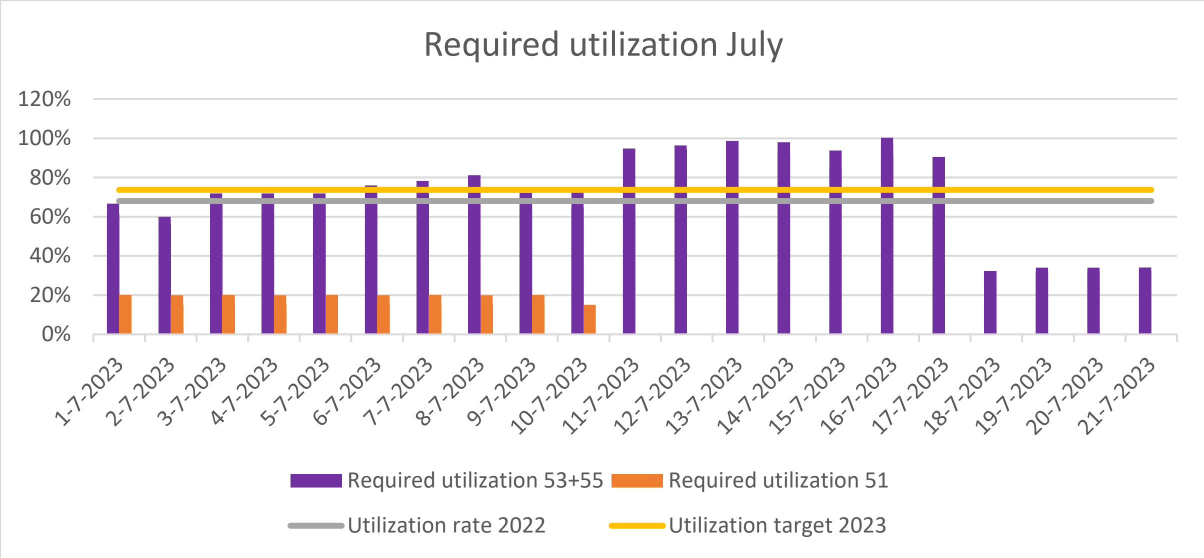



*Figure 4.4 Required utilization of carcass building machines to meet the curing demand in July 2023*

**3. Unreliable inventory**

As Section 2.5 explains every start of the shift the operators count the component, carcass, and green tyre inventory. Every shift there are deviations in the inventory levels. Based on the new inventory levels the planning department creates a new production plan. The problem is that manually counting the inventory levels includes several errors. Regarding the errors in component inventory, most components are stored in rolls. This leads to errors as it is hard to estimate how much volume of a component is still on a roll. Regarding the green tyre inventory, errors occur due to forgotten inventory locations. The green tyre location is not very clear, so locations can easily be forgotten in the counting. Next to this, the green tyres are stacked, so reading mistakes can be made when reading the higher located tyres. Furthermore, for all inventories applies that there is no clear definition of "inventory" hence some operating teams count the WIP, and others do not. In addition to this, errors also occur due to typing mistakes. All these errors in manually counting lead to an unreliable production plan. It occurs that the plan states there is enough inventory to produce a certain number of tyres, while during the production it turns out the inventory is not enough. This eventually leads to delay in production and NGTs.

Next, we discuss problem 4, 5, and 6 that occur in the category "Planning".

**4. Production plan exceeds inventory capacity**

It occurs that the production plan leads to production exceeding the inventory capacity. The shift planners can plan more production than the inventory capacity can handle as they do not take into account the inventory capacity. The planners do not determine an optimal inventory level for the carcass inventory or green tyre inventory. They only use target inventory levels to steer on. These target inventory levels are expressed in shifts, meaning that with that inventory level the next machine should be able to produce according to its production plan for a certain number of shifts. For the carcass inventory the target level is not very clear, one planner aims for an inventory of 2 shifts while the other aims for 3 shifts. For the green tyre inventory, the planners aim for an inventory level of 1.5 shift. The problem is that these target levels are based on experience and do not consider the capacity of the inventory locations. Next to this, planners only use these target inventory levels to steer on, so it occurs that planners plan more production than necessary for the target inventory levels. Since PIBS does not show a notification when the planned inventory exceeds the inventory capacity, the planners can plan more production than the inventory capacity can handle. This is a problem as a full inventory location blocks the production of the machine before it, which eventually leads to production delay and NGTs.

**5. Orbitread production plan exceeds capacity of certain positions**

Section 2.2 explains that the orbitread machine has 4 positions. Currently, the planner only considers the total utilization of the orbitread machine. As Section 2.4 explains, to avoid that the planner exceeds the maximum capacity of the orbitread machine PIBS shows the planner the total required time for the planned production, sum of norm times, against the total available production time. To determine the norm times, Apollo Tyres considers 2 situations. The situation that there is one operator and the situation that there are 2 operators. Most of the time there are 2 operators. Section 2.2 explains that for this scenario, the operators can apply breakers to 2 positions at the same time as the extruder applies the thread to 1 position. Because of this Apollo Tyres Ltd. determines the norm time in this situation by comparing the breaker time (time to apply a breaker to a certain SKU) divided by two with the extrusion time (time apply the thread to a certain SKU). The norm time of a SKU is the breaker time divided by two if this is larger than the extrusion time. If this is not the case, the norm time is the extrusion time. When taking the breaker time divided by two, Apollo Tyres Ltd. assumes that all positions are equally utilized. However, this is not the case. Due to restrictions in size, height, etc, not every position of the orbitread machine can handle every SKU. Therefore, the planned product mix (the mix of SKUs) determines the utilization of each position. If due to the required product mix the planner plans more tyres on one position than on the others, the utilization of the 4 positions is not balanced. Due to this the norm time increases, but this is not considered in the total utilization and total capacity calculation. This results in planners planning more production than certain positions can handle, which eventually leads to production delay and NGTs.

**6. Lack of production sequence in orbitread plan**

Section 2.4 shows the production plan of the orbitread machine and explains that this plan does not include a sequence in which the SKUs should be produced. Because of this the operators now decide what SKUs they produce on which position and in which sequence they produce the SKUs. The orbitread plan does not include a sequence of SKUs as "in theory" the sequence should not matter as long as the operators produce all tyres within the shift. However, this only holds if the inventory levels of the carcass, breakers, and green tyres are always greater than 1 shift and priority is never necessary. In practice this is not the case. When the inventory levels are critical, the planners plan production of inputs in the same shift as they plan to use those inputs. They for example plan production of the carcasses in the same shift as they plan to use them on the orbitread. If this occurs, priority at the orbitread is necessary to align the production. In addition to this, it occurs regularly that planners plan production of breakers in the same shift as they plan to use them at the orbitread machine. The production plan of the BIAS machine (machine that produces breakers) depends on the production plan of the orbitread machine and the production plan of the carcass building machine. Because of this, the production sequence of the BIAS machine depends on the sequence of the carcass production and the sequence of the orbitread production. However, as there is no pre-defined sequence in the orbitread production plan, the alignment between these two machines depends on the communication of the operators of these machines. This communication does not always go well and because of this, it occurs regularly that there are no breakers available. This eventually leads to production delay.

Next to this, the lack of a production sequence in the orbitread plan results in several inefficiencies in the execution of the plan. Although this research focuses on the theoretical planning, we do want to highlight the practical impact of this problem. Due to the lack of a pre-defined sequence, the operators now prioritize the SKUs and determine a sequence. To determine a sequence of SKUs the operators consider several factors. Based on the green tyre inventory and the curing plan, the operators determine the criticalilty of the green tyre inventory. A green tyre inventory level is critical if it is below 1.5 shift (target inventory level). If there are no critical green tyre inventories, the operators determine the sequence by putting the SKUs within the same size range behind each other to minimize the number of changeovers. If some SKUs do have a critical green tyre inventory level, these SKUs get priority. Hereby, the operators also consider whether they can produce this SKU by checking the carcass inventory and the breaker inventory. If the inputs are not available, the operators check the production plans of the inputs. They do this by communicating with the operators of the carcass building phase and the breaker phase. The problem is that the operators not always determine an efficient sequence of SKUs. First, as the operators should consider multiple factors of which they do not have a clear overview, determining an efficient sequence is complex. Second, some operators tend to mostly prioritize on the number of changeovers as that is convenient for them. Thirdly, the process requires a lot of communication whereby mistakes are likely to occur. Because of an inefficient sequence, efficiency losses occur that can lead to production delay. So, the lack of a predefined sequence of SKUs at the orbitread machine causes breakers to not be available and other efficiency losses. These losses eventually lead to production delay and NGTs.

Lastly, we discuss the problem 7 that occurs in the category “Planning process”.

**7. Too late arrival of new shift plan**

As Section 2.5 explains the inventory is counted every start of the shift. Because of this, the new shift plan arrives 1 to 1.5 hour after the start of the shift. This causes efficiency problems at the orbitread machine. As the production plan of the orbitread machine does not have a production sequence, the planners do not know which SKUs the operators produce in the first 1 to 1.5 hour of the shift. Therefore, the operators cannot align the new shift plan with the ‘current’ operations at the orbitread machine. This leads to efficiency losses, like unnecessary changeovers, that can eventually lead to production delay and NGTs.

We verify the relevance of the alignment problems by engaging with a wide variety of stakeholders. The key stakeholders that we involve are the operators, the shift managers, the shift planners, the planning head, the industrial engineers, and the management. We conduct 10 interviews with these stakeholders to discuss and verify the alignment problems. All stakeholders confirm that they experience the alignment problems found. In addition to this, they verify that the alignment problems found cover a significant part of the causes of NGTs.

## 4.3 Prioritize the alignment problems

This section performs phase 2 of the improvement framework in Figure 4.1. This section prioritizes the alignment problems using the adjusted FMEA technique as Section 4.1 explains. Next to this, this section selects the most constraining alignment problems. Chapter 5 investigates solutions for the most constraining alignment problems.

To involve all stakeholders in the prioritization process, we conduct a survey. Appendix B shows the survey that supports the prioritization of the alignment problems. We conduct the survey on 5 relevant stakeholders that work in the management, the Industrial Engineering department, the

Planning department, and the production floor. According to the adjusted FMEA technique, we prioritize the alignment problems on two criteria: occurrence and severity. Occurrence refers to the likelihood of a problem to occur. Severity refers to the impact of the problem in terms of time loss. We rate both criteria on an ordinal scale from 1 to 5, with: 1 = Very low, 2 = Low, 3 = Average, 4 = High, 5 = Very high. Next, we determine the RPN of each problem, by multiplying the average rating on occurrence with the average rating on severity. Table 4.1 shows the results of the survey. It provides an overview of all alignment problems and sorts all problems from highest priority to lowest priority based on their RPN. According to the survey, problems 6 and 2 have the highest priority (red), problems 5, 3, and 7 have a medium priority (orange), and problems 1 and 4 have a low priority (green).

| Problem | Occurence | Severity | RPN |
|---|---|---|---|
| 6. Lack of production sequence in orbitread plan | 4.8 | 3.8 | 18.2 |
| 2. Mismatch effective capacity of carcass building machine and curing presses | 4.4 | 4 | 17.6 |
| 5. Orbitread production plan exceeds capacity of certain positions | 3.4 | 3.8 | 12.9 |
| 3. Unreliable inventory | 3.2 | 3.8 | 12.2 |
| 7. Too late arrival of new shift plan | 4.6 | 2.6 | 12.0 |
| 1. Unrealistic norm times | 2.8 | 2.6 | 7.3 |
| 4. Production plan exceeds inventory capacity | 2.2 | 2.6 | 5.7 |

*Table 4.1 Results prioritization survey*

We emphasize that all problems interrelate with each other, therefore Apollo Tyres Ltd. can only improve the alignment of the AGRI production process by seeing the problems as priority packages. Hereby, the prioritization functions as an indicator for the order of improvements. First all high priority problems need to be solved before solving all medium priority problems, etc. Because of time limitations, this research cannot investigate solutions for all alignment problems. Hence, we select the 5 most constraining alignment problems for further investigation. The 5 most constraining alignment problems are the problems from Table 4.1 with a high and medium priority as these are supposed to be solved first. These are problems 6, 2, 5, 3, and 7. Chapter 5 investigates possible solutions for these problems.

## 4.4 Discussion on impact of alignment problems

The goal of this research is to reduce the NGT percentage by improving the alignment problems, therefore this section discusses the impact of the 5 most constraining alignment problems on the NGT percentage in more detail. As section 1.4 explains the NGT percentage is the downtime due to NGT as percentage of the total scheduled production time. Currently the average NGT percentage is 7%, meaning that on average there is about 7000 min downtime due to NGT per week. This is too high as the corporate's target is a NGT percentage of 2%. We express the impact of the alignment problems as a percentage of the downtime due to NGT(e.g. an alignment problem with an impact of 20% means that 20% of the NGT downtime is caused by this alignment problem). As Section 4.1 explains Apollo Tyres Ltd. has neither a track-and-trace system nor a closed ERP system. Hence, all operators register the downtimes manually. As a result, there is a lack of historical data on inventory levels and product paths, and slightly unreliable data of downtimes. Due to these limitations in data availability, we cannot quantify the impact of all the alignment problems with data. Also due to time limitations, we cannot track the alignment problems over a significant period of time. Hence, this section discusses the impact of the alignment problems on the percentage of NGT in the best possible way considering the limitations.

**Impact estimation**

Regarding problem 2 "Mismatch effective capacity of carcass building machine and curing presses", we can estimate the impact on the NGT percentage by analyzing the data of Figure 4.4. We assume that every production minute that the required production (curing demand) exceeds the carcass building capacity(utilization target rate 2023), there is a mismatch between the output of the carcass machines and the demand of the curing machines that directly results in an equal amount of NGT downtime. For the month July on average 1336 min per week are demanded more than the carcass building department is able to realize. We assume the mismatch in July thus results in 1336 min of NGT downtime. This is 19% of the total downtime due to NGT. As Section 4.2 explains July is a rather extreme example for this problem, therefore we estimate the impact of this problem to be 17% of the total NGT downtime. We thus estimate that solving problem 2 reduces the NGT percentage from 7% to 5.8%.

Due to data limitations we cannot estimate the impact of the other alignment problems based on data. Therefore, we create a survey in which stakeholders can estimate the impact of each problem on the downtime due to NGT to get an indication. Unfortunately, due to time limitations only 3 stakeholders responded to the survey, of which 2 are operators and 1 is a shift manager. Figure 4.5 shows the results of the survey. Even though, problem 2 is not included in the survey as we estimated its impact based on data, Figure 4.6 does show problem 2 to provide an overview.

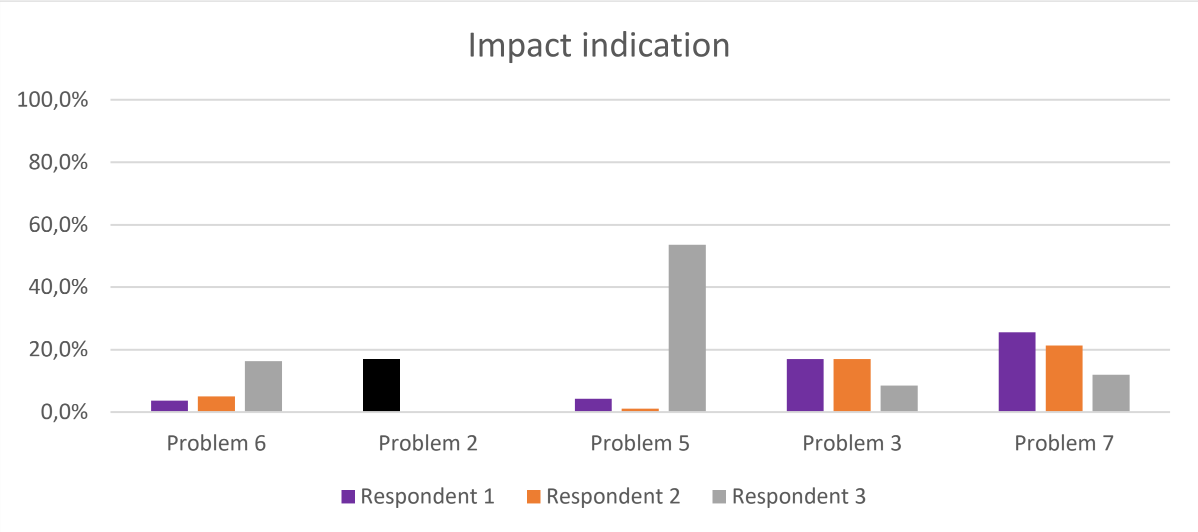



*Figure 4.5 Impact indication of alignment problems on the NGT downtime*

**Discussion**

It is questionable whether we can draw valid conclusions from the survey. We have three reasons for this. First, the number of responses is very low and the variety in respondents functions is also low. Therefore, it is unsure whether the responses are representative for all stakeholders of this research. Second, the responses show quite some inconsistencies, especially for problem 5, where the responses have more than 50% variation. Lastly, the responses also contain some internal inconsistency. For example, summing the indications of respondent 3 result in an impact of 107%, which is impossible. Because of this, we provide a final impact indication based on our own experience and knowledge and our interpretation of the survey results. We do this as a best guess to provide an indication/sense for the impact of the alignment problems on the NGT percentage. We analyse and discuss the results of the survey per problem.

Regarding problem 6 “Lack of production sequence in orbitread plan”, the responses vary between an impact of 3.6% and 16.2%. This shows some inconsistency in the opinions of the respondents. The first point of discussion is that the 2 responses that indicate an impact of around 4% come from operators. For the operators, problem 6 might be a sensitive topic because due to problem 6 the operators are currently responsible for determining the production sequence at the orbitread. Therefore a high impact indication for this problem indirectly states something about the performance of the operators in determining the production sequence. Even though we believe the operators filled in the survey with integrity, they maybe were unconsciously biased. Second, during the research we experienced that problem 6 is a severe problem that occurs every shift. Every shift the orbitread plan does not include a production sequence. As Section 4.3 explains this leads to problems when the inventory levels are critical as the planners than plan production of inputs in the same shift as they plan to use those inputs. From the observations we found that this occurs almost every shift. Because of this even though 2 responses lay around 4%, we agree more with response 3 that indicates an impact of 16.2%. Hence, we estimate that problem 6 causes 16% of the downtime due to NGT. Consequently, we estimate that solving problem 6 reduces the percentage of NGT from 7.0% to 5.9%.

For the impact of problem 5 “Orbitread production plan exceeds capacity of certain positions” the results of the survey show some great variation, ranging from 4.3% to 53.6%. On the one side, the operators indicated an impact of 4% or lower, which is significantly lower than expected considering their frequent mention of this problem during the interviews. This suggest a contradiction in their responses. On the other side, shift manager’s response was unexpectedly high. While all shift managers acknowledged this problem during the interviews, they never emphasized it as forming 50% of the alignment problems. Consequently, we believe these responses may not accurately indicate the impact of this problem. Based on the interviews and observation we rather expect this problem to be responsible for 12% of the NGT downtime. Accordingly, solving problem 5 results in a reduction of NGT percentage from 7% to 6,1%.

The impact indications for problem 3 “Unreliable inventory” vary from 8.5% to 17%, showing some inconsistency. Section 4.2 explains that Apollo Tyres Ltd. experiences counting mistakes every day which leads to an unreliable inventory. It occurs that due to this the production plans show a inventory to be there that turns out not to be there. During the observations we experienced that problems due to unreliable inventory not always result in NGT as the affect can sometimes be resolved before resulting in NGT. Therefore, we agree with respondent 3 and estimate problem 3 to cause 9% of the NGT downtime. Hence, we expect that solving problem 3 results in a reduction of NGT percentage from 7% to 6.4%.

The impact indications for problem 7 “Too late arrival of new shift plan” vary between 11.9 and 25.5%. This again shows some variation in the opinions of the respondents. There are two discussion points. First, both indications of an impact of 20% or higher come from the two operators whereas the shift manager indicated an impact of around 12%. From the observations and interviews we found that especially the operators experience several inconveniences due to problem 7, as they need to deal with the consequences of the new shift plan arriving 1 to 1.5 hour after the start of the shift. Therefore, the might have unconsciously overestimated the impact of this problem on NGT downtime. Second, from the observations we found that the new shift plan arrives too late every shift. However, it does not necessarily leads to problems every shift as sometimes it arrives too late but does not cause NGTs. Because of this, we estimate the impact of problem 7 to be 11%. Hence, we expect that solving this problem results in a reduction of NGT percentage from 7% to 6.2%.

**Conclusion**

Figure 4.6 shows an overview of the final impact indications. The final impact indications show the same priority groups as Section 4.3. discussed. Section 4.3 determined problems 2 and 6 to have high priority and problems 5,7,and 3 to have medium priority. In line with this, figure 4.6 shows a significant higher impact indication for the high priority problems compared to the medium priority problems. The exact order within the groups is slightly different. Therefore, we recommend to see the priority as problem packages, first all high priority problems need to be solved before addressing the medium priority problems, etc. The order within the problem packages is of less importance.

According to the final impact indications the high priority problems, problems 2 and 6, form 33% of the NGT downtime. Accordingly, we expect solving the high priority problem results in a reduction of the NGT percentage from 7% to 4.7%. The medium priority problems form 32% of the NGT downtime. So the high and medium priority alignment problems are responsible for 65% of the NGT downtime. We expect solving the high and medium priority alignment problems reduces the NGT percentage from 7% to 2,5%. This is somewhat above the corporate's target of 2%.

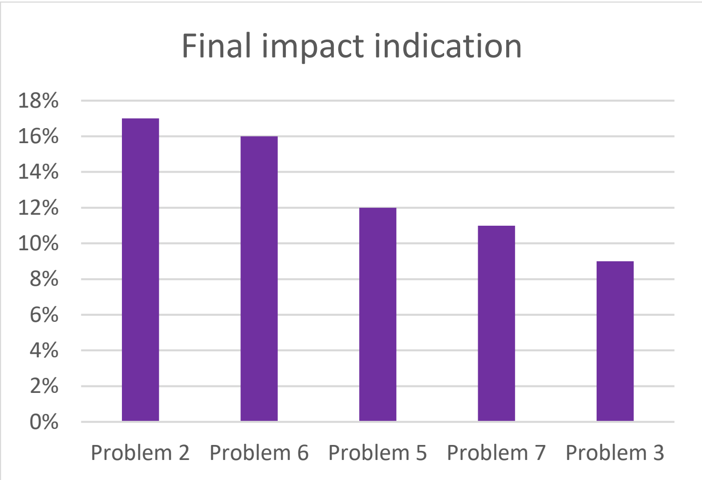



*Figure 4.6 Final impact indication of alignment problems on NGT downtime*

## 4.5 CONCLUSION

Chapter 4 discussed the identification of the alignment problems in the carcass building, orbitread, and curing phase of the AGRI production process.

Section 4.1 developed of an improvement framework to support the identification and improvement of the alignment problems. The improvement framework is an application of the literature of Chapter 3. Improving the alignment between the carcass building, orbitread, and curing plan fits within third step of the TOC cycle "Subordinate process to the constraint". Hereby, Apollo Tyres Ltd. identified the curing phase to be the constraint. Within the third step of the TOC cycle, we perform 3 phases. Phase 1 identifies the alignment problems, phase 2 prioritizes the alignment problems, and phase 3 improves the most constraining alignment problems.

Section 4.2 performed phase 1 of the improvement framework. This section identified the alignment problems by performing a Gemba walk. This resulted in the following 7 alignment problems:

1. Unrealistic norm times
2. Mismatch effective capacity of carcass building machine and curing presses
3. Unreliable inventory
4. Production plan exceeds inventory capacity
5. Orbitread production plan exceeds capacity of certain positions
6. Lack of production sequence in orbitread plan
7. Too late arrival of new shift plan

Section 4.3 performed phase 2 of the improvement framework and prioritized all alignment problems by applying an adjusted FMEA technique. In line with this technique, we conducted a survey that rated each problem on occurrence and severity. From these ratings we determined an RPN score for each problem that indicated the priority of the problem. The problems with the highest priority are problems 6 and 2. The problems with a medium priority are problems 5, 3, and 7. The problems with the lowest priority are problems 1 and 4. Chapter 5 performs phase 3 of the improvement framework and investigates possible solutions for the most constraining alignment problems. Section 4.3 selected the problems with a high and medium priority as most constraining alignment problems.

Section 4.4 discussed the impact of the alignment problems. Figure 4.6 shows the final impact indications that function as an indication/sense for the impact of the alignment problems. We estimate the high priority and medium priority problems to cause 33% and 32% of the NGT downtime respectively. Solving the high and medium priority problems should hence reduce the NGT percentage from 7% to 2.5%.

# 5. Improvement of most constraining alignment problems

This chapter performs phase 3 of the improvement framework by investigating possible solutions for the most constraining alignment problems. This chapter discusses the improvements for the problems in descending order of priority. Section 5.1 identifies solutions for problem 6 “lack of production sequence in the orbitread plan”. Section 5.2 discusses solutions for problem 2 “Mismatch effective capacity and curing presses”. Next, Section 5.3 investigates solutions for problem 5 “Orbitread production plan exceeds capacity of certain positions” and Section 5.4 for problem 3 “unreliable inventory”. Lastly Section 5.5 investigates solutions for problem 7 “Too late arrival of new shift plan”. Finally, this chapter finishes with a conclusion in Section 5.6.

## 5.1 Problem 6: Lack of production sequence in orbitread plan

Currently, the production plan of the orbitread does not include a pre-defined (prioritized) production sequence. Section 4.2 explains that if the inventory levels of the carcasses, breakers, or green tyres are critical, priority is necessary. Now, the orbitread operators determine the priority and production sequence by verbally communicating with the operators of the carcass building machines, the BIAS, and curing presses. This is time consuming and complex. As a result, operators regularly perform the production in an inefficient sequence. This leads to efficiency losses and misalignment resulting in NGTs.

**Solutions for this problem**

We identify 2 ways to create a pre-defined production sequence for the orbitread plan:

1. Develop a prioritization tool

One solution is to develop a prioritization tool in for example Excel VBA. This tool can be used in addition to the production planning system. When the planners finish the orbitread MPS in PIBS, they can use the MPS as input for the tool. Based on an algorithm the tool than determines a sequence that considers all necessary factors, as Section 4.2 explains. Next, the shift planners can adjust their planning in PIBS with the correct sequence. The advantage of this solution is that it is easy to develop, easy to implement, and relatively cheap. A disadvantage of this solution is that is requires several extra steps that the shift planners should take.

2. Integrate prioritization in Apollo’s new AMES planning system

Another solution is to integrate prioritization in the new planning system of Apollo Tyres Ltd. Currently, Apollo Tyres Ltd. is developing a new production information and operating system called AMES. Among others this system will support the production planning. In the development of this system a function can be added that determines a production sequence for the orbitread. An advantage of this solution is that this it does not add more work to the daily operations of the planners. A disadvantage of this solution is that it is more complex to develop, and implementation will take more time as the development of the new production information and operating system is a time-consuming process.

Both solutions require a step-approach to determine an production sequence that considers all necessary factors. Figure 4.3 shows a flowchart that illustrates how the solutions should determine the production sequence on the orbitread. In the figure GT refers to green tyre. The first step is to determine the green tyre inventory level of each SKU on the orbitread production plan. The inventory level should be expressed in the number of shifts that the production can continue with the current green tyre inventory. The second step is to assign the SKUs to a group, SKUs with a critical inventory level and SKUs with a non-critical inventory level. The inventory level is critical when it is less than 1 shift as that means the green tyre should be cured in the same shift as it needs to be produced on the orbitread machine. The third step is to prioritize the critical SKUs on green tyre level. The fourth step groups the non-critical SKUs on flange sizes to minimize the necessary changeovers. Flanges are small drums on which the carcasses rest in the orbitread machine. As the carcass SKUs differ in size, flange changeovers are necessary and should be minimized. Next, the fifth step optimizes the sequence of the non-critical SKUs by prioritizing the flange groups on the green tyre inventory level of the SKUs within the flange groups. The sixth step combines all SKUs into one production sequence, by putting the prioritized list of critical SKUs first and the list of non-critical SKUs second. Finally, step 7 adjusts the prioritized list based on the carcass inventory level and carcass plan.

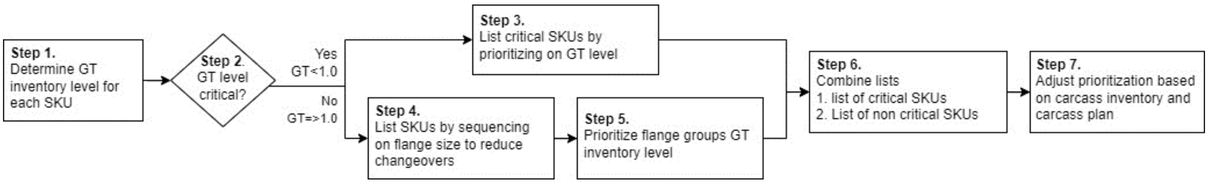



*Figure 5.1 Flowchart to support the development of an orbitread production sequence*

## 5.2 PROBLEM 2: MISMATCH EFFECTIVE CAPACITY OF CARCASS BUILDING MACHINE AND CURING PRESSES

As section 4.2 explains, Apollo Tyres Ltd. experiences a market trend of an increase in demand for tyres with a larger size and a decrease in demand for tyres with a smaller size. Consequently, the demand for smaller sized tyres limits the production of the Farrel 51, as this machine can only handle the tyres with a smaller size. Next to this, the load for the VMI 53 and Mesnac 55 keeps increasing. As the performance of these machines is not increasing that much, the total effective capacity of the carcass building phase does not match with the demand of the curing presses anymore. This leads to NGTs.

**Solutions for this problem**

We identify 3 solutions to improve the alignment of the effective capacity of the carcass machines on the demand of the curing presses:

1. Shut down one curing press

One solution to improve the alignment is to shut down one of the curing presses for large tyres. By shutting down one of the curing presses Apollo Tyres Ltd. can decrease the internal demand of the curing machines. As a results, the workload on machine 53 and 55 decreases and the carcass production meets the required curing demand. The advantage of this solution is that with this solution Apollo Tyres Ltd. avoids the costs of downtime due to NGT. However, this solution is not ideal as it also results in an overall lower output and thus a cost of lost sales. It does not challenge the building department. In addition to this, it is not in line with the overall improvement strategy as this solution subordinates the production process to the carcass department and not to the curing department.

2. Improve performance of machine 53 and 55

Another solution is to set-up an improvement project on the performance of machine 53 and 55. Apollo Tyres Ltd. aims to reach the utilization target rate of 74% by the end of 2023. The demand for this is high enough. However, the performance of machine 53 and 55 is currently not high enough to reach this target and therefore NGTs occur. The advantage of this solution is that improving the performance of carcass building machine 53 and 55 not only results in a lower number of NGTs but also in an overall better performance of the production process. Furthermore, it is in line with the improvement strategy. A disadvantage of this solution is that it is a short-term solution. If the market trend and the curing improvement project continue, at some point the performance improvement will no longer be enough as the machines will produce against their maximum capacity.

3. Increase capacity by buying a new carcass building machine

The third solution is to increase the capacity of the curing department by buying a new carcass building machine that can handle the larger sized tyres. An advantage of this solution is that it is a long term-solution as it considers that the impact of this problem is increasing due to the market trend and the curing improvement project. This solution solves the problem for at least a significant amount of time. The disadvantage of this solution is that it is quite expensive as a new machine costs a lot of money and requires skilled operators. Furthermore, even though the demand is increasing, buying a new carcass building machine with the current demand results in a relatively low utilization rate of the carcass machines in the first years of the investment. A low utilization rate costs Apollo Tyres Ltd. money which is not beneficial.

## 5.3 Problem 5: Orbitread production plan exceeds capacity of certain positions

The orbitread machine has 4 positions. Section 4.2 explains that it regularly occurs that the planners plan too many tyres of a SKU that can only be produced on one position. When this happens, the orbitread production plan exceeds the capacity of that position. This problem occurs because production planning only considers the total capacity of the orbitread machine and not the capacity per position.

**Solutions for this problem**

We identify two solutions for this problem:

1. Integrate an algorithm in Apollo's new AMES planning system that considers the capacity per position and warns the planner when the production plan exceeds the capacity of that position

One solution is to develop an algorithm that considers the capacity per position and warns the planner when the production plan exceeds the capacity of that position. An algorithm is necessary as determining the utilization is complex when considering that not all positions are equally utilized. When all positions are not equally utilized the norm time depends on how many positions are utilized. Furthermore, the norm time depends on which SKUs are on each position at a certain moment. Because of this there are multiple scenarios in which the norm times are different. Only an algorithm can accurately consider which scenario is the case and what the norm time corresponds to that. As the current planning system PIBS is too old to implement such an algorithm, this solution only applies for the new plannings system AMES. An advantage of this solution is that an algorithm can determine the utilization per position very accurately and therefore it really prevents planners from exceeding the capacity per position. However, some disadvantages are that it is expensive and very time consuming to develop such an algorithm. Furthermore, the development of the new plannings system AMES is a time-consuming process, so Apollo Tyres Ltd. must wait before they can implement this solution.

2. Determine a maximum production quantity per positions

As precisely determining the utilization per position is very complex, another solution is to determine a maximum production quantity per position. Based on the experience of the operators, Apollo Tyres Ltd. can determine a maximum production quantity per position. By making sure that the planners never plan more production per position than the maximum allowed quantity, this solution is likely to avoid the planners exceeding the capacity of certain positions. An advantage of this solution is that it is relatively cheap to implement, and it contributes to a more realistic production plan of the orbitread machine. However, a disadvantage is that the determination of a maximum production quantity based on operators' experience might result in an unnecessary low maximum, hereby limiting the output of the orbitread machine.

For both solutions, it is important that the orbitread production plan includes a production sequence as for both solutions it is necessary to know what SKUs are being built on which position. In addition to this, for this problem we need to consider that Apollo Tyres Ltd. is currently planning to buy a new orbitread machine. This new orbitread machine does not consist of 4 positions and therefore this problem does not apply to the new machine. Hence, we need to consider whether it is worth implementing one of the solutions until the new machine arrives or not. Section 6.2 elaborates on this.

## 5.4 Problem 3: Unreliable inventory

As Section 4.2 explains, currently the daily production plans are created based on the inventory levels that the operators count every start of the shift. Several errors occur in the manually counting leading to an unreliable inventory, and thus an unreliable production plan. Consequently, it occurs that the plan states there is enough inventory to produce a certain number of tyres, while during the production it turns out the inventory is not enough. This eventually leads to delay in production and NGTs.

**Solutions for this problem**

We identify two solutions for this problem:

1. Develop a clear counting procedure for the operators and improve counting circumstances.

One solution is to improve the manual counting system by the developing a clear counting procedure and improve the circumstances. Currently, there are some procedural differences between the different operating teams causing inventory deviations. By developing a clear counting procedure Apollo Tyres Ltd. can resolve these differences and create uniformity in counting. The procedure should at least include a clear definition of "inventory" and a clear overview of all inventory locations and how to fill them. A definition of "inventory" should provide clarity to the operating teams on whether the work in progress should be counted or not. Next to this, several errors occur due to forgotten inventory locations, especially at the green tyre inventory as these are randomly stacked. An overview of all inventory locations and a clear procedure on how to fill these, provides standardization and a better insight into where tyres are stored. This reduces the number of errors due to forgotten inventory locations. In addition to a clear counting procedure, some counting circumstances can be improved. At the green tyre location counting errors occur due to reading mistakes as the SKU tickets of the higher stored tyres are hard to read. By printing the SKU tickets on a larger size, the readability improves, and the number of reading errors decreases. The advantage of this solutions is that it is cheap and easy to implement. However, a disadvantage is that it still relies on human counting which involves human mistakes.

2. Develop a digital track and trace system

Another solution is to develop a digital track and trace system. A digital track and trace system is independent on humans and enables constant monitoring of the inventory levels. The advantage of this, is that it is objective and reliable. Next to this, it improves the data availability on inventory levels as it enables saving historical data on the inventory levels. Furthermore, it saves the time spend on counting the inventories. A disadvantage of this solution is that it is hard to develop, and it costs a lot of money.

## 5.5 PROBLEM 7: TOO LATE ARRIVAL OF NEW SHIFT PLAN

Section 4.2 explains that in each shift inefficiencies occur at the orbitread machine due to a too late arrival of the new shift plan. The new shift plan arrives on average 1 to 1.5 hour after the start of the shift. Currently this leads to misalignments between the new shift plan and the 'current' operations of the operators.

**Solutions for this problem**

We identify five solutions for this problem:

1. New shift plan at the start of the shift based on inventory estimations

A first solution is to make sure the new production plan is ready at the start of the shift by estimating production during the shift before. Currently as Section 2.5 explains, at the end of each shift the operators determine the new inventory levels by estimating the production during that shift. In the start of the next shift the operators manually count the inventory and based on this the planners create a new production plan. This solution proposes to create the new shift plan based on the estimated inventory levels at the end of a shift. An advantage of this solution is that with this solution the new production plans are ready at the start of the shift, hereby avoiding the misalignments. Next to this it is cheap and relatively easy to implement. A disadvantage is that basing the new production plans on estimated inventory levels might result in an unreliable production plan, which reinforces problem 3.

2. New shift plan at start of the shift based on inventory levels from a digital track and trace system

The second solution is to make sure the production plan arrives at the start of the shift, by implementing a digital track and trace system. As Section 5.4 explains a track and trace system enables constant monitoring of the inventory levels. Based on these inventory levels, the planners can create the new production plans at the end of each shift hereby making sure the production plans are ready at the start of the new shift. An advantage of this solution is that it makes sure there cannot be any alignment problems between the new shift plan and the operations in the first hour. Furthermore, it saves time spend on counting the inventories. A disadvantage is that a track and trace system is hard to develop and costs a lot of money. Another disadvantage is that this solution still relies on some form of estimations as the production during the creation of the new production plan should be estimated.

3. Develop a procedure for the communication between the orbitread operators and the shift planners

The third solution is to develop a communication procedure. Currently, there is poor communication between the orbitread operators and the shift planners. Because of this the shift planners cannot align the new production plans with the operations of the orbitread operators in the first 1 to 1.5 hour. This communication procedure should make sure that the orbitread operators and shift planners communicate what is being produced in the first 1.5 hour of the shift. Based on this information the shift planners can make sure to align the new shift plan. An advantage of this solution is that it is cheap and easy to implement. A disadvantage is that it costs the operators extra time, and it relies on human communication which is prone to cause human mistakes.

4. Use an orbitread production sequence and 'freeze' the first SKUs in the sequence

The fourth solution is a replication of what the planning does for the carcass building production plans. This solution requires an orbitread production sequence for which Section 5.1 offers solutions. When having a production sequence in the orbitread plan the planners can 'freeze' the first SKUs in the sequence. Meaning that the planners can only change the production plan of the SKUs further in the sequence, to make sure the new plan aligns with the orbitread operations of the first 1.5 hour. An advantage of this solution is that it improves the alignment of the new production plan and the operations of the first 1.5 hour. However, a disadvantage is that it is hard to determine how much SKUs the planners should "freeze" because as section 5.3 explains it is complex to determine accurate norm times for the orbitread machine.

5. Prioritize AGRI within the planning process

Currently, the prioritization in the planning process does not match the strategy of Apollo Tyres Ltd. As Section 3.1 explains Apollo Tyres Ltd. shifted focus towards AGRI production. However, within the planning process the shift planners create the production plans of PCR first, of SM second, and lastly of AGRI. Because of this the AGRI production plans arrive 1 to 1.5 hour after the start of the shift. By prioritizing the AGRI production plans first, the AGRI production plan will arrive earlier. The advantage of this solution is that it reduces the losses due to misalignments between the new production plan and the operations of the first 1.5 hour of the shift and it is cheap and easy to implement. A disadvantage of this solution is that it does not solve the problem entirely, it only minimizes the efficiency losses.

## 5.6 CONCLUSION

This chapter investigated solutions for the 5 most constraining alignment problems and discussed them in descending order of priority.

Section 5.1 investigated solutions for problem 6 “Lack of production sequence in orbitread plan”. This problem can be solved by either developing a prioritization tool or integrating a prioritization in Apollo’s new AMES planning system. In addition to this, Section 5.1 provided a step-approach to develop a prioritized production sequence as a blueprint for both solutions.

Section 5.2 investigated solutions for problem 2 “Mismatch effective capacity of carcass building machine and curing presses”. This problem can be solved in three ways. The first option is to decrease the internal demand by shutting down one curing press. The second option is to improve the performance of carcass building machine 53 and 55. The last option is to increase the capacity of the carcass building department by buying a new carcass building machine.

Section 5.3 investigated solutions for problem 5 “Orbitread production plan exceeds capacity of certain positions”. This problem can be solved in two ways. One solution is to integrate an algorithm in Apollo’s new AMES planning system that considers the capacity per position and warns the planner when the production plan exceeds the capacity of that position. The second solution is to determine a maximum production quantity per position. Both solutions require a pre-defined production sequence. So, to solve problem 5 with one of these solutions problem 6 should be solved first. In addition to this, Apollo Tyres Ltd. is planning on buying a new orbitread machine for which this problem might not apply. Hence, we need to consider whether it is worth implementing one of the solutions until the new machine arrives or not.

Section 5.4 investigated solutions for problem 3 “Unreliable inventory”. This problem can be solved by either developing a clear counting procedure for the operators and improving the counting circumstances or developing a digital track and trace system.

Section 5.5 investigated solutions for problem 7 “Too late arrival of new shift plan”. This problem can be resolved in 5 ways. The first option is to make sure the new shift plan is ready at the start of the shift based on inventory estimations. The second option is to make sure the shift plan is ready at the start of the shift based on inventory levels from a digital track and trace system. The third option is to develop a procedure for the communication between the orbitread operators and the shift planners. The fourth option is to develop an orbitread production sequence and ‘freeze’ the first SKUs in the sequence. Finally, the fifth option is to prioritize the AGRI planning within the planning process.

# 6. Conclusion and recommendations

This chapter completes this research through the presentation of the conclusions, recommendations, and a discussion on the limitations of this research as well as suggestions for further research. Section 6.1 concludes the main findings. Section 6.2 provides recommendations and Section 6.3 discusses the limitations of this research and highlights areas for further research.

## 6.1 Conclusion

This research investigated improving the high NGT percentage caused by a sub-optimal alignment of the carcass building, orbitread, and curing department of the AGRI production process with the goal to increase the output of the curing department. We achieve this, by answering the main research question:

*“How can the alignment of the three sub-processes of carcass building, orbitread and curing be improved to decrease the NGT percentage?"*

To answer this question, this research started with analysing the current situation at the AGRI production process at Apollo Tyres Ltd. Next, we reviewed the literature on existing improvement approaches, improvement techniques, and improvement tools. Based on the knowledge about the current situation and the known improvement theories, we developed an improvement framework that supported the identification and improvement of the alignment problems. TOC is the improvement approach that Apollo Tyres Ltd. generally follows for monitoring and improving their production processes. Our improvement framework placed this research in step 3 of the TOC cycle: “Subordinate process to the curing department”. Within this step, the framework consists of 3 phases: identify alignment problems, prioritize alignment problems, and improve alignment problems.

From all this, we conclude that the alignment problems with the highest priority and their possible solutions are:

- Problem 6 “Lack of production sequence in orbitread plan”
  We expect this problem to be responsible for 16% of the NGTs. This problem can be solved by either developing a prioritization tool or integrating a prioritization in Apollo’s new AMES planning system.
- Problem 2 “Mismatch effective capacity of carcass building machine and curing presses”
  We expect this problem to account for 17% of the NGTs. This problem can be solved in three ways. The first option is to decrease the internal demand by shutting down one curing press. The second option is to improve the performance of carcass building machine 53 and 55. The last option is to increase the capacity of the carcass building department by buying a new carcass building machine.

The alignment problems with an average priority and their possible solutions are:

- Problem 5 “Orbitread production plan exceeds capacity of certain positions”
  We estimate the impact of this problem on the NGTs to be 12%. This problem can be solved in two ways. One solution is to integrate an algorithm in Apollo’s new AMES planning system that considers the capacity per position and warns the planner when the production plan exceeds the capacity of that position. The second solution is to determine a maximum production quantity per position.

- Problem 3 “Unreliable inventory”
  We estimate this problem to be responsible for 9% of the NGTs. This problem can be solved by either developing a clear counting procedure for the operators and improving the counting circumstances or developing a digital track and trace system.
- Problem 7 “Too late arrival of new shift plan”
  We estimate this problem to account for 11% of the NGTs. This problem can be resolved in 5 ways. The first option is to make sure the new shift plan is ready at the start of the shift based on inventory estimations. The second option is to make sure the shift plan is ready at the start of the shift based on inventory levels from a digital track and trace system. The third option is to develop a procedure for the communication between the orbitread operators and the shift planners. The fourth option is to develop an orbitread production sequence and ‘freeze’ the first SKUs in the sequence. Finally, the fifth option is to prioritize the AGRI planning within the planning process.

The alignment problems with a low priority are:

- Problem 1 “Unrealistic norm times”
- Problem 4 “Production plan exceeds inventory capacity”.

This research provided Apollo Tyres Ltd. insight into the alignment problems and offered solutions for the 5 most constraining alignment problems. We emphasize that all problems interrelate. Therefore, Apollo Tyres Ltd. should see the priority indications as problem packages. Stressing that the high priority problems should be solved before solving the medium priority problems and the medium priority should be solved before solving the low priority problems. Hereby, the exact order within a “problem package” is of less importance. By implementing a selection of the offered solutions Apollo tyres Ltd. can improve the alignment between the carcass building, orbitread, and curing sub-process. We expect solving the high and medium priority problems results in a reduction of the NGT percentage from 7 to 2.5%.

## 6.2 Recommendations

This section provides recommendations on the findings of this research. Section 6.2.1 provides recommendations on the implementation of the solutions and Section 6.2.2 provides additional recommendations based on information gathered during this research.

### 6.2.1 Recommendations on implementation of findings

This research identified 7 alignment problems and offered multiple solutions. This section provides recommendations on which problems to focus on and which solutions to implement.

We recommend Apollo Tyres Ltd. to first focus on the problems in the high priority group. Based on the observations, interviews, and information gathered we expect these problems to have the greatest impact on the alignment and the number of NGTs. Regarding these problems, we recommend the following:

- **Problem 6 “lack of production sequence in orbitread plan”**
  This is a problem that has great impact in the daily operations of the orbitread machine and priority on this machine is essential to properly align the production of the carcass building, orbitread, BIAS, and curing departments. Therefore, we recommend Apollo Tyres Ltd. to implement both solutions for this problem. The best solution is to integrate prioritization into Apollo’s new AMES planning system, as that does not require any additional steps for the planners. However, that is a long-term solution. Therefore, we recommend Apollo Tyres Ltd. develop a

prioritization tool as a short-term solution. We recommend using the blueprint from Section 5.1 to develop this tool.

- **Problem 2 "Mismatch effective capacity of carcass building machine and curing presses"**
  This is a problem that structurally causes NGTs. Especially considering the curing improvement project and a continuation of the market trend, we expect this problem to become bigger and bigger. Therefore, we recommend implementing 2 solutions for this problem. As a short-term solution we recommend Apollo Tyres Ltd. to set up an improvement project to improve the performance of machines 53 and 55. As a long-term solution we recommend investigating the options for buying a new carcass building machine that can handle larger sized tyres.

Regarding the problems with a medium priority, we recommend the following:

- **Problem 5 "Orbitread production plan exceeds capacity of certain positions"**
  This is a problem that regularly occurs. However, both solutions that we found have some significant disadvantages. Considering that Apollo Tyres Ltd. is planning on buying a new orbitread machine, for which this problem might not apply. We recommend Apollo Tyres Ltd. to not invest time into implementing one of the solutions, but we do recommend Apollo Tyres Ltd. to investigate how this problem can be avoided by the new orbitread machine.
- **Problem 3 "Unreliable inventory" and problem 7 "Too late arrival of new shift plan"**
  These problems have one shared long-term solution. Namely, developing a track and trace system. We recommend Apollo Tyres Ltd. to implement this solution as based on all observations, interviews, and data gathered, we expect this solution to not only tackle these alignment problems but also other problems that Apollo Tyres Ltd. experiences. As short-term solution for problem 3 we recommend Apollo Tyres Ltd. to develop a counting procedure as this is easy to implement and it improves the uniformity in counting between the operating teams. As short-term solution for problem 7 we recommend developing a communication procedure and prioritizing the AGRI planning in the planning process, as this is easy to implement and results in an earlier arrival of the AGRI planning.

We discuss the recommendations regarding problems with a low priority in Section 6.3.

### 6.2.2 Additional recommendations

This section provides some additional recommendations that we gathered during the research that apply to topics outside of the scope of this research. We summarize each recommendation with a short phrase after which the explanation follows.

- **Improve focus on short-term bottlenecks**
  Apollo Tyres Ltd. applies the TOC as improvement approach. According to this theory Apollo Tyres Ltd. defines the long-term bottleneck as the ideal bottleneck on the long-term. Hereby, they identified the curing department as long-term bottleneck. Because of this approach, a great part of the KPIs of the daily analysis focuses on the performance of the curing department, where the greatest focus is on the KPI "the percentage of NGT". We recommend Apollo Tyres Ltd. to also identify the short-term bottlenecks and analyse some KPIs of these. Hereby, short-term bottlenecks refer to the current (real) bottlenecks in the system. We expect the short-term bottlenecks to constantly shift between the carcass building department and the orbitread department. Identifying the short-term bottleneck can improve the understanding of the current performance and support prioritization in decision-making. By constantly improving the short-term bottleneck Apollo Tyres Ltd. can work towards the curing department being the only bottleneck, which is not the case yet.

- **Prioritize the AGRI production**
  As Apollo Tyres Ltd. recently shifted focus from PCR to AGRI tyres, we still see some misalignments with the new strategy. Hence, we recommend Apollo Tyres Ltd. to keep working on implementing the new strategy and to make sure the AGRI production gets the highest priority in all decision making.
- **Focus on large AGRI tyres**
  Based on the market trend which shows an increase in demand for larger tyres and the fact that Apollo Tyres Ltd. makes the most profit with the larger tyres, we recommend Apollo Tyres Ltd. to prioritize the large AGRI tyres in their decision-making and prepare for a product mix with more larger tyres. Hereby, we recommend Apollo Tyres Ltd. to only invest in large T-trucks, large cones, and machines that can handle large tyres. Not only will this prepare Apollo Tyres Ltd. on the shift in product mix, but also this will improve the standardization as the small tyres fit on the larger equipment's and large tyres do not fit the small equipment's. We emphasize that standardizing the equipment is good as it reduces complexity in the production process, which is beneficial for the AGRI production process.
- **Change performance indicator of operators**
  We recommend Apollo Tyres Ltd. to change the performance indicator that they use to assess the performance of the operators. Currently, Apollo Tyres Ltd. assesses the operators on how many tyres they produce per shift. This causes a high pressure and leads to operators deviating from the production plan as Appendix A explains. Hence, we recommend Apollo Tyres Ltd. to implement a performance indicator that assesses the operators on performing according to the production plan.
- **Improve knowledge transfer**
  At Apollo Tyres Ltd. a lot of decisions and operations are based on experience of the employees. This means that the functioning of the operations at Apollo Tyres Ltd. currently depends for a great part on the knowledge of the employees. This forms a risk as this knowledge is lost when the employees leave the company. Therefore, we recommend Apollo Tyres Ltd. to develop and implement a clear policy on knowledge transfer to ensure continued performance of the plant.
- **Include tracing and order times in AMES**
  Apollo Tyres Ltd. only registers the downtimes of the production process. They have no data available on the inventory levels and the production paths of SKUs. Due to this Apollo Tyres Ltd. cannot trace back the causes of the downtimes in the data. Next to this, the current system PIBS does not include an order time for each SKU. The order time is the time at which a product should be produced to be in time for the next production phase. In the current system PIBS, there is no order time available in the production phases after the component preparation. Due to this, during the shift there is no insight into whether the operators are on schedule or not. As a result, Apollo Tyres Ltd. mostly controls the production process based on historical data on downtimes rather than on (near) real time data and historical data on product paths. We recommend Apollo Tyres Ltd. to investigate solving these problems by including the order times in AMES and develop a track and trace system.

## 6.3 LIMITATIONS AND FURTHER RESEARCH

This section discusses the limitations of this research. Based on the limitations we suggest topics for further research. We summarize each suggestion with a short phrase after which the explanation follows.

- **Further investigate the impact of the alignment problems**
  Due to time limitations and limited data availability, we could not quantify the impact of the problems on the NGT percentage. We provided an indication of the impact based on our own knowledge and experience and a survey. However, the survey results showed a lot in of consistencies which decreased its validity. Therefore, we recommend Apollo Tyres Ltd. to investigate the impact of all problems before solving one of the alignment problems. We advise Apollo Tyres Ltd. to do this by either developing an ERP system or including tracing and order times in AMES as Section 6.2 explains or by manually monitoring the NGTS and alignment problems over a significant period of time (at least 4 months). Every time a NGT occurs the operators should not only register the downtime but also the time at which it occurs. Next, if a NGT occurs in a shift all operators should register all downtimes of that shift and the time at which the downtimes were caused. Hereby, they should monitor how often the downtimes are caused by one of the alignment problems. In addition, the historical data on inventory levels should be saved. Having all this information, Apollo Tyres Ltd. can trace done how often a NGT occurs due to one of the alignment problems when having enough inventory. Regarding problem 2 "Mismatch effective capacity of carcass building machine and curing presses" we recommend Apollo Tyres Ltd. to monitor the mismatch over a significant period of time to know how big the mismatch is. Furthermore, we advise determining the impact of this problem by monitoring how often the carcass production does not meet the production plan, how much delay this causes, and to how much NGT downtime this leads. The impact of problem 6 "Lack of production sequence in orbitread plan" can be measured by monitoring how often delay on the orbitread occurs due to miscommunications/inefficient production sequence, and how often this delay causes NGT downtime. The impact of problem 3 "unreliable inventory" can be determined by monitoring how often counting mistakes lead to delay and NGT downtime. To determine the impact of problem 5 "Orbitread production plan exceeds capacity of certain positions", Apollo Tyres Ltd. can monitor how often the orbitread plan is not met due to overdemand on certain positions, and to how much NGT downtime this leads. Lastly, the impact for problem 7 "Too late arrival of new shift plan" can be measured by monitoring how much efficiency delays this problem causes, and to how much delay and NGT downtime this leads.
- **Investigate solutions for the low priority problems**
  Problem 1 "Unrealistic norm times" and problem 4 "Production plan exceeds inventory" are the problems with a low priority as the outcomes of the survey showed that the employees do not expect these problems to occur often and have a severe impact. Due to time limitations, we therefore did not investigate the impact or possible solutions for these problems. Hence, we recommend Apollo Tyres Ltd. to investigate the impact of these problems and investigate solutions for these problems.
- **Investigate alignment problems in other production phases**
  Due to time limitations we scoped our research down. We only investigated the alignment problems in the carcass building, orbitread, and curing phase. Hence, we recommend Apollo Tyres Ltd. to also investigate the alignment problems in the phases before the carcass building phase, as these can also lead to NGTs.

- **Further investigate the idea of "equal batch sizes"**
  During the research multiple stakeholders stated that an ideal scenario would be if the carcass building machines and the orbitread machine would have the same batch size. The advantage of such a batch size is that it will reduce a lot of complexity and improve the alignment. However, determining such a batch size is complex as the determination should consider the component supply, the inventory capacities, the machine capabilities, and machine capacities. Because of this complexity and the limited time available, we have not investigated this solution. Therefore, we recommend Apollo Tyres Ltd. to further investigate this idea.

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# APPENDIX

## APPENDIX A: ROOT CAUSE ANALYSIS

This appendix explains the results of a root cause analysis we conducted to find the core problem of why the curing phase is not reaching its target output.

To find the core problem, we retrieve information by conducting interviews with the Industrial Engineering department and the management. We visualize the information in a problem cluster that shows all problems and the causal relationships between them. Figure A.1 shows the problem cluster. We explain all problems and assess all potential core problems on their feasibility for this research and their suitability regarding the scope of this research.

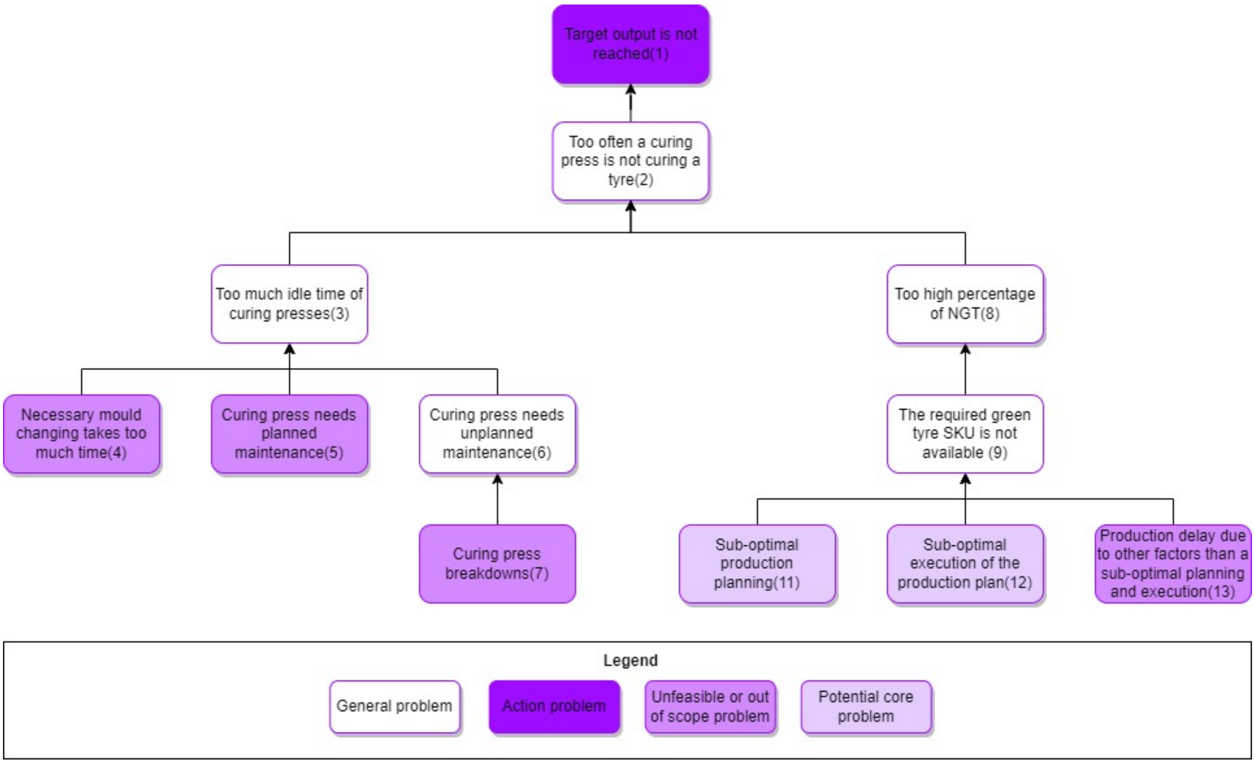


*Figure A.1 Problem cluster*

Apollo Tyres Ltd. identified that the constraint of the AGRI production process is the curing phase as this department is not reaching its target output (1). This target output is not reached because it occurs too often that a curing press is not curing a tyre (2). There are two reasons for this. On the one side the curing presses have too much idle time (3) and on the other side the NGT percentage is too high (8). Green tyres are the input for the curing presses. NGT, No Green Tyre, is the percentage of planned working time during which a machine is not working because the required green tyre SKU is not available in inventory.

**Too much idle time of curing presses**

Idle time is defined as the time during which a curing press is not curing a tyre while there is enough green tyre inventory. This high idle time of the curing presses is caused by the time it takes to change a mould (4), the time of planned maintenance for the curing presses (5), and the time of unplanned maintenance (6) because of curing press breakdowns (7). Mould changes at the curing press (4) and planned maintenance (5) are necessary and simply require time. Investigating the possibilities to minimize the required time needed for these activities is not of interest to the company, because they have already investigated this and are currently working on minimizing it. Therefore, we consider these potential core problems out of scope. Unplanned maintenance (6) is a problem caused by machine breakdowns (7). To solve this problem specific mechanical knowledge is needed, since this is not part of the Industrial Engineering & Managment study, we consider this problem unfeasible.

**Too high NGT percentage**

On the other side, curing presses are repeatedly not working due to a too high percentage of NGT (8). Logically this percentage increases when the required green tyre SKU is not available (9). It occurs too often that the inventory level and mix of green tyres deviate from the planned inventory level and mix. At Apollo Tyres Ltd. this manifests itself in two forms. First, it could be that there are not enough green tyres available at all. Second, it could be that there are enough green tyres available, but not of the required SKU. For the sake of simplicity both problems are summarized in problem 9 "The required green tyre SKU is not available".

There are multiple causes for not having the required green tyre SKU available. The main causes are a sub-optimal production planning (11), a sub-optimal execution of the production plan (12), and production delay due to other factors than a sub-optimal planning and execution (13).

The first cause is problem 11 "a sub-optimal production planning". The inventory level and mix of green tyre SKUs are determined by the production plans of the carcass building and orbitread machines. Currently, there are several mismatches between the production plans of the carcass building & orbitread machines on the demand of the curing machine. It occurs that the production plans of the carcass building and orbitread machines produce less or more than the curing machine demands. When this happens the product mix is not balanced correctly and consequently NGTs occur. That the production plans produce less or more than the curing presses demands has several causes. An example of a possible cause is an unrealistic planning. An unrealistic planning causes the production to not meet the planned target, consequently this results in not meeting the demand of curing. Currently Apollo Tyres Ltd. has no insight into what mismatches exactly occur in the planning and how often they occur.

The second cause is problem 12 "a sub-optimal execution of the production plan". Currently the execution of the production plan is sub-optimal since operators tend to deviate from the production plan. This is mainly because of two reasons. First, the operators' performances are measured by the number of SKUs they produce in one shift. This performance measure does not consider which SKUs the operators produce. Therefore, there are no penalties for the operators for deviating from the production plan. In addition to this, the operators are unaware of the consequences of deviating from the production plan. Subsequently, they do not see the problem of deviating from the production plan. However, since the carcass building machines supply the orbitread machines, and the orbitread machines supply the curing machines, mismatches occur when the operators at one of those machines are not producing according to the production plan. Again, such mismatches result in not having the required green tyre SKU available.

The last cause of not having the required green tyre SKU available is production delay due to other factors than a sub-optimal planning and execution (13). Production delays occur because of several problems related to mismatches in production planning and execution. However, there are two other factors causing delay that do not relate to planning and execution. The first factor is that there is a lack of (qualified) operators. Due to this it happens that machines cannot work because there are no operators available. The second factor is unplanned machines & equipment breakdowns. As in the curing phase, machine & equipment breakdowns also occur in the carcass building and orbitread phase. The difference is that delay caused by machine & equipment breakdowns in carcass building and orbitread phase result in NGTs whereas breakdowns at the curing phase do not impact the NGT percentage. Currently, the company is already working on improving the "lack of operators". Furthermore, improving "machine & equipment breakdowns" requires technical knowledge that is not part of the Industrial Engineering and management study. Therefore problem 13 is inappropriate for this research since it is partially out of scope and partially unfeasible.

Hence, there are two potential core problems left:

- Problem 11, "Sub-optimal production planning"
- Problem 12, "Sub-optimal execution of the production plan"

Both the production planning and the execution are sub-optimal because they result in mismatches of the planning and activities of the carcass building & orbitread machines on the demand of the curing machines. In other words, there is a sub-optimal alignment between the three production phases. Therefore, the potential core problems 11 and 12 can be combined into the following core problem:

*"At Apollo Tyres Ltd. there is a sub-optimal alignment of the carcass building, orbitread, and curing phase causing a too high NGT percentage."*

## Appendix B: Production plan

### B. 1 Curing plan

Figure B.1 is an example of a part of the curing plan. On the left side it shows 5 curing presses(pers). Next to this are the planned SKUs(maat). On the right side of the SKU code, the planning shows the number tyres to produce of this SKU (aantal). The curing department produces this quanity and then executes a changeover. The planned date for a changeover is shown by the displayed shift. Hereby 1 refers to the night shift, 2 the morning shift, and 3 the afternoon shift.

```
JOHNNY      LB267      VULKANISATIEPLAN 4 WEKEN                23/05/23  13:35
                                                                  Afbeelden

          Huidige-          Week :  21     22     23     24    Nieuwe-
Pers Maat              Vorm   Aantal mdwdvz mdwdvz mdwdvz mdwdvz Maat              Vorm    K
Kern V4
209  600/65R28TRX1542817-01   150 ...... ..3... ...... ......
     600/65R28TRX1542817-01   101 ...... ...... ....1. ...... 600/70R28TRX1572906-01
     600/70R28TRX1572906-01   100 ...... ...... ...... .....2 600/70R34TRX1602907-01
211  620/75R30TRO1722896-01    90 .....2 ...... ...... ...... 540/65R38TVZ1472724-01
     540/65R38TVZ1472724-01    90 ...... ......3...... ......
     540/65R38TVZ1472724-01   106 ...... ...... ...... 3..... 600/65R38TVZ1532725-01
213  600/70R30TRX1582818-01   180 ....2. ...... ...... ...... 650/65R34TRO1702839-01
     650/65R34TRO1702839-01    90 ...... ...... 1..... ...... 540/65R30TRO1582759-01
     540/65R30TRO1582759-01   100 ...... ...... ...... .2.... 600/65R28TRX1472817-01
215  600/70R28TRX1572906-01   150 ...... .....2 ...... ...... 650/40R22FTT1502941-01
     650/40R22FTT1502941-01   121 ...... ...... ...... 1..... 680/50R22FTT1572832-01
231  800/45R26FLT1742929-01   100 ...... .1.... ...... ......
     800/45R26FLT1742929-01   132 ...... ...... ..3... ...... 650/65R42TVZ1582898-01
233  900/60R42TRO1892891-01    58 ...3.. ...... ...... ...... 710/70R42TRO1822893-01
     710/70R42TRO1822893-01    70 ...... ...... 3..... ......
     710/70R42TRO1822893-01    60 ...... ...... ...... .3.... 800/70R32TRH1752813-01
```

*Figure B.1 Curing Plan*

## B.2 Carcass building plan

Figure B.2 shows an example of the carcass MPS for Machine 55. Per SKU it shows the starting inventory (Begin- voorraad), the planned quanity for curing (Vulk. gepland), and the planned quantity for carcass building (Bouw gepland). In the carcass building plan the starting inventory consists of green tyres and carcasses.

```
JOHNNY        LB142  HANDMATIG PLANNEN KONV. BOUW                  23/05/23  13:39
                           Datum 23/05/23  Dienst 2                       Wijzigen
Mach:  55  Prio: 2.01
 L900/60R42-189K 2.02      D       D+1     D+2     D+3 |   D+4     D+5  tot 2321-wo/3
   Begin-voorraad:       18       16      14      12      10       8  Order :  58
   Vulk. gepland :        2        2       2       2       2       2  Af    :  41
1  Bouw gepland  :        0        0       0       0       0       0                U
 H800/45R26-174K 2.10      D       D+1     D+2     D+3 |   D+4     D+5  tot 2323-di/3
   Begin-voorraad:       11       15      22      16      10      15  Order : 232
   Vulk. gepland :        6        6       6       6       6       6  Af    :  31
2  Bouw gepland  :       10 10    13 13    0       0      11 11   12 12
 L620/75R30-172K 2.08      D       D+1     D+2     D+3 |   D+4     D+5  tot 2321-vr/2
   Begin-voorraad:       23       19      15      28      30      26  Order :  90
   Vulk. gepland :        4        4       4       4       4       4  Af    :  44
3  Bouw gepland  :        0        0      17 17    6  6    0       0                U
 L900/50R42-180K           D       D+1     D+2     D+3 |   D+4     D+5  tot 2321-vr/1
   Begin-voorraad:        0        0       0       0      10      18  Order :  18
   Vulk. gepland :        0        0       0       0       0       1  Af    :   0
4  Bouw gepland  :        0        0       0      10 10    8  8    0                U

Bouwers  gepland:         7        6       7       7       5       5        Maten: 5
 (RETURN=Blader, 91=<->, 92=MATBST, 93=OW/NOW, 94=Hand/Auto, 95=Verw. maat)
Regelnummer: ##  (96=Toek. maat, 97=Wijz mach, 98=Terug, 99=Akk/Volgende)
```

*Figure B.2 MPS Carcass Building*

## B.3 Orbitread plan

Figure B.3 shows an example of a orbitread plan for position 96. Per SKU it shows the starting inventory of green tyres(Begin-voorraad), the planned quantity for curing (Vulk. gepland), the starting inventory of carcasses (Vrd. karkassen), and the planned quanity for the orbitread machine (Bouw gepland).

```
JOHNNY        LB142  HANDMATIG PLANNEN KONV. BOUW                  23/05/23  13:39
                           Datum 23/05/23  Dienst 2                       Wijzigen
Mach:  97
 H800/45R26-174G 2.10      D       D+1     D+2     D+3     D+4     D+5  tot 2323-di/3
   Begin-voorraad:        7        7       7       7       7       7  Order : 232
   Vulk. gepland :        6        6       6       6       6       6  Af    :  31
   Vrd. karkassen:  4    14       21      15       9      14      20
1  Bouw gepland  :        6        6       6       6       6       6
 N650/65R38-157G 2.05      D       D+1     D+2     D+3     D+4     D+5  tot 2322-wo/1
   Begin-voorraad:        8        4       4       4       4       4  Order : 500
   Vulk. gepland :        4        4       4       4       4       4  Af    : 434
   Vrd. karkassen: 12    12       12      26      22      18      14
2  Bouw gepland  :        0        4       4       4       4       4




Totaal bouw ORBIT B       6       10      10      10      10      10
Bouwers  gepland:      41/386  43/371  38/350  41/401  35/329  35/359   Maten: 2
                 (RETURN=Blader, 91=<->, 93=OW/NOW, 94=Hand/Auto, 95=Verw. maat)
Regelnummer: ##  (96=Toek. maat, 97=Wijz mach, 98=Terug, 99=Akk/Volgende)
```

*Figure B.3 MPS Orbitread*

## Appendix C: Survey

This appendix shows the survey that we created to prioritize the alignment problems. We conducted this survey at 5 stakeholders working in the management, Industrial Engineering department, planning department and production floor. We conducted this survey in Dutch, but for the readability of this report we translated it into English.

Dear Stakeholder,

For my bachelor thesis, I am doing research on how the alignment between the carcass building, the orbitread, and the curing phase in the AGRI production process can be improved. During my research, I have found some alignment problems that I would like to prioritize with the help of this survey.

Completing this survey will approximately take about 10 minutes. All your answers will be confidential and treated with care. Your participation is completely voluntary, and you have the right to stop your participation at any time. By completing this survey, you confirm that you are aware of your rights.

Thank you for participating in my survey!

**Assessing the alignment problems**

My research reveals the following alignment problems:

1. Unrealistic norm times
2. Mismatch between effective capacity of carcass building machine and curing presses.
3. Unreliable inventory
4. Production plan exceeds inventory capacity
5. Orbitread production plan exceeds capacity of certain positions
6. Lack of production sequence in orbitread plan
7. Too late arrival of new shift plan

We assess the alignment problems on 2 criteria:

1. Occurence: How often do you think this problem occurs?
2. Severity: How much time loss do you expect this problem to cause each time it occurs?

Assess each alignment problem on the two criteria and rate each criterion on a scale of 1 to 5, whereby: 1 = Very low, 2 = Low, 3 = Average, 4 = high, 5 = Very high

Write down your answers in the table below.

| | **Occurence**<br>*1 = Very low, 2 = Low, 3 = Average, 4 = high, 5 = Very high* | **Severity**<br>*1 = Very low, 2 = Low, 3 = Average, 4 = high, 5 = Very high* |
|---|---|---|
| **Problem 1** | | |
| **Problem 2** | | |
| **Problem 3** | | |
| **Problem 4** | | |
| **Problem 5** | | |
| **Problem 6** | | |
| **Problem 7** | | |