BACHELOR THESIS INDUSTRIAL ENGINEERING AND MANAGEMENT

# IMPROVING THE STORAGE PROCESS OF ALUMINUM AT TWENTSCHE KABELFABRIEK: REDUCING QUALITY ISSUES

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University of Twente

2022

UNIVERSITY OF TWENTE.

TKF CONNECTIVITY SOLUTIONS

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Bachelor Thesis Industrial Engineering and Management

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**Publication:**
August 2022

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# Acknowledgment

This thesis finalizes my bachelor's in Industrial Engineering and Management at the University of Twente. For the past half year, I have performed research at the Twentsche Kabelfabriek B.V. (TKF) to reduce quality issues by improving the storage process of aluminum. I am very grateful for the opportunity TKF gave me to use their company for this research.

In the first place, I want to thank my supervisors from TKF, Jordy Oude Vrielink and Tom Bijen, for their guidance, feedback and for answering all my questions. I also want to thank all other employees at TKF that have supported me. You were always willing to help and answer any questions that I had. Because of all of you, I look back at my time at TKF with a smile.

Second, I thank my supervisor from the University of Twente, Peter Schuur, for his feedback and guidance during my research. His enthusiasm and efforts helped me get the most out of my research. I also would like to thank my second supervisor, Engin Topan, for his time and feedback.

Finally, I would like to thank my family and friends for their support, enthusiasm and kind words. They kept me positive and motivated to successfully finish my bachelor's.

I hope you enjoy reading this thesis!

Lisa van Oost

Enschede, August 2022

# Management Summary

Twentsche Kabelfabriek (TKF) is an organization located in Haaksbergen that develops and produces cable solutions for customers worldwide in the Building, Industrial and Telecom market segments. In Q1 of 2022, the production output related to raw material aluminum increased by 5.4% compared to Q1 of 2021. This growth has been a trend over the past few years and has resulted in increased capital requirements, e.g., storage space. However, larger storage space is not available currently, meaning that an efficient and effective storage method for all materials and products is increasingly important. The same applies to the storage of the raw material aluminum. Currently, lacking storage and traceability methods for aluminum, and a scarcity in the aluminum market which makes purchasing aluminum from multiple suppliers necessary, has led to a suboptimal allocation of aluminum to production, resulting in high costs of poor quality (COPQ). With suboptimal allocation, we mean either using two different suppliers simultaneously for production or using low-quality aluminum for producing conductors with smaller diameters (which are more sensitive). Currently, the COPQ related to aluminum is estimated at over €X per annum. TKF wants to reduce COPQ. To achieve this, we formulated the following research question:

"*How can TKF improve the storage method and traceability of aluminum such that aluminum can be adequately allocated to production and COPQ can be reduced?"*.

A literature review and analysis of the current situation provided insight into the characteristics of the storage- and traceability processes at TKF, including their performance and bottlenecks. Based on the requirements and limitations of TKF, we proposed alternatives on how to improve the storage- and traceability processes. The most suitable alternatives are merged to provide TKF with a Standard Operating Procedure (SOP) which serves as improved storage- and traceability method.

We divided the storage process into three subprocesses: receiving, storage (or put away) and picking. Within each of these subprocesses, we viewed traceability as a supporting factor for improvement. We identified five bottlenecks that contribute to a high COPQ. We mention each of them, including approaches on how to solve the bottlenecks.

- *Receiving; Lack of registration of received aluminum*

To be able to adequately allocate aluminum to production, we propose to register the following information in the warehouse management system (WMS): supplier, received quantity and storage location indication. Furthermore, we propose that each coil receives a unique identification number. The identification number is among others linked to the supplier, quantity and storage location.

- *Receiving; Lack of identification of received aluminum*

To properly identify the received aluminum, we propose to attach a label to each coil. This label contains a barcode linked to the identification number and a color code that visualizes the supplier.

- *Storage; Missing storage location assignment policy*

We suggest adopting a shared policy for the storage of aluminum at TKF. This policy dedicates no storage locations and storage positions to a specific aluminum supplier in advance. However, once a position within a storage location is occupied by a certain aluminum supplier, the location is dedicated to that supplier.

- *Picking; No method for replenishing aluminum at the production line*

A suggestion is to place an information board, next to the production line, which informs the forklift truck driver about what aluminum (from which supplier) to pick. The board is based on colors that correspond with the color on the labels of the aluminum.

- *Picking; No identification possible of the aluminum when packaging is removed*

At the production line, the packaging, which is wrapped around the aluminum, is removed. The packaging differs per supplier and often contains the supplier's name. Therefore, it is possible to distinguish between suppliers in some way. However, when the packaging is removed from the aluminum, all aluminum looks identical. To make aluminum identifiable when packaging is removed, again an information board can be used. Each storage position that can be occupied by aluminum has its section on the board. When the packaging is removed from the aluminum, we suggest placing a card containing the information of the label in the section related to the position that the aluminum occupies.

The bottlenecks that were found, collectively show that currently no organized storage and traceability process related to aluminum is in place. Therefore, in this research we make a first attempt to organize these processes. We do this by formulating a Standard Operating Procedure (SOP) that provides a clear overview of the steps needed to be taken in the receiving, storage and picking processes. The proposed solutions are the basis for the SOP.

Before the SOP is successfully implemented, multiple actions need to be taken. These actions, and the sequence in which we propose to take the actions are provided in Table 1. Each action is assigned an actor that is responsible for the action.

| **Priority** | **Action** | **Actor** |
|---|---|---|
| 1 | Link the purchase order automatically to the aluminum supplier in WMS. | WMS Administrator & Logistics Manager |
| 2 | Assign a color to each aluminum supplier. | Logistics Manager |
| 3 | Link the aluminum supplier automatically to the assigned color in WMS. | WMS administrator & Logistics Manager |
| 4 | Purchase stickers of the colors that have been assigned to the aluminum suppliers. | Logistics Manager |
| 5 | Design and print/purchase boards, which are placed at storage locations. The boards contain the name of the storage location and a unique barcode. | Logistics Manager |
| 6 | Add an input for the storage location of an aluminum coil in WMS. | WMS Administrator |
| 7 | Design, print and buy components needed for information board. | Industrial Engineer |
| 8 | Provide conform lines 1 and 2 with a label printer. | Industrial Engineer |

| | | |
|---|---|---|
| 9 | Mark/color intermediary storage positions at conform lines 1 and 2. | Industrial Engineer |
| 10 | Design, print and buy components needed for traceability board. | Industrial Engineer |
| 11 | Inform planners about supplier selection for a production order. | Industrial Engineer & Planner |
| 12 | Provide conform lines 1 and 2 with information document about match between conductor variant and supplier. | Industrial Engineer |
| 13 | Inform goods receiving employees on SOP. | Logistics Manager & Goods Receiving Employees |
| 14 | Inform forklift truck drivers on SOP. | Logistics Manager & Forklift Truck Drivers |
| 15 | Inform machine operators on SOP. | Industrial Engineer & Machine Operators |

*Table 1 – Implementation plan for SOP*

The implementation of the SOP is expected to improve the performance of the storage system in terms of storage accuracy, picking accuracy and scrap rate. Currently, the storage accuracy and picking accuracy of aluminum cannot be measured for two reasons. First, no data is collected about the storage and picking of aluminum. Second, a "correct" storage location and a "correct" pick are not defined, making it impossible to determine whether aluminum is stored and picked accurately. This research provides a framework that allows to measure both, the storage accuracy and the picking accuracy. Furthermore, the current scrap rate of X% in Q1 of 2022 is expected to decrease.

After implementation it is possible to measure the storage accuracy, picking accuracy and scrap rate. We propose to use this information to evaluate on the performance of the SOP and to see whether it has the desired effect, namely a reduction in COPQ. If not, improvement possibilities can be easily identified by evaluating the KPIs. This is information is useful to (further) reduce COPQ. Also, we advise TKF to start collecting data about what supplier is used for a production order. This allows concluding on the circumstances in which artifacts occur, which in turn is relevant for reducing the COPQ. Next, we recommend TKF to frequently talk to stakeholders that are affected by the SOP since this increases their understanding and willingness to adhere by the SOP. Finally, we recommend TKF to look into pallet racking as a long-term alternative for the storage of aluminum coils.

# Abbreviations and Glossary

### Abbreviations

| | | |
|---|---|---|
| TKF | Twentsche Kabelfabriek | Page 1 |
| COPQ | Costs of poor-quality | Page 1 |
| TKH | Twentsche Kabel Holding | Page 1 |
| SLAP | Storage Location Assignment Problem | Page 7 |
| SKU | Stock Keeping Unit | Page 8 |
| LIFO | Last-In-First-Out | Page 9 |
| FIFO | First-In-First-Out | Page 9 |
| KPI | Key Performance Indicator | Page 10 |
| RFID | Radio-Frequency Identification Technology | Page 12 |
| MTO | Make-To-Order | Page 14 |
| CDCC | Completely Dry Curing and Cooling | Page 14 |
| YTD | Year to Date | Page 15 |
| WMS | Warehouse Management System | Page 18 |
| SOP | Standard Operating Procedure | Page 24 |
| UID | Unique Identifier | Page 26 |

### Glossary

| | | |
|---|---|---|
| COPQ | Costs incurred when an artifact in the aluminum conductor of a cable leads to electrical discharge | Page 1 |
| Artifact | Damage or poor-quality of a product | Page 2 |
| Storage location | A lane on the floor that contains multiple positions to store aluminum coils | Page 19 |
| Storage position | A position at a storage location that allows for the storage of one aluminum coil | Page 19 |

# Contents

# 1 Introduction

In the framework of completing my bachelor's degree in Industrial Engineering & Management at the University of Twente, I performed research at the Twentsche Kabelfabriek to improve the storage- and traceability process of incoming aluminum.

Twentsche Kabelfabriek (TKF) is a well-established organization that develops and produces cable solutions for customers worldwide. In Q1 of 2022, the production output, related to aluminum, increased by 5.4% compared to Q1 of 2021. This growth has been a trend over the past few years and has resulted in increased capital requirements, e.g., storage space. However, larger storage space is not available currently, meaning that an efficient and effective storage method for all materials and products is increasingly important. A lack thereof at TKF has led to a suboptimal allocation of input materials (aluminum) to production, resulting in high costs of poor quality (COPQ). In Q1 of 2022, the COPQ related to aluminum is estimated by TKF at €X, which means €X per annum is lost. This research aims to improve the storage method of aluminum such that the allocation of aluminum to production is improved and additionally COPQ decreases.

This chapter introduces this research. In Section 1.1, we introduce the company where this research is conducted. Then, Section 1.2 identifies the problem faced by the company. Also, the causes are analyzed to determine the core problem. Thereafter, in Section 1.3, the design of this research, including research questions, is provided.

## 1.1 Company Introduction

TKF, with headquarters located in Haaksbergen, is an organization with a broad portfolio of cables, systems, and services, that offer customers worldwide, solutions for creating safe and reliable energy data connections. Since its founding in 1930, TKF has developed from a cable manufacturer to a technologically leading supplier of connectivity solutions. Medium-voltage cables, telephone cables, and high-voltage cables are among the products produced by the company. In 1980, the acquisition of several companies in the Netherlands and Germany lead to the creation of N.V. Twentsche Kabel Holding (TKH). In the next years, TKH concentrates on growing through acquisitions. TKH headquarters are located next to TKF. Through a focused commitment to the Building, Industrial, and Telecom market segments TKF distinguishes itself through its specialized knowledge of applications and solutions, with a high degree of reliability, quality, and service (TKF, n.d.). In 2022, TKF has around 800 employees.

TKF owns two production facilities located in Haaksbergen and Lochem. The facility in Haaksbergen is divided into six departments: Installation, Multi-Conductor, Energy, Fiber Optics, Drafa and Expedition. This research concerns two departments, Energy and Expedition. The Energy department focuses specifically on the production of cables transporting large amounts of electricity to factories, residential areas and big machines. The Expedition department controls the movement of goods, both raw materials, semi-finished products and end-products. Their set of tasks also includes wrapping and packaging.

## 1.2 Problem Identification

Currently, TKF its reliability, quality and service are jeopardized by the problems the company is facing. The origin of the problems at the Energy department of TKF starts with underperforming in terms of high costs of poor quality (COPQ). Poor quality means an artifact (quality issue) in the product. In Q1 of 2022, X artifacts have occurred in a total number of X products. Often one product contains multiple artifacts, so we find that X, or X%, unique products contain one or more artifact(s). An artifact in a product does not immediately imply that costs are incurred. Only when an artifact results in electrical discharge additional costs need to be considered.

During an inspection, products are assessed to verify that a cable is free from discharges above a specified magnitude at a specified voltage. If there are any discharges, they will eventually result in short-circuit (In Dutch: kortsluiting). Products that discharge are faulty and cannot be sold to the customer. Of the X products containing artifacts eventually X cases (X% of the total number of products) of electrical discharge due to artifacts have been identified. Figure 1.1 provides an overview of the number of artifacts and discharges per week as a percentage of the total number of artifacts and discharges in Q1 of 2022.

The costs incurred in case of electrical discharge are referred to as costs of poor quality (COPQ) and consist of two types of costs: cable cost price and artifact handling costs. The cable cost price is relevant since the part of the cable containing the artifact goes to waste even though materials and manpower are used, and processing is done. All these costs are included in the cost price. The artifact handling costs comprise all costs related to handling cables that contain artifacts. These include transportation costs, rework costs, and time costs (for both production and office). Based on all these costs, the estimated total COPQ in Q1 of 2022 is €X. This would mean that over €X per annum is lost. Appendix A explains in detail how the COPQ is calculated. TKF realizes it does not maximize profit currently and wants to focus on reducing COPQ.

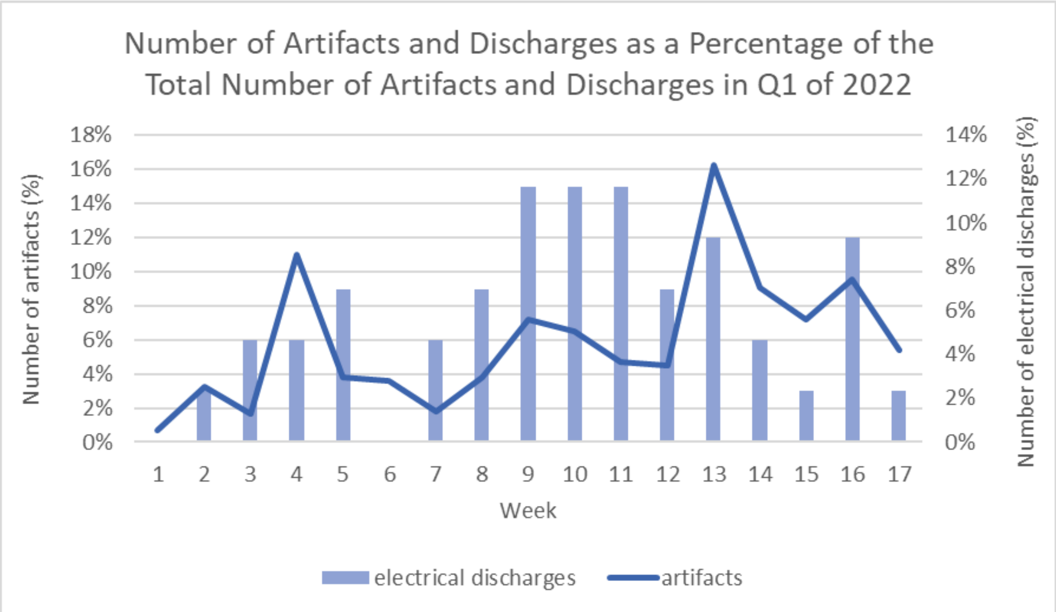



*Figure 1.1 - Number of artifacts and discharges as a percentage of the total number of artifacts and discharges in Q1 of 2022*

### 1.2.1 Problem causes

Through interviews with employees at the Energy and Expedition departments, process improvement engineers and machine operators, the causes for artifacts are identified. The cause that has a major impact on the occurrence of artifacts, is the suboptimal allocation of aluminum to production. Suboptimal allocation means either using two different suppliers simultaneously for production or using low-quality aluminum for producing conductors with smaller diameters (which are more sensitive). From this, two core problems, which make an optimal allocation of aluminum impossible at this stage are identified: (1) a lack of storage method for aluminum, and (2) a lack of a method to trace aluminum. This results in the following main research question:

"*How can TKF improve the storage method and traceability of aluminum such that aluminum can be adequately allocated to production and COPQ can be reduced?*".

Apart from the two core problems, four other causes might result in artifacts. These causes can either not be influenced or are out of the scope of this research. To get a holistic overview of the problem and its context, they will each be discussed briefly. An overview of the problem and its causes can be found in Figure 1.2.

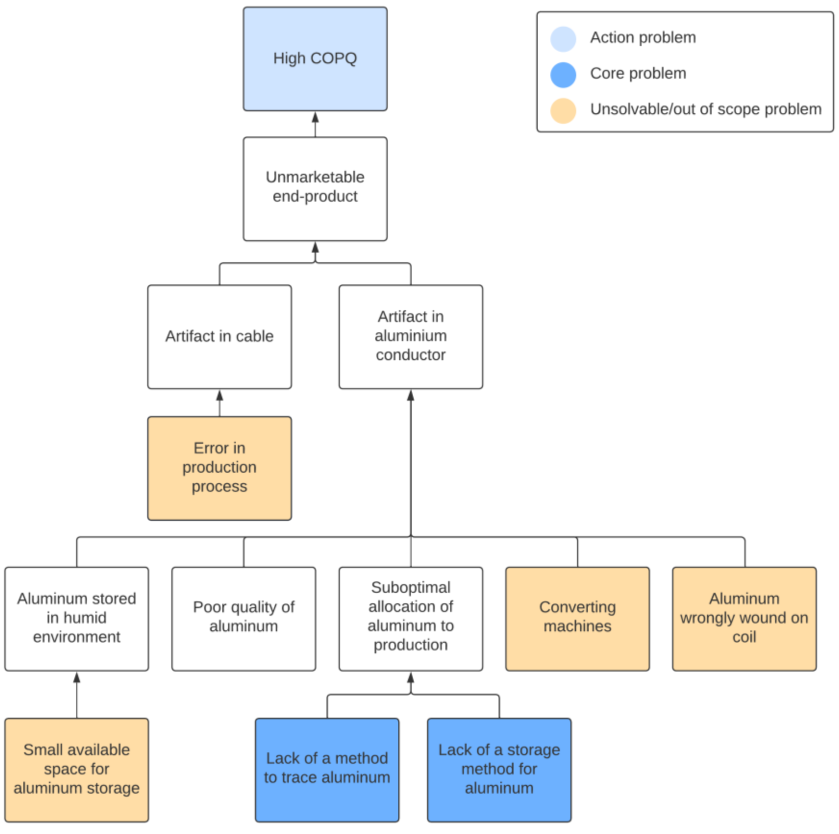



*Figure 1.2 - Overview of problems and causes at TKF*

*Aluminum is stored in a humid environment* – When aluminum is stored in a humid environment it corrodes. The corrosion that occurs on the aluminum wire is passed on to the aluminum conductor during production. This might lead to an artifact. Because the space available for the storage of aluminum is scarce, it occasionally occurs that aluminum is indeed stored in a humid environment. This research seeks to reduce COPQ with the available resources at hand, including storage capacity. Therefore, we assume that storage capacity cannot be increased, so this problem is not considered.

*Aluminum wire is of poor quality* – A poor quality of the aluminum increases the chance of artifacts. A poor-quality aluminum has a bigger impact on conductors with smaller diameters. So, to optimally allocate aluminum to production, the quality should be considered. TKF purchases aluminum from multiple suppliers. In principle, all suppliers provide aluminum that meets the requirements set by TKF. However, differences in processability between supplier are observed. We refer to this as quality differences. Due to scarcity in the aluminum market, TKF also needs to purchase aluminum from suppliers that is harder to process. Therefore, we do not see the processability of aluminum as a core problem. One thing to mention is that quality issues to aluminum are extremely hard to detect, meaning that incoming aluminum with quality issues are often not rejected.

*Adjusting machines settings (converting)* – Adjusting the machine settings, necessary to switch between production orders with different requirements for conductor diameter, is a reason for artifacts. When machine settings have been changed, there is a warm-up period in which artifacts are more likely to occur. The number of artifacts that occur for this reason can be reduced by optimizing production planning in which the focus lies on minimizing the number of changes in machine settings. However, optimizing production planning lies out of the scope of this research, and will thus not be considered.

*Aluminum is wound wrongly on coil* – When aluminum is wrongly wound on the coil, the traction necessary to draw the wire from the coil into the machine might be too high. Figure 1.3 shows an aluminum coil. Given the fact that aluminum is very fragile, wrongly wound aluminum may cause artifacts. In this research, we assume that TKF cannot influence the way aluminum is wound on the coil.

*Figure 1.3 - Aluminum coil*

## 1.3 Research Design

In Section 1.2, the problem has been identified, from this the following main research question has been formulated: "*How can TKF improve the storage method and traceability of aluminum such that aluminum can be adequately allocated to production and COPQ can be reduced?*".

To arrive at an answer to this question, research is conducted which is guided by the regulative cycle developed by Van Strien (1997). The regulative cycle, shown in Figure 1.4, is a commonly used problem-solving method consisting of five steps:

1. Identifying problem; *identification of the problem faced by the company, and the core problem is determined using a problem cluster*
2. Analysis & Diagnosis; *the context of the problem is fully investigated, and research questions to determine the reason for the discrepancy between As-Is and To-Be situation*
3. Design; *research, plan, and recommendation for possible solutions to the problem*
4. Implementation; *executing the plan*
5. Evaluation; *is the initial problem solved*

The bachelor thesis, in general, aims to provide a company with a recommendation on how they can solve a problem they are facing and to provide them with the conditions for a successful outcome. This means that the focus of this research lies on the first three steps and that phases four (Implementation) and five (Evaluation) are out of scope.

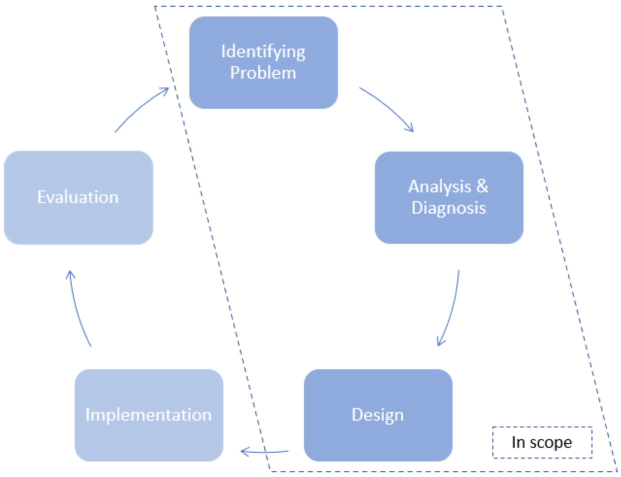



*Figure 1.4 - Regulative cycle by van Strien (1997)*

In the Analysis & Diagnosis phase, the primary goal is to provide a complete description of the storage- and traceability process, both in a general way and specifically for that of aluminum at TKF. A description of the storage- and traceability process in a general way is based on literature from academic journals and conference proceedings. The storage- and traceability process of aluminum at TKF is described by observing the current situation and interviewing relevant stakeholders. The following research questions are answered:

1. What literature is available about storage- and traceability processes?
   1.1 What is written in literature about storage?
   1.2 What is written in literature about traceability?

2. What is the current situation of the storage system and traceability process related to aluminum?
   2.1 How is the current storage system of aluminum organized?
   2.2 What is the current performance of the storage system of aluminum?
   2.3 How is the current traceability process of aluminum organized?

In the Design phase, the goal is to improve the storage method and traceability of aluminum. This improvement is based on literature about storage and traceability approaches. Approaches found in literature are analyzed together with the requirements of TKF to find the most suitable approach. During this phase also the impact and feasibility of the chosen approach are determined. Based on this a recommendation is provided to TKF. The following research questions are answered:

3. Which storage- and traceability approaches are the most suitable for TKF?
   3.1 What are the requirements for storage and traceability set by TKF?
   3.2 What are the storage- and traceability method alternatives?
   3.3 What method fits TKF best, based on method characteristics and requirements of TKF?

4. What is the impact and feasibility of the chosen storage- and traceability methods for TKF?

When both phases have been completed successfully, the following deliverables are provided to TKF. First, a comprehensive analysis of the current situation of the storage and traceability process is provided. This includes an overview of the activities, performance and bottlenecks. Second, suggestions for an improved storage method are provided. This includes a standardized working method for the storage of aluminum in which actions are assigned to actors. The suggestions are substantiated with information on impact and feasibility. The same goes for an improved traceability method.

# 2 Literature Review

This chapter provides an overview of literature related to this research to answer research question 1: *"What literature is available about storage- and traceability processes?"*. In Section 2.1, literature about the storage of incoming material flows is provided to answer research question 1.1: *"What is written in literature about storage?"*. Then, Section 2.2 provides an answer to research question 1.2: *"What is written in literature about traceability?"*. Lastly, this chapter is concluded in Section 2.3.

## 2.1 Storage of Incoming Material Flows

This section discusses the storage of incoming material flows. First, Section 2.1.1 discusses storage systems in general. Second, Section 2.1.2 identifies block stacking as a storage method related to this research. Also, literature on the storage location assignment problem (SLAP) and its relation to block stacking is provided in Section 2.1.2. Third, Section 2.1.3 provides an overview of frequently used indicators to measure storage performance.

### 2.1.1 General storage systems

Matson and White (1981) state that the appropriate selection of a storage method and material handling method plays a major role in controlling costs. An increased emphasis on cost control requires evaluating storage system alternatives and selecting those that minimize costs while meeting service level objectives (Matson & White, 1981). Rouwenhorst et al. (2000) distinguish two types of storage systems: the distribution- and production storage system. The main task of a distribution storage system is to store products and fulfill external customer orders. Concurrently, production storage systems focus on storing raw material, work-in-process, and finished products associated with a manufacturing process. In this research, the focus is on production storage systems.

Rouwenhorst et al. (2000) describe that storage systems may be viewed from three different perspectives: processes, resources and organization. Products arriving at a storage location are taken through several steps called processes. All means, equipment and personnel needed to operate the storage system are referred to as resources. Lastly, organization includes all planning and control procedures used to run the system.

Storage systems for incoming material flows consist of three basic processes: receiving, storage (or put away) and picking. Lanza et al. (2022) mention that the receiving process is concerned with the organization of all the operations required to manage entering items. Activities include unloading trucks, inspecting goods, and comparing production orders (Kusrini et al., 2018). Storage is concerned with the organization of the products held in the storage area to achieve high space utilization and facilitate efficient material handling (Lanza et al., 2022). The main tasks of this process are identifying the product and storage location, moving the product, and updating records (Kusrini et al., 2018). Lastly, picking refers to the organization of items to be picked and the resources needed for picking.

Storage system design decisions occur at three levels: the strategic level, the tactical level, and the operational level. At the strategic level decisions that have an impact on the long-term are considered. Often these decisions incur high investments and concern the design of the process flow and the selection of the types of storage systems. On the tactical level, mid-term decisions are made based on the outcomes of decisions made on the strategic level. Tactical decisions concern dimensions of resources, layout design, storage policies, and organizational issues. The operational level makes decisions within the constraints set by the higher levels. Decisions mainly concern assignment and control problems of people and equipment (Rouwenhorst et al., 2000).

### 2.1.2 Block stacking

A frequently used storage method, and relevant in this research is block stacking or deep-lane storage. Derhami et al. (2017), Pfrommer and Meyer (2020), and Matson and White (1981) define block stacking as a method in which pallets of product types, are stacked on top of one another in lanes on the floor. A typical block stacking layout consists of lanes perpendicular to aisles, see Figure 2.1 (Derhami et al., 2019). Pallets are stacked to the maximum stacking height which depends on the height of the pallets, load weights, safety limits and clearance height, of the storage environment. This storage method usually requires no storage racks, which makes it inexpensive to implement, but challenging in terms of space planning because certain pallets cannot be reached until the ones stacked on top and in front of them are retrieved. To maintain an efficient operational flow, complex decisions are required (Reyes et al., 2019). These decisions are known as the storage location assignment problem (SLAP). In the following section, the SLAP is discussed in more detail.

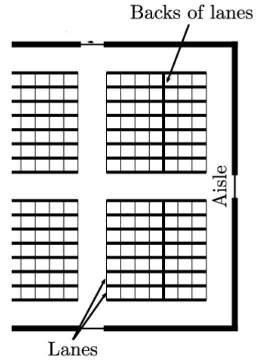



*Figure 2.1 - Block stacking layout (Derhami et al., 2019)*

**Storage Location Assignment Problem (SLAP)**

Reyes et al. (2019) describe that the SLAP, in a general warehouse setting, is concerned with the allocation of products into storage space and optimization of the material handling costs or storage space utilization. Related parameters are the storage area design, storage space capacity, physical characteristics of the products, arrival times, and demand behavior. In terms of complexity, the SLAP is classified as being NP-hard. Reyes et al. (2019) state that this is caused by the variations in the number of products and storage space characteristics.

Various storage space allocation policies can be distinguished, among which the dedicated policy, the shared policy and the class-based policy are the most popular. Each of them in relation to block stacking is described in greater detail now.

A dedicated policy dedicates lanes to SKUs and only pallets of the assigned SKUs are allowed to be stored in a lane. By applying a dedicated storage policy, blockings are often completely avoided (Zaerpour et al., 2014). On the other hand, a shared policy dedicates no lanes to SKUs meaning an empty lane is available to all SKUs. To avoid blockage and relocation of pallets, a lane is temporarily dedicated to an SKU once it occupies the first position of the lane. A result is that the storage space utilization is restricted because some unoccupied pallet positions in a partially occupied lane will not be available to other SKUs. This effect is also known as honeycombing (Derhami et al., 2017). A combination of both, the dedicated- and shared policy, is also possible. This policy is called a class-based policy. Wang et al. (2020) describe this policy by first dividing SKUs into several classes and then assigning each class to a fixed lane. Within this lane, the shared policy is adopted. Mainly two types of strategies are used to divide SKUs into classes: ABC-classification and family-based classification. ABC-classification assigns SKUs to classes depending on their order frequency, where category A contains SKUs with the highest frequency. Family-based classification assigns items to classes based on relations or similarities between SKUs (Nilsson & Tiensuu, 2018).

The SLAP can be quite diverse due to a wide variety of storage systems and optimization criteria. Gu et al. (2007) state that three SLAP classes can be distinguished depending on the amount of information known about the arrival and departure of the products stored: item information (SLAP/II), product information (SLAP/PI), or no information (SLAP/NI). The SLAP/II problem assumes that all information regarding the arrival and departure times of the individual items is available. Hence, the problem aims to assign items to storage locations. The SLAP/PI problem assigns individual items to product classes based on product characteristics such as size, quality, or usage rate. Consequently, these product classes are assigned to storage locations. This problem is applicable when only product information is known about the items to be stored. When no information is known about arriving items, the problem is known as SLAP/NI. For this problem, only simple storage policies can be designed, for example, Closest-Open-Location in which an item is assigned to a location based on distance. The basis of all SLAP models is formulated by Gu et al. (2007) as follows:

*Given:*

(1) Information on the storage area, including its physical configuration and storage layout.
(2) Information on the storage locations, including their availability, physical dimensions, and location.
(3) Information on the set of items to be stored, including their physical dimensions, demand, quantity, arrival, and departure times.

*Determine:*

The physical location where arriving items will be stored.

*Subject to performance criteria and constraints such as:*

(1) Storage capacity and efficiency
(2) Picker capacity and efficiency based on the picker cycle time.
(3) Response time.
(4) Compatibility between products and storage locations.
(5) Item retrieval policy such as First-In-First-Out (FIFO) and Last-In-First-Out (LIFO).

Based on the context in which the SLAP is used, the SLAP can be adjusted to a specific situation. We briefly mentioned the three SLAP classes. All three are explained in more detail now.

1. Storage location assignment problem based on item information (SLAP/II)

We mentioned that complete information is available about the arrival and departure times of individual items in the SLAP/II problem. In this problem, the objective is to assign a storage location to each item. However, because of large problem instances, an optimal solution for this problem is computationally impractical. Therefore, a frequently used heuristic is the Duration-of-Stay (DOS) policy (Gu et al., 2007). The DOS policy arranges items by their duration of stay in ascending order. Next, items are assigned to classes based on their duration of stay. The classes with the shortest duration of stay are then assigned to the closest storage locations (Goetschalckx & Ratliff, 1990).

2. Storage location assignment problem based on product information (SLAP/PI)

When only product information about the items to be stored is known, the problem is classified as SLAP/PI. This problem assigns product classes to storage locations based on the following most frequently used criteria:

*Popularity* - Popularity is defined by Gu et al. (2007) as the number of storage/retrieval operations per unit time period. Product classes are ranked by decreasing popularity and the classes with the highest popularity are assigned the most desirable storage locations. What exactly the most desirable location depends on the storage system and company objectives.

*Maximum inventory* - Maximum inventory is defined as the maximum storage space allocated to a product class. Product classes are ranked by increasing maximum inventory and the classes with the lowest maximum inventory are assigned the most desirable storage locations.

*Cube-Per-Order Index (COI)* - COI is defined as the ratio of the maximum allocated storage space to the number of storage/retrieval operations per unit time. The COI considers both an item's popularity and its storage space requirement. Product classes are ranked by increasing COI value and the classes with the lowest COI are assigned to the most desirable storage locations (Gu et al., 2007).

*Order Oriented Slotting (OOS)* - OOS is defined as a method in which SKUs are assigned to locations in such a way that the total traveling time of all tours is minimized. Unlike the COI policy which stores items based on how often it is picked without regard to picking sequences, OOS aims to store items, that appear together in orders close to each other (Mantel et al., 2007).

3. Storage location assignment problem based on no information (SLAP/NI)

We mentioned that the SLAP/NI problem deals with no information on the characteristics of the arriving items. As a result, only simple storage policies can be constructed. Whether there is a variation in performance between them is unknown. Examples of simple storage policies are Closest-Open-Location (COL), Farthest-Open-Location (FOL), Random (RAN), and Longest-Open-Location (LOL). The COL and FOL policies choose a storage location based on the proximity to the arrival point. The LOL policy chooses a storage location that has been vacant for the longest period of time (Gu et al., 2007).

### 2.1.3 Measuring storage performance

Increasing competition requires companies to improve their overall performance (Kusrini et al., 2018). An important aspect is the storage system performance. A performance analysis has the objective to analyze performance and make decisions accordingly. The most frequently used performance measures are efficiency and effectiveness. Efficiency is about using fewer resources for the same level of output, or in other words "performing activities properly". Effectiveness measures how well an activity contributes to the achievement of organizational goals, thus whether a company "does perform the right activities". Staudt et al. (2015) divide performance measures into two categories: soft metrics and hard metrics. Soft metrics deal with qualitative measures such as customer satisfaction. These metrics often require sophisticated tools for performance measurement. Hard metrics on the other hand are quantitative measures such as order cycle time and fill rate. Often, hard metrics are easily computable by using some simple mathematical expressions. Staudt et al. (2015) divide hard metrics into four classes: time, quality, cost, and productivity. Each of these classes includes multiple key performance indicators (KPIs). After the KPIs have been divided into classes, Staudt et al. (2015) subdivide them over the storage system processes. Based on literature from Rouwenhorst et al. (2000) and Staudt et al.

(2015), we formulate eleven frequently used storage system KPIs. An overview, including the classification of these KPIs, is provided in Table 2.1. Definitions are provided in Table 2.2.

<table>
<tr><th rowspan="2"></th><th colspan="3">Processes</th></tr>
<tr><th>Receiving</th><th>Storage</th><th>Order picking</th></tr>
<tr><th rowspan="2">Time</th><td>Receiving time</td><td>Putaway time</td><td>Order picking time</td></tr>
<tr><td colspan="2">Dock to stock time</td><td></td></tr>
<tr><th rowspan="2">Quality</th><td></td><td>Storage accuracy</td><td>Picking accuracy</td></tr>
<tr><td colspan="3">Scrap rate</td></tr>
<tr><th>Cost</th><td colspan="3">Cost as a % of sales</td></tr>
<tr><th rowspan="2">Productivity</th><td>Receiving productivity</td><td></td><td>Picking productivity</td></tr>
<tr><td colspan="3">Throughput</td></tr>
</table>

*Table 2.1 - Storage system key performance indicators based on Staudt et al. (2015)*

| KPI | Definition |
|---|---|
| Receiving time | Unloading time |
| Putaway time | Lead time since a product(s) has been unloaded to when it is stored in its designated place |
| Order picking time | Lead time to pick an order |
| Dock to stock time | Lead time from supply arrival unitl prodcut is available for order picking |
| Storage accuracy | Storing products in proper locations |
| Picking accuracy | Accuracy of the order picking process where error may be caught prior to shipment such as packaging |
| Scrap rate | Rate of product loss and damage |
| Costs of % of sales | Total storage system costs as a percentage of total company sales |
| Receiving productivity | Number of vehicle unloaded per labour hour |
| Picking productivity | Total number of products picked per labour hours in picking activity |
| Throughput | Items/hour leaving the storage system |

*Table 2.2 - Definitions of the key performance indicators (Staudt et al., 2015)*

The KPIs shown in Table 2.1 and Table 2.2, are according to literature frequently used indicators to measure the performance of storage systems. However, lots of other KPIs, not mentioned in this section, can be used to measure the performance of storage systems. The actual KPIs that are used depend on company objectives, the configuration of the storage systems, and the choice of what is to be measured.

## 2.2 Traceability of Incoming Material Flows

To support decision-making, organizations require information that is relevant, accurate, and readily available. Hence, traceability has become a key topic for manufacturers. In the context of this research, traceability is viewed as a supporting factor in improving the storage of aluminum. Traceability is defined as the ability to retrace steps and verify that certain activities have taken place (Sohal, 1997). Achieving traceability can be quite a challenge from a technical, coordination, and cost perspective (Jianfu et al., 2008). A frequently faced challenge is that operators either forget or do not see the importance to register items or activities. However, an accurate traceability system allows organizations for example to trace which batch of material went into a faulty product (Sohal, 1997).

Two types of traceability can be distinguished, backward traceability and forward traceability. Backward traceability is the ability to determine a products' origin and characteristics based on one or more criteria. For example, when a cable (end-product) contains an artifact, all the used materials and relevant processes can be identified to determine the origin of the artifact. Forward traceability refers to the ability to determine the location of products based on one or more criteria at every point in the end-to-end process. For example, when an artifact is observed in the aluminum wire (raw material) of a certain supplier, all products containing that specific aluminum wire can be identified. Because the effectiveness of one type of traceability does not necessarily imply the effectiveness of the other type, an information system needs to support both (Jianfu et al., 2008). The level at which traceability takes place can be further divided into three forms: status traceability, performance traceability and goal traceability. Jianfu et al. (2008) define status traceability as the ability of a system to provide accurate and timely knowledge of the current situation. Typical information includes for example batch size, buffer stock sizes, throughput time, available machines, number of operators and engineers, and resource utilization. Performance traceability is referred to the ability of a system to provide efficient and effective data about progress against plans. To examine patterns and variance in performance, a record of previous events must be kept. The quality and quantity of systems output can be determined to measure performance. Variability of processing times, the variance between planned output and actual output, machine output, and output per employee are examples of typical performance tracing information. Goal traceability is the ability to evaluate performance to achieve objectives. It is essential to reduce costs and risk throughout the entire end-to-end process. Typical performance tracing information includes improving quality, reducing inventory, and streamlining operations (Jianfu et al., 2008).

To be able to trace the flow of material, three technical solutions are proposed by Jianfu et al. (2008). The chosen method depends on the degree of compatibility with the product and the production process. Also, the reason for wanting to use a traceability system is important to consider when choosing a traceability method. The first method is using an alphanumerical code. This code consists of a sequence of numbers and letters placed on a product or its packaging. The main advantage of alphanumerical codes is that this method is simple, cost-efficient, and easy to implement. The main disadvantage comprises a bad performance of the method since data integrity corruption is a big concern and no standards are defined. The second technical solution is a barcode, which consists of digits that serve as identification number. A barcode can store important data such as price, name, manufacturer, weight, and inventory information. When materials are moved from one location to another, their labels must be arranged in such a way that the reader can detect and identify them. This feature requires human interventions throughout the scanning process, which introduces the risk of inaccuracy and inefficiency. Also, the large dimensions of labels and the fact that they are easily destroyed make the use of barcodes less desirable. The third method is the radio-frequency identification (RFID) technology which stores a serial number, and other information on a microchip attached to an antenna. RFID technology enables tracking of raw materials, work in process, finished products, and even assembly status during production (Jianfu et al., 2008).

## 2.3 Conclusion

In this chapter we have provided an answer to research question 1: *"What literature is available about methods to improve the storage- and traceability process?".* We distinguished two types of storage systems: the distribution storage system and the production storage system. Each storage system consists of three processes: receiving, storage (or put away) and picking. However, how these processes are organized differs for every organization. We defined a specific storage method called block stacking. Block stacking is defined as a method in which pallets of product types are stacked on top of one another in lanes on the floor. An important decision in block stacking is assigning lanes or locations to items. This decision is known as the storage location assignment problem (SLAP). The SLAP is adjustable to a specific situation and aims to allocate products into storage space to improve desired objectives, for example, the material handling costs. Often, three space allocation policies are distinguished: dedicated policy, shared policy and class-based policy.

Furthermore, we identified several frequently used KPIs to measure the performance of storage systems. They are arranged per process (receiving, storage and picking) and per class (time, quality, cost and productivity). Examples are receiving time, storage accuracy and scrap rate. The actual KPIs that are used by an organization depend on its objectives.

At last, we explained the concept of traceability. Traceability is defined as the ability to retrace steps and verify that certain activities have taken place. Two types of traceability are distinguished: backward traceability and forward traceability. Technical solutions to trace material flows include alphanumerical codes, barcodes and radio-frequency identification (RFID).

# 3 Context Analysis

This chapter answers research question 2: *"What is the current situation of the storage system and traceability process related to aluminum?"*. To get a holistic view of the context of this research, first, a description of the production process at the Energy department of TKF is given in Section 3.1. Section 3.2 discusses the usage and supply of aluminum at TKF. Then, Section 3.3 provides an analysis of the current storage system at TKF. Section 3.4 discusses the current traceability process at TKF. Lastly, Section 3.5 concludes this chapter.

## 3.1 Production Process

The primary function of aluminum at TKF is to produce conductors for medium- and high voltage cables. The production of these products is categorized as a Make-To-Order (MTO) process, where production takes place in response to customer demand. The production process starts with a process called conform extrusion. During this process, two aluminum wires are fused to produce one solid aluminum conductor. A visual of the conform extrusion process is provided in Figure 3.1.

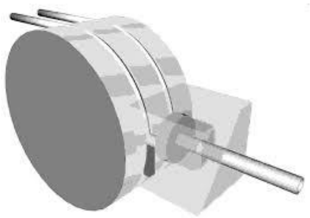


*Figure 3.1 - Conform extrusion (Dawson, n.d.)*

The next step, Completely Dry Curing and Cooling (CDCC), provides the conductor with three layers of plastic (XLPE) to ensure correct isolation properties. The aluminum conductor plus the plastic is now called a "core". After the core has been produced, two possibilities for further production exist dependent on the production order requirements:

1. Production order requires a cable that consists of multiple cores.

In this situation, a core is wrapped in tape on the screening line directly after CDCC. Then, the drum twister combines three cores by stranding them around each other and consequently produces one solid cable. The drum twister also fills up the gaps between the cores by adding rubber and wraps the cable in copper wires and tape. Copper wire and tape are used to ground the cable. In the last step of the production process, sheeting, a layer of plastic is added for protection purposes. Within this process, additional precautionary measures can be taken to protect the cable even more. The extent to which these additional measures are taken depends on how the cable will be used. Now the production of the cable has been finished. One last step, before the cable is sent to the customer, is inspection. During the inspection, the cable is tested to see whether it meets all requirements.

2. Production order requires a cable that consists of a single core.

Directly after CDCC, the core is wrapped in copper and tape on the screening line. Different from situation 1 is that the core is wrapped in both copper and tape on the screening line. In situation 1 only tape is added. In this situation, less processing is needed. Immediately after screening, a layer of plastic is added during the sheeting process. Again, additional protection measures can be taken to better protect the cable. Finally, the cable is inspected. If the cable meets all requirements, it is sent to the customer.

The steps of the production process and the structure of the cable throughout the production process is provided in Figure 3.2.

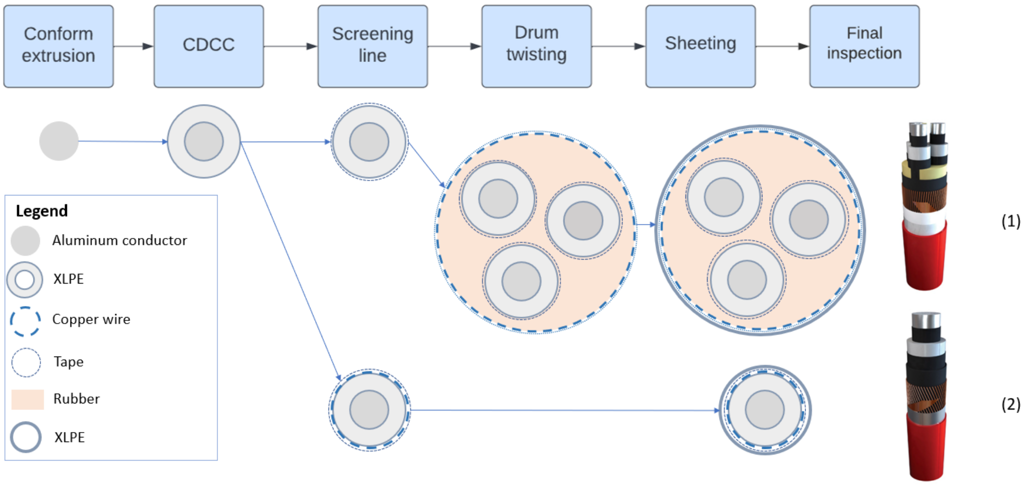



*Figure 3.2 - Production process & cable structure*

## 3.2 Usage and Supply of Aluminum

In Section 1.2 we briefly discussed the existence of differences in the quality of aluminum between suppliers. These small differences allow for a distinction between poor quality and good quality aluminum. Preferably, good quality aluminum wire is used for producing aluminum conductors with smaller diameters, since these are more sensitive to artifacts. The explanation is that the frequency in which artifacts occur, and the size of the artifacts are similar for all aluminum conductor variants, no matter the diameter of the conductor. However, the smaller the diameter of the conductor, the larger the size of the artifact relative to the conductor size. This makes conductors with a small diameter more sensitive to artifacts and thus to the quality of the aluminum wire. Figure 3.3 shows the production volume of the conductor variants as a percentage of the total production volume until Year to Date (YTD) May of 2022. We see conductor variants A – L as conductors with a relatively small diameter and conductor variants M – Q as conductors with a relatively large diameter.

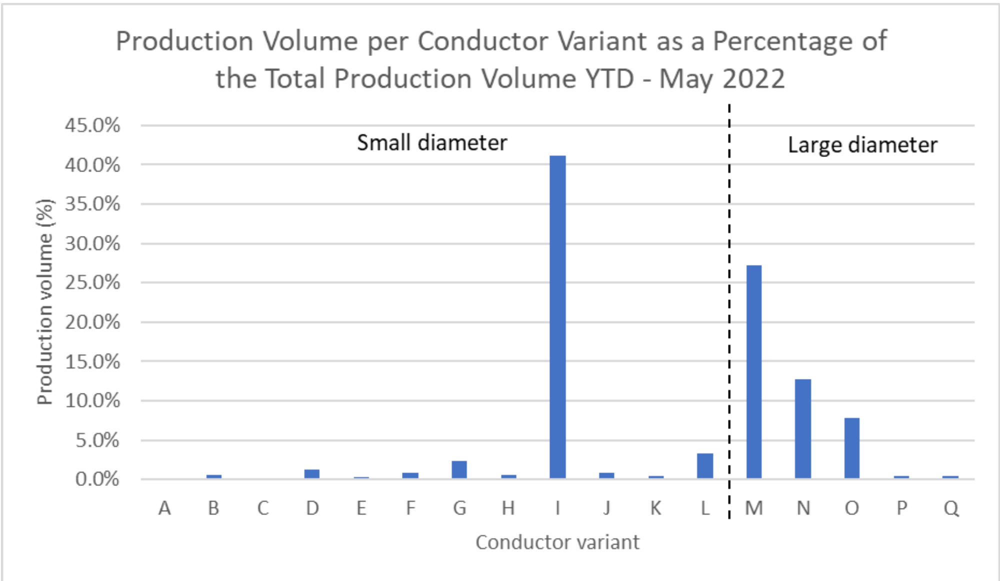



*Figure 3.3 - Production volume per conductor variant as a percentage of the total production volume until YTD - May 2022*

During this period, we find that the total quantity of aluminum used is X kg, which is equal to X kg per week. Two points draw our attention when looking at the graph. First, we see that the production volume of the variants I, M, N and O are relatively high compared to other variants. This is due to the high demand for cables containing these conductor variants.

Due to scarcity in the aluminum market, it is not possible to purchase aluminum from one or two suppliers that offer good quality. Instead, five suppliers are needed to meet the aluminum demand of 150,000 kg per week. Figure 3.4 shows the quantity of supplied aluminum per supplier as a percentage of the total supplied aluminum until May of 2022. We find that the total supplied quantity equals X kg, which is around X kg per week. All suppliers meet the specifications in terms of pallet type, dimensions, direction of rotation, and properties. So, in principle, all incoming aluminum should be of sufficient quality. However, observations regarding the number of artifacts show that differences between the aluminum of different suppliers do exist. Generally, the time between order and delivery is set at one month. However, to be certain of the arrival of aluminum in the right volume at the right time, aluminum is purchased three months in advance. This means that the purchasing department of TKF needs a forecast of the expected aluminum demand three months in advance as well. For some suppliers, especially the smaller ones, it is even necessary to buy aluminum for the whole coming year in advance.

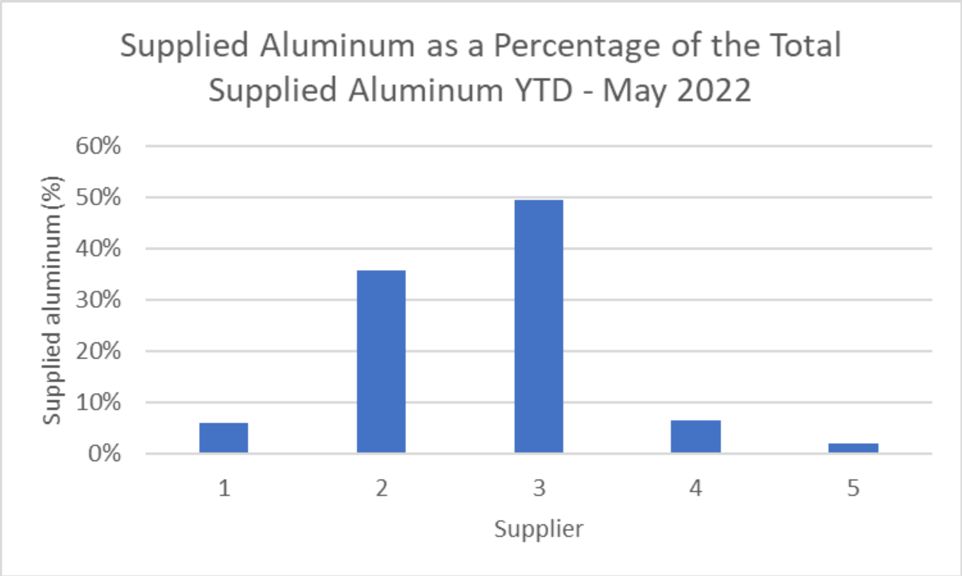



*Figure 3.4 – Supplied aluminum per supplier as a percentage of the total supplied aluminum YTD-May 2022*

## 3.3 Storage System

This section discusses the current storage system at TKF. First, an introduction is provided about the relevance of storage systems in relation to this research. Then, Section 3.2.1 identifies the current receiving process, Section 3.2.2 identifies the current storage (or put away) process and Section 3.2.3 identifies the picking process. After the three processes at TKF have been identified, the bottlenecks in each of the processes are discussed in Section 3.2.4. Lastly, Section 3.2.5 provides an analysis of the current storage system performance.

In Section 1.2, problem identification, a lacking storage method for aluminum has been identified as a reason for the existence of quality issues. Mainly due to limited resources, e.g., people and time, no attention has been paid to improving the storage system. This research focuses specifically on the storage of aluminum wire (⌀ 12mm). Aluminum wire is a raw material used as input for the conform extrusion process. As mentioned in Section 3.1, this process produces one solid aluminum conductor by fusing two aluminum wires. Due to a lacking storage method and the fact that there is a difference in properties of aluminum wire between suppliers, quality issues occur.

TKF owns two identical conform extrusion machines, each placed at one conform line, which produce a wide variety of aluminum conductors. Before aluminum is used for production it has come a long way since it arrived at TKF. The literature review in Chapter 2 described that storage systems for incoming material flows consist of three processes: receiving, storage (or put away) and picking. An analysis of the situation of these three processes at TKF is given in the following sections.

### 3.3.1 Receiving process

Aluminum wire arrives at the goods receiving depot of TKF in trucks. Figure 3.5 shows the location at TKF of the goods receiving depot. Each truck contains aluminum wire coils and fits 12 coils in total. The total weight of the 12 coils equals approximately 24,000 kg (2,000 kg/coil). Depending on the conductor variant and the order length, the average number of aluminum coils used per production order is shown in Figure 3.6. From the figure, we can see that for example the conductor "J", uses around 13 coils per production order. Meaning that at least thirteen aluminum coils of the same supplier need to be available throughout production. We must note that this number is higher than the number of coils that fit in one truck.

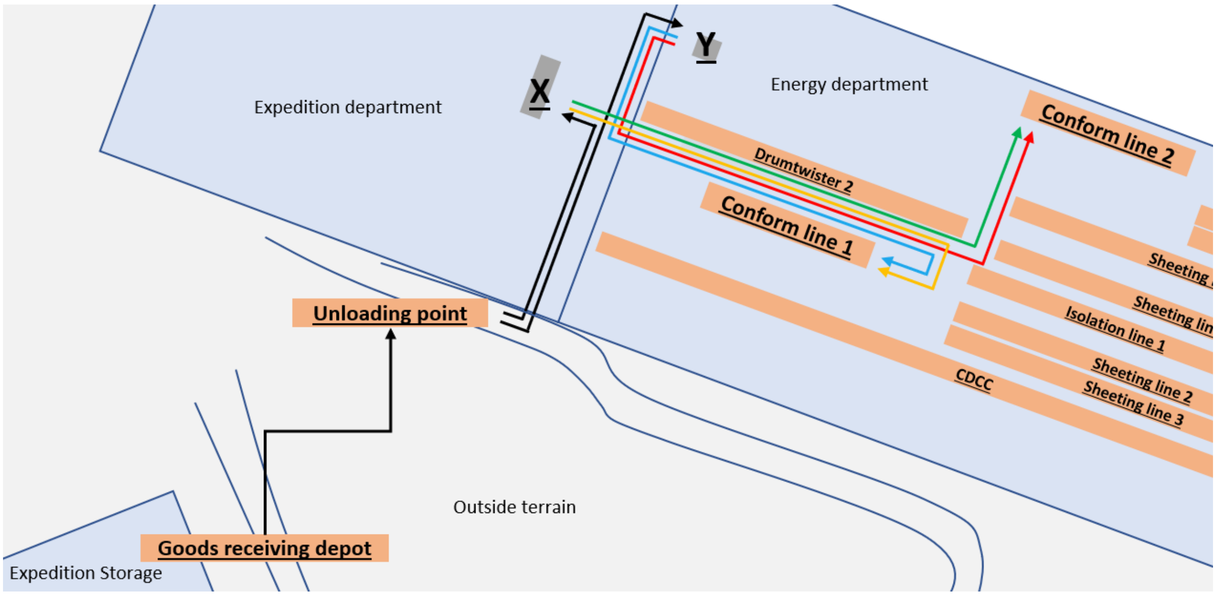



*Figure 3.5 – Map of TKF with the aluminum flow*

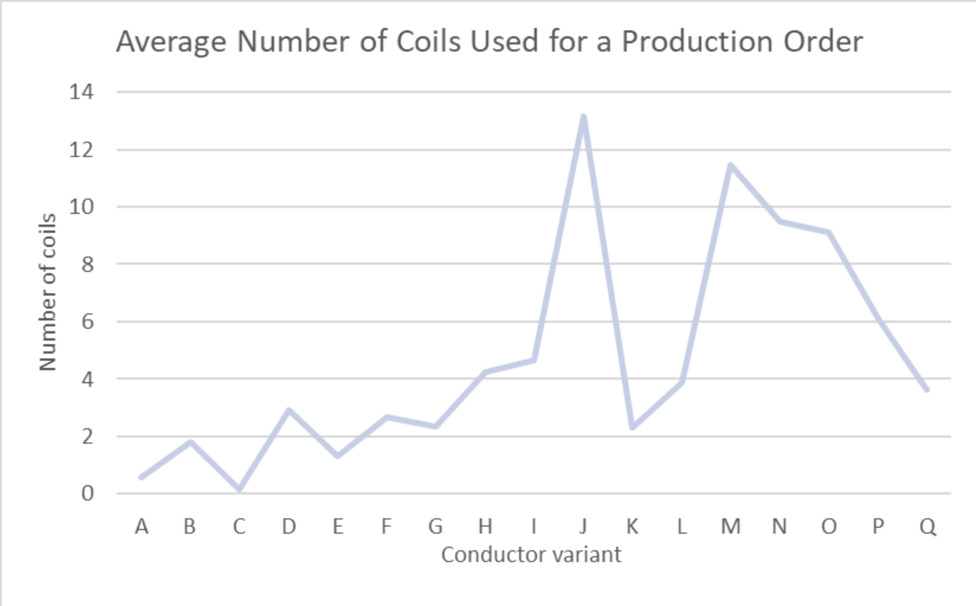



*Figure 3.6 – Average number of coils used for a production order per conductor variant*

At the goods receiving depot, the truckload is registered in the warehouse management system (WMS). During the registration, the entire truckload is seen as one item. Each truck load (12 coils) receives a unique LE-number. LE stands for logistieke eenheid, in English logistic unit. The LE-number serves as an identification number to which information is linked. For example, the article number, time of arrival, weight (in KG) and the purchasing order of the aluminum wire. Table 3.1 shows the information about arriving aluminum that is registered at the goods receiving depot. Information about the supplier or the number of coils is not registered by the receiving employee.

| Artikel NR | LE | Datum vrd. aangemaakt | Hoeveelheid | Inkoop order | Dragertype | Artikel Omschrijving | EH |
|---|---|---|---|---|---|---|---|
| 211120 | LE001543481 | 2/25/2022 15:07 | 24118 | PR042736 | BLOK | Alu Walsdraad 12,0 mm | KG |
| 211120 | LE001543920 | 2/28/2022 7:11 | 23784 | PR066820 | BLOK | Alu Walsdraad 12,0 mm | KG |

*Table 3.1 – Registered information at the goods receiving depot of TKF*

Furthermore, no labels or barcodes are attached to the coils. This makes it impossible to identify the aluminum. When registration is completed, the truck is driven to the unloading location (see Figure 3.5), where aluminum is unloaded from the truck using a forklift truck. Often, all coils are unloaded from the truck first, and briefly stored on the terrain near the unloading point before they are moved to the storage locations. This reduces the unloading time, so the truck can leave in a shorter amount of time. After the aluminum coils have been unloaded from the truck, they are stored in one of the two available storage locations. We, see that during the entire storage process no inspection of the received aluminum is performed.

For clarity, we explain the difference between registration and identification. By registration, we mean the information about arriving aluminum that is filed in the WMS. Identification refers to how the aluminum is made identifiable for stakeholders during the entire storage process.

### 3.3.2 Storage (or put away) process

At TKF, two locations within the factory are assigned to store aluminum coils. Both storage locations, location X and location Y use block stacking as a storage method. Figure 3.5 shows the location of storage location X and storage location Y at TKF denoted with X and Y, respectively. As explained in Section 2.1, block stacking is a storage method in which pallets are stacked on top of one another in lanes on the floor. Storage location X consists of two lanes, each with a lane depth of seven. Forklift truck limitations allow for a maximum stacking height of two aluminum coils on top of each other. Meaning the total number of storage positions in location X equals 28. Storage location Y has two lanes with a lane depth of three. Again, due to forklift truck limitations, the stacking height equals two coils. This means that the total storage capacity of location Y is 12 coils. The layout of location X and location Y is provided in Figure 3.7.

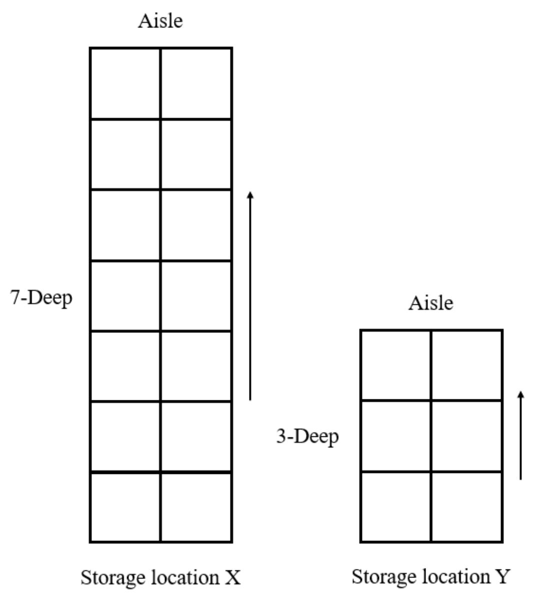



*Figure 3.7 – Layout of storage location X and storage location Y*

After the aluminum has been unloaded from the truck, the aluminum coils are stored at location X or location Y. Storage location selection is not based on a policy, instead, the forklift truck driver decides where to store the aluminum coils. Since the distance from the unloading point to location X is smaller than the distance from the unloading point to location Y, forklift truck drivers often prefer to store the coils at location X. However, this is no guarantee. Also, when location X has reached its maximum capacity, coils must be stored at location Y. A lacking storage policy has the consequence that coils from different suppliers are stored at the same storage locations. Coils are stored at the back of the lanes, and from that point, inventory is complemented with new coils moving from the back to the front. The arrows in Figure 3.7 depict the direction, from the back to the front (the aisle), in which coils are stored in the lanes. When the coils have been stored, no registration is done on the precise storage position or storage location. This means that at the end of the receiving and storage process, the only information available is the weight of aluminum that has arrived at TKF. No information on the number of coils, their supplier, and their storage position or location is available.

### 3.3.3 Picking process

The picking process is the process in which aluminum coils are transported from their storage position to the production line. Picking is done by the Last-In-First-Out (LIFO) principle. This principle ensures that coils that are put in storage last are picked first.

The production line where the aluminum wire is used is called the conform line. TKF has two conform lines, conform line 1 and conform line 2, see Figure 3.5. Both conform lines contain four supply reels (In Dutch: afwikkelblok), see Figure 3.8.

*Figure 3.8 – Supply reel (In Dutch: afwikkelblok)*

Each supply reel fits one aluminum coil. An aluminum coil is not directly placed onto a supply reel when it is moved from its storage position in storage location X or Y to the conform line. Instead, intermediary aluminum storage positions next to both conform lines, two per line, are used to supply the machines. The entire picking process is primarily managed by forklift truck drivers. When a driver observes an empty supply reel, they use their forklift truck to move one aluminum coil from its intermediary storage position onto the supply reel. At an earlier time, packaging has been removed from the aluminum coil by the machine operator. Each aluminum coil is wrapped in packaging. The packaging differs per supplier and often contains the suppliers' name. These differences make it possible to distinguish between aluminum in some way. Figure 3.9 shows aluminum coils of two different suppliers and its packaging. However, when the packaging is removed, all aluminum looks identical, making it impossible to identify the aluminum.

*Figure 3.9 – Aluminum coils of two different suppliers wrapped in packaging*

Furthermore, the supply of aluminum coils to the intermediary storage positions is also based on the observations of forklift truck drivers. When an empty intermediary storage position is observed, the forklift truck driver picks an aluminum coil from either storage location X or storage location Y and moves the coil to the empty intermediary storage position. The decision about which storage location to pick from is random. An overview of the entire storage process is provided in Figure 3.10.

### 3.3.4 Bottlenecks of storage system

The current situation of each of the three processes of the storage system of TKF is identified. All three processes, receiving, storage, and picking are lacking a method to properly handle materials and therefore contribute to COPQ. During the receiving process, the main bottleneck is the registration and identification of arriving aluminum. Currently, all aluminum coils that arrive in one truck are registered as one item. This means that no information is registered about the number of coils that a truck contains. Also, no information about the supplier is registered, and the coils are not labeled. As a result, there is no insight at TKF into the characteristics of the aluminum that has arrived. This primarily affects the subsequent processes since they are not able to identify the aluminum. The primary bottleneck during the storage process is a missing storage location assignment policy. At TKF, no model, either theoretical or mathematical, is used to allocate arriving aluminum to storage locations. Due to this, storage is unorganized and aluminum coils of multiple suppliers with different qualities are stored through each other. On top of this, there is no overview of what aluminum is stored at which location. The picking process' bottlenecks are a missing method to identify the aluminum coils when their packaging is removed and a missing method to replenish aluminum coils at both conform lines. Altogether, the bottlenecks in each of the three processes contribute to a lacking insight into the characteristics of the aluminum that is moved, stored and used.

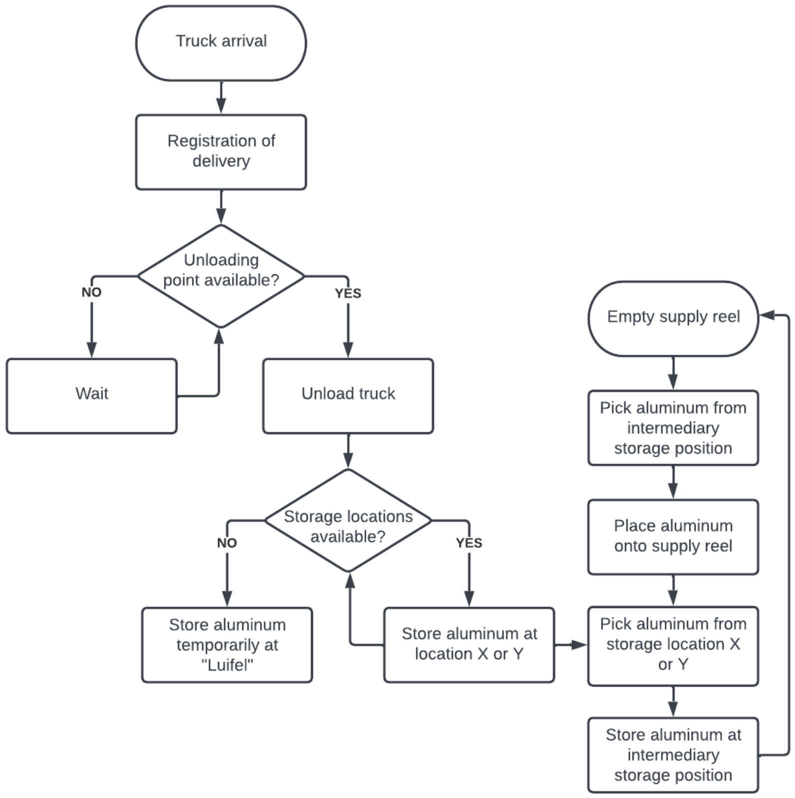



*Figure 3.10 – Process map of the storage system at TKF*

### 3.3.5 Performance of storage system

In Section 2.1.3 we mentioned several frequently used performance indicators, divided over four classes to measure the performance of storage systems. In this section, we determine which of these performance indicators are relevant for this research and measure, if possible, the performance of TKF on these indicators. We aim to find performance indicators that measure the performance of the storage system, such that aluminum can be adequately allocated to production and COPQ is reduced. For this, quality-related performance indicators are the most suitable. From Section 2.1.3, we find that quality-related performance indicators include storage accuracy, picking accuracy and scrap rate. Each of them is discussed now.

*Storage accuracy* – Storage accuracy refers to the percentage of coils that have been stored at the correct storage location. Storing aluminum at the correct storage location is essential to be able to efficiently and correctly allocate aluminum to production and reduce COPQ. For example, consider the fact that each location is assigned to store aluminum from a certain supplier and aluminum at each location is used for specific production order(s). If aluminum is stored at the wrong location, it is used in production orders that it was not originally assigned to. This might increase the COPQ. Therefore, in the context of this research, we view storage accuracy as a suitable indicator to measure the performance of the storage system. The closer the number is to 1, the more accurate aluminum is stored. The storage accuracy is determined as follows:

$$Storage\ accuracy = \frac{Number\ of\ items\ stored\ correctly}{Total\ number\ of\ items\ stored}$$

In Section 3.2.4 we identified that there is no storage location assignment policy at TKF currently. Hence, the correct storage location of aluminum is not defined. Also, no traceability is in place to determine where aluminum is stored. Therefore, the storage accuracy cannot be calculated at this stage.

*Picking accuracy* – Picking accuracy refers to the percentage of coils that have been accurately picked from storage for production. Picking accuracy is a direct indicator to measure whether aluminum is adequality allocated to production. Hence, we view picking accuracy as a relevant performance indicator for this research. Again, the closer the number is to 1, the more accurate aluminum is picked. The picking accuracy is determined as follows:

$$Picking\ accuracy = \frac{Number\ of\ items\ picked\ correctly}{Total\ number\ of\ items\ picked}$$

In Section 3.2.4 we identified that there is no method for picking aluminum currently. Also, the definition of a correct pick is not defined. Furthermore, there is no traceability to determine what aluminum is picked. This makes it impossible to determine the picking accuracy.

*Scrap rate* – Scrap rate, in the context of this research, is defined as the rate of products that contain an artifact (or multiple) that leads to electrical discharge and consequently incurs COPQ. The scrap rate is an indicator that measures the performance of the main research goal, reducing COPQ. As the storage process influences the COPQ, the scrap rate measures the performance of the storage system. The scrap rate is measured as follows:

$$Scrap\ rate = \frac{Number\ of\ products\ produced\ with\ artifact\ resulting\ in\ electrical\ discharge}{Total\ number\ of\ products\ produced}$$

We determine the scrap rate for Q1 of 2022. The aim is to achieve a scrap rate of 0, meaning that no artifacts have led to electrical discharge. In Chapter 1 we identified that in Q1 of 2022 a total number of X products contained one or more artifacts that resulted in an electrical discharge. During this period, the total number of products produced was equal to X. Meaning that the scrap rate is X, or X%.

## 3.4 Traceability Process

In Section 2.2 traceability has been defined and we mentioned that within the context of this research traceability is viewed as a tool that may contribute to improving the storage of aluminum. Traceability can support the storage process in two ways. First, a proper traceability of aluminum provides a good overview of the available aluminum at TKF. A good overview of the available aluminum, including quality classification and storage location of coils, makes it possible to allocate aluminum coils to a certain production order. Second, traceability allows TKF to trace back artifacts that occur during the production process to their origin. This helps identify circumstances, for example, a certain combination of an aluminum supplier and a production order, in which artifacts frequently occur.

At this point, the traceability of aluminum at TKF is in a bad shape. There is no information on the number of coils, suppliers and storage locations. In other words, there is no way in which aluminum can be identified meaning that all aluminum is viewed as the same product. Therefore, both ways in which traceability can support the storage process are not applied at TKF.

## 3.5 Conclusion

This chapter has answered research question 2: *"What is the current situation of the storage system and traceability process related to aluminum?"*. We mentioned that a difference in properties of aluminum between suppliers allows for a distinction between poor- and good-quality aluminum. Preferably, good quality aluminum is used for producing conductors with smaller diameters, since these are more sensitive to artifacts. Currently, a proper allocation of aluminum to production is impossible due to multiple reasons. First, during the receiving process, aluminum is not sufficiently registered and made identifiable, resulting in a lack of overview about the available aluminum. Second, there is no storage location assignment policy for aluminum at TKF, meaning that storage is unorganized, and coils of multiple suppliers are stored through one another. Third, there is no method to replenish aluminum at the conform lines and no identifiability when packaging is removed from the aluminum. Altogether, this makes a proper allocation of aluminum to production and consequently a reduction in COPQ impossible. To measure the performance of the storage system, we used three performance indicators: storage accuracy, picking accuracy and scrap rate. Only the scrap rate can be determined at this point and is equal to X, while we aim for 0.

# 4 Solution Design

This research aims to improve the storage and traceability of aluminum at TKF such that aluminum can be adequately allocated to production and COPQ is reduced. This chapter answers research question 3: *"Which storage- and traceability approaches are most suitable for TKF?"*. First, the requirements for an improved traceability process are discussed in Section 4.1. Second, Section 4.2 provides alternatives for improvements regarding the storage system of aluminum at TKF. Lastly, this chapter is concluded in Section 4.3.

## 4.1 Improving the Traceability Process

In Section 3.4 we mentioned that traceability is an important aspect to consider, especially as a supporting factor in storage systems. Before we provide a new design of the storage system of aluminum at TKF, it is important to consider the demands regarding the traceability process.

There are two types of information we are particularly interested in, (1) the available aluminum at TKF and (2) the aluminum supplier that is used for production. As mentioned in Section 2.2, traceability that acquires this information is called forward traceability and backward traceability, respectively. The level of detail in which we want to use traceability is correlated with the design of the storage location assignment policy evaluated in Section 4.2. When we want to assign a specific storage position to each coil, we need a high level of traceability, since we need information about occupied storage positions, for example. The level of traceability is allowed to be lower when the storage location assignment requires less detail about occupied storage positions.

We propose that the traceability system at least contains the following three specifications. First, incoming aluminum must be registered properly such that the total number of available aluminum coils per supplier is always known. Second, when an aluminum coil is used for production, the inventory level of that supplier should be reduced with one. Third, the supplier of aluminum coils used for production is important to be known. Together, these specifications ensure that we have an accurate knowledge of the current situation, can determine the performance of the system and evaluate these against objectives. In other words, as mentioned in Section 2.2, we are interested in status traceability, performance traceability and goal traceability.

## 4.2 Improving the Storage System

In Section 3.3 we analyzed the current situation of the current storage system of aluminum at TKF. We concluded that several bottlenecks exist within the system which together led to an unorganized process and a lack of insight into the movement, storage and usage of aluminum. This section provides the first step towards improving the storage system related to aluminum. In Section 2.1.1, we mentioned storage system design decisions are made on three levels. In this research, we mainly focus on the tactical level, where we propose and analyze, and design alternatives for the mid-term. However, also alternatives on the strategic level are provided. Section 4.2.1 provides an alternative design for the receiving process keeping in mind the requirements of TKF and the aim of this research. Then, in Section 4.2.2 we show how we can improve the storage (put away) process. Lastly, Section 4.2.3 explains alternatives for the picking process. Altogether, this section is a framework for developing a standard operating procedure (SOP), which is the topic of Chapter 5.

### 4.2.1 Improving the receiving process

In Section 3.3.4 we mentioned the bottlenecks of the receiving process in the current storage system. The main bottleneck during the receiving process comprises the lack of registration and identification of aluminum. The difference between both has been explained in Section 3.3.1. Given the fact that incoming aluminum is not sufficiently registered and identified, there is no insight into the characteristics and quantities of the aluminum that has arrived at TKF. Especially the subsequent processes are affected by this since it is impossible to store and pick aluminum according to a policy when there is no information about the available aluminum. Therefore, we aim to improve the receiving process by registering and identifying aluminum in such a way that we have a clear overview of the available aluminum at TKF. First, we discuss the registration of aluminum. Second, we discuss the identification of aluminum. Lastly, we discuss inspection as an additional improvement during the receiving process.

**Registration**

The receiving employee at the goods receiving depot is responsible for the registration and identification of aluminum. In Table 3.1 of Section 3.3.1, we showed how incoming aluminum wire is currently registered. The first step towards an improved storage system is deciding what information to be registered by the receiving employee to be able to effectively manage the aluminum in subsequent processes.

*Information to be registered*

To decide on what information to register, we are mainly interested in the information that is needed for the subsequent processes of the receiving process, namely the storage- and picking process. We mentioned that the storage process is mainly managed by forklift truck drivers. Forklift truck drivers have limited possibilities to determine the location where aluminum must be stored. They need to deal with a wide range of materials and do not have the tools and time to select the best storage location for the aluminum. So, preferably all information needed to decide on where to store the aluminum should be already provided to the forklift truck driver. So, the first information source to be registered is an indication of the storage location. After the aluminum has been stored, the next process in the storage system is the picking process. To decide what aluminum to pick, three information sources are essential, namely the type of aluminum (supplier), the available quantity and an indication of the storage location.

To summarize, we propose to register three information sources by the receiving employee: supplier, quantity and storage location. We discuss each of them.

1. Supplier

The supplier of the aluminum should be known (1) to determine the quality of the material, (2) to determine the inventory level of aluminum per supplier, (3) to assign aluminum coils to the correct storage locations and (4) to use the proper aluminum for production. To identify the supplier of the aluminum each supplier should have a unique identification number. A field should be added in the WMS to register the suppliers' identification number. This field can for example be called "Supplier_ID".

2. Quantity

The current registration process determines the total weight of all aluminum coils inside one truck. However, no information is registered on the number of coils. Since having information about the number of coils is essential to determine how many storage positions will be occupied, they should be counted by the receiving employee. The number of coils is used to get an accurate image of the inventory level.

3. Storage location indication

We mentioned that forklift truck drivers have limited resources to determine the storage location of aluminum themselves. Therefore, the information on where to store aluminum should be provided in advance using a storage location assignment policy. Since we aim to separate aluminum from different suppliers, the storage location should depend on the supplier. Alternatives for the storage location assignment policy are discussed in Section 4.2.2.

We have determined what information to register in the WMS. The next step is to decide how this information can be registered in the WMS.

*Method to register information*

To link information to incoming aluminum coils, each aluminum coil must be made identifiable by assigning a unique identifier (UID). In Section 2.2, we mentioned that a unique identifier can be either a numeric or alphanumeric string that can store information about coils. The aim of the identifier at TKF is to reveal characteristics of the aluminum such that a clear overview of the available aluminum is at hand which is useful to determine storage locations and use the proper aluminum for production. We discuss two alternatives for the application of unique identifiers.

- Alternative 1: Unique identifier for each aluminum coil

The first alternative assigns a unique identifier to each coil that arrives. This alternative allows complete traceability of coils which includes accurate knowledge of the current situation and data about performance. Table 4.1 shows the advantages and disadvantages of this alternative.

| **Advantages** | **Disadvantages** |
|---|---|
| Ability to trace each coil | Lots of data to be stored |
| Ability to assign exact storage locations or positions to each coil | Lots of similarities between coils from same arriving order |
| Overview of what coils are stored at what storage location or position | |

*Table 4.1 – Unique identifier for each aluminum coil: advantages and disadvantages*

- Alternative 2: Unique identifier for each truckload (or batch)

The second alternative assigns a unique identifier to each truckload. In other words, each coil receives an identification number that is the same for all coils in the receiving order. Since all coils from a receiving order share the same characteristics, data can be stored collectively. Assigning an identification number to all coils in one truck is especially useful when we want to know the characteristics, but we do not need complete traceability for each coil. The advantages and disadvantages of this alternative are shown in Table 4.2.

| Advantages | Disadvantages |
| --- | --- |
| Ability to assign coils from one arriving order to storage lanes | No full traceability of each coil |
| Little data to be stored | No exact information on exact storage location or position of each coil |
| | Losing overview of available aluminum throughout the storage process and production process |

*Table 4.2 – Unique identifier for each truckload: advantages and disadvantages*

We find that the primary advantage of a unique identifier for each coil is that it allows complete traceability. We determined that we are interested in the available aluminum, its characteristics and where it is stored. For this complete traceability is necessary. Furthermore, TKF sees no limitations in the data volume that can be stored. Therefore, we find alternative 1, a unique identifier for each aluminum coil, to be the best fit for TKF within this context.

**Identification**

After information about incoming aluminum coils is registered, the aluminum must be identified by the receiving employee such that stakeholders (e.g., forklift truck drivers) in the subsequent process can easily identify the aluminum, which is necessary for storage, picking and determining which supplier is used for production. We will identify aluminum coils with labels. The components that the label should (at least) consist of are discussed now.

*Barcode*

We have determined how we use UID. Thereafter, we need to decide on how to display the UID. Two alternatives are discussed.

- Alternative 1: 1D barcode

A 1D barcode, shown in Figure 4.1, is a visual black pattern, using variable width lines and spaces for encoding information. The 1D barcode can contain a maximum of 48 characters and is linked to the information stored to that specific code. As the number of characters grows, the size of the label increases. 1D barcodes can be scanned with a traditional laser scanner, but 2D scanners can be used as well. Table 4.3 shows the advantages and disadvantages of a 1D barcode,

*Figure 4.1 – 1D barcode*

| Advantages | Disadvantages |
| --- | --- |
| Best option when size of data to be stored is limited | Large label needed as number of characters in barcode increases |
| Both 1D- and 2D barcode scanners can be used | Limited amount of data can be stored |
| 1D barcode scanners are less expensive than 2D barcode scanners | If label is damaged or poorly printed it cannot be read |

*Table 4.3 – 1D barcode: advantages and disadvantages*

- Alternative 2: 2D barcode

A 2D barcode, often referred to as a Data Matrix code or QR code, consists of patterns, shapes and dots that encode information. An example of a 2D barcode is shown in Figure 4.2. The 2D barcode can contain over a thousand characters that can store lots of data including images and website addresses. Compared to a 1D barcode, the size of a 2D barcode is relatively small, meaning it will fit even on the smallest labels. Furthermore, the labels can be read even if damaged or poorly printed. The advantages and disadvantages are shown in Table 4.4.

*Figure 4.2 – 2D barcode*

| Advantages | Disadvantages |
|---|---|
| Lots of data can be stored including images and website addresses | More expensive scanning equipment needed compared to 1D barcode |
| Relatively small label needed to fit long barcode | |
| If label is damaged or poorly printed it can still be read | |

*Table 4.4 – 2D barcode: advantages and disadvantages*

We find that the primary advantage of a 2D barcode is the amount of data that can be stored. However, the barcode linked to information about aluminum only needs to store a limited amount of data, meaning that a 1D barcode would suffice. Currently, stakeholders within the storage system have different scanners. Some have scanners that can only be used for 1D barcodes and others have scanners that can be used for both 1D and 2D barcodes. Therefore, TKF decided to print every label with both a 1D barcode and a 2D barcode. Adding both barcodes to a label requires little effort, but allows it to be scanned with all scanning equipment. Therefore, we will use both barcodes on the label.

*Supplier/Storage location*

We mentioned that the storage location of an aluminum coil is provided to the forklift truck driver. The storage location of a coil depends on its supplier. Therefore, the supplier should be clearly indicated on the label. Also, the storage locations themselves should be recognizable for the successful operation of the storage system. We discuss three alternatives on how suppliers can be identified on the label and how storage locations can be made identifiable.

- Alternative 1: Color coding

Color-coded labels are an alternative to reduce storage and picking time and increase storage accuracy. By using color coding, suppliers or storage locations receive a specific color that is easily identified by the forklift truck driver. Colors are detected by the human brain more simply and quickly than printed words or numbers (One2id, 2022). As a result, using colors provides a variety of benefits. First, forklift truck drivers will work faster, since their brain recognizes colors easier compared to (alpha)numeric information. Second, storage accuracy is improved, and costs are reduced, since contrasting colors are noted immediately by the brain, making supplier and storage locations more recognizable for forklift truck drivers. This helps reduce the number of storage and picking errors. Third, color coding results in a safer working environment, since recognizing colors requires less brain capacity than (alpha)numeric codes. This means that forklift truck drivers will be less fatigued and more alert. Lastly, color coding is an easily understandable method making it suitable for people speaking different languages and temporary workers (One2id, 2022). Table 4.5 shows the advantages and disadvantages of color coding.

| Advantages | Disadvantages |
|---|---|
| Faster storing and picking | Storage locations only identifiable per lane |
| Improves storage accuracy | |
| Reduces costs | |
| Safer working environment | |
| Easy understandable | |

*Table 4.5 – Color coding: advantages and disadvantages*

- Alternative 2: (Alpha)numerical system

An (alpha)numerical system uses letters and/or numbers to identify aluminum suppliers and storage locations. Similar aluminum can be grouped by assigning a letter for example, and each coil within this group can be assigned a number to identify the exact aluminum coil. The advantages and disadvantages of this alternative are displayed in Table 4.6.

| Advantages | Disadvantages |
|---|---|
| Ability to assign aluminum to exact location | Requires detailed instructions to operate system |
| | Hard to identify aluminum and storage locations for forklift truck drivers |
| | Reduction in storage accuracy |

*Table 4.6 – (Alpha)numerical system: advantages and disadvantages*

- Alternative 3: Combination of color coding and (alpha)numerical system

Besides using color coding or an (alpha)numerical system, integrating both is also an alternative. An example of how such a combination can look like shown in Figure 4.3. This alternative will reap the benefits of both color coding and an alphanumerical system.


*Figure 4.3 – Color coding and (alpha)numerical system*

The decision on which alternative suits TKF best, depends primarily on the design of the storage location assignment policy and the level of traceability that we seek. When we want to assign aluminum coils to exact storage positions and exactly know at which location coils are stored, we need either alternative 2 or 3. When evaluating alternatives 2 and 3, we prefer to use alternative 3, since this alternative has the benefits that relate to the color coding. When the storage system does not require to have detailed information on the exact storage position of an aluminum coil, alternative 1 will suffice.

*Label*

We have determined the two most important components that the label to identify aluminum should contain. Besides the UID and the storage location, it is also useful to add the article number, since this clarifies what material is dealt with, especially if multiple materials look similar. A possible design of the label attached to aluminum coils is provided in Figure 4.4.


*Figure 4.4 – Example of a label for TKF*

**Inspection**

Besides properly registering and identifying aluminum, we propose one more improvement during the receiving process that might contribute to reducing COPQ. In Section 3.3.1, we mentioned that no inspection on the received aluminum is done. To prevent the production with aluminum that has obvious damages, we suggest that the first task when a truck with aluminum arrives at TKF, is inspection.

### 4.2.2 Improving the storage process

In Section 3.3.4 we identified a lacking storage location assignment policy as the main bottleneck during the storage process. As a result, the storage process is unorganized and aluminum coils of multiple suppliers with different qualities are stored through each other. In this section, we first discuss the storage location assignment policy. Second, we discuss alternative storage methods that might be interesting to consider for the long term.

**Storage location assignment policy (SLAP)**

In the literature review in Chapter 2, we mentioned three storage location assignment policies: dedicated policy, class-based policy and shared policy. The available storage space at TKF for aluminum cannot accommodate a dedicated storage policy since there is not enough capacity for each aluminum supplier to be stored in a dedicated lane. A class-based policy is not suitable since we want to separate all aluminum from different suppliers from each other, and not divide them into classes. Therefore, we choose a shared policy to be the most suitable policy for TKF. The shared policy dedicates no locations to aluminum suppliers meaning that an empty location is available to all SKUs. To avoid blockage and relocation of pallets, a location is temporarily dedicated to an aluminum supplier once it occupies the first position of the location. This policy is perfectly suitable for TKF, since it efficiently occupies storage space, without storing aluminum of different suppliers together. For this policy, it is important that labels are clearly visible, and that the supplier of an aluminum coil can be easily identified at all times such that forklift truck drivers can determine where to store the aluminum. To improve visibility, we provide a method for forklift truck drivers using an informative board.

An example of an informative board to increase visibility is provided in Figure 4.5. The moment a forklift truck driver stores an aluminum coil in one of the three storage locations, the board is updated with the correct supplier by the correct storage location. For example, aluminum arrives at TKF and has Supplier_ID: 001. All labels on the aluminum coils from this supplier are marked with a blue color. When the received aluminum is stored at ALU storage 1, the forklift truck driver places a blue card on the board under ALU storage 1. When all aluminum is picked from this storage location, the blue card must be removed from the board. By using this board, the forklift truck driver always has a clear overview of what aluminum supplier is stored at what location, improving decision-making regarding the storage of received aluminum.

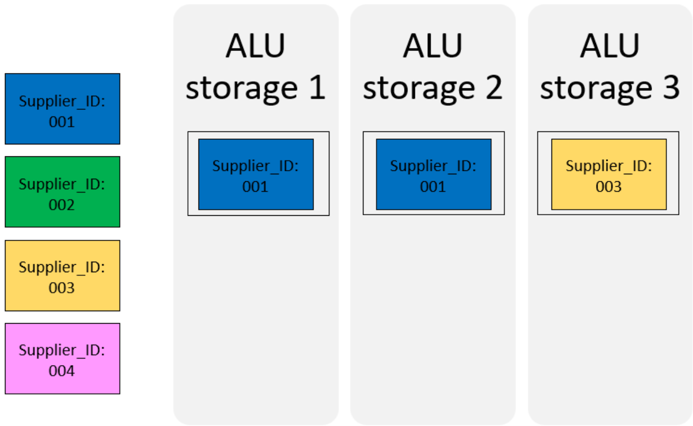



*Figure 4.5 – Example of an informative board to increase storage visibility*

Using this policy does not require marking storage locations since aluminum is not dedicated to a specific location. However, since we are also interested in tracing aluminum, it is necessary to mark storage locations.

*Traceability*

Once aluminum coils are stored, it is beneficial to know that and where they have been stored. This way, we have a clear overview of the available aluminum which can be used by the planner to decide on what aluminum to use for production. The storage locations of aluminum can be registered in WMS, by first defining the possible locations within WMS. In Section 3.3.2, we mentioned the two storage locations, X and Y, which are available for the storage of aluminum. We divide storage location X into 2 locations: ALU storage 1 and ALU storage 2. Storage location Y is called ALU storage 3. We propose to provide each location with a barcode. By first scanning the barcode on the aluminum coil and then scanning the barcode of the storage location where it will be put away, WMS will register this storage location for the specific aluminum coil. We have two possibilities on how to place barcodes on storage locations. The first possibility is placing a barcode on the floor in front of the storage location as in Figure 4.3. The second possibility, which is already used at TKF for other materials, is hanging a board above the storage locations, see Figure 4.6. We prefer the second option since this is better identifiable for forklift truck drivers. Furthermore, the first option is prone to wear.

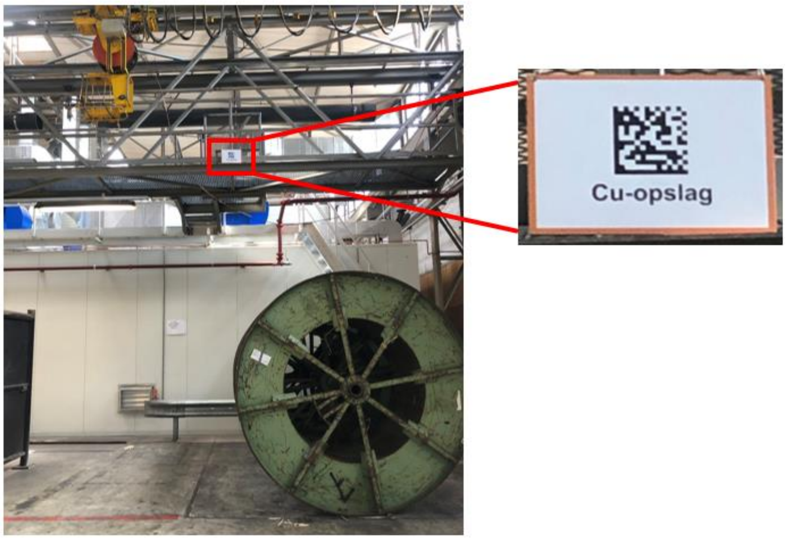



*Figure 4.6 – Storage location barcode*

**Alternatives for the long-term**

When improving the storage system, we deal with the limitations at TKF in terms of storage capacity, storage method and equipment. However, it may be interesting to consider alternatives that do not consider these limitations. Then, we look at improvements in the long term. An alternative to block stacking is pallet racking. Pallet racking is a system that uses racks to store materials instead of stored materials on the floor and directly on top of each other. Currently, aluminum coils have a maximum stacking height of two due to safety requirements. As a result, the height of the storage areas is not effectively used, meaning that more floor space is required to store aluminum. Multiple types of pallet racking systems exist. We discuss the two main systems.

- Alternative 1: Selective pallet racking

Selective pallet racking is the most basic type of pallet racking system. This method creates a shelf for storing pallets by using uprights and cross beams and often has multiple levels per lane. The number of levels in which pallets can be stored depends on the height of the storage area and the height of the pallets. Table 4.7 shows the advantages and disadvantages of selective pallet racking.

| **Advantages** | **Disadvantages** |
|---|---|
| Accessibility to all pallets | Requires accessibility from the side to store and access all pallets |
| Low investment compared to more advanced racking systems | Low storage density, since aisles are needed between racks |
| Both FIFO and LIFO handling possible | |

*Table 4.7 – Selective pallet racking: advantages and disadvantages*

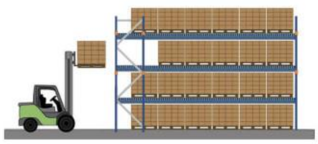
- Alternative 2: Pallet flow racking

A pallet flow racking system uses uprights and angled cross beams equipped with rollers. First pallets are loaded into the high end of the rollers. Due to the angled cross beams, the pallets move automatically towards the low end. So, every time a pallet is removed from the system all pallets move forward one position. Multiple variants of pallet flow racking exist, for example, electric rollers instead angled cross beams. These variants have the same characteristics as pallet flow racking. The advantages and disadvantages are shown in Table 4.8.

| Advantages | Disadvantages |
|---|---|
| High storage density area needed | Poor accessibility to all pallets |
| Can have deep lane | High investment due to expensive rollers |
| Pallets move automatically forward | Expensive maintenance |
| FIFO handling | |

*Table 4.8 – Pallet flow racking: advantages and disadvantages*

In a situation where TKF can change the circumstances in which aluminum must be stored, we have provided two alternatives that are interesting to consider. A comparison between both alternatives is provided in Table 4.9. Note that this does not mean that other methods should not be considered. The decision between the two alternatives mainly depends on the trade-off between storage density and accessibility. In turn, the level of storage density and accessibility required depends on the number of suppliers and inventory levels. For example, high accessibility is beneficial when there are multiple suppliers with relatively low inventory levels.

| **System** | **Block stacking** | **Selective pallet racking** | **Pallet flow racking** |
|---|---|---|---|
| |  |  |  |
| **Product Flow** | LIFO | FIFO & LIFO | FIFO |
| **Storage Density** | Low | Low | High |
| **Accessibility** | Low | High | Low |
| **Investment Costs*** | - | €4,000 | €20,000 |
| **Maintenance Costs** | Low | Low | High |

* Based on 40 pallet locations (Stein Service & Supply, 2022)

*Table 4.9 – Comparison between two pallet racking systems*

Lastly, we compare pallet racking to block stacking in terms of the total area that they occupy. *Currently*, the floor space designated for aluminum is 14 positions at storage location X and 6 positions at storage location Y. Each pallet with aluminum has a size of 1.2 x 1 meter.

$$Area\ for\ storage\ using\ block\ stacking = 1.2 * 1 * 20 = 24\ m^2$$

Besides the area needed for storage, also space for the forklift truck, to put away, pick and turn is required. The blue area shown in Figure 4.7 represents the area needed for the forklift truck. We assume that the aisle width and length need to be around 3.5 meters (Sijtsma, 2021). This means, that we require 12.25 $m^2$ per storage location.

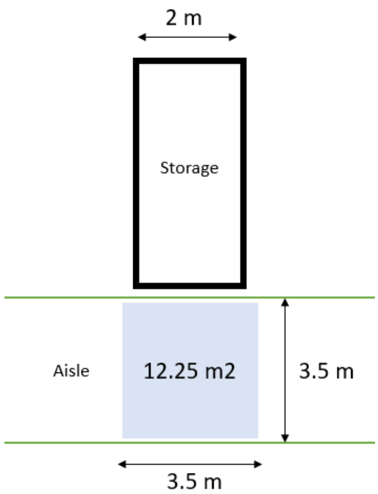



*Figure 4.7 – Area needed for forklift truck to store, pick and turn*

Since we have two storage locations, we have,

$$Area\ for\ forklift\ truck\ using\ block\ stacking = 12.25 + 12.25 = 25\ m^2$$

Adding these two areas results in the total area needed for block stacking, based on the current size of the storage locations.

$$Total\ area\ needed\ for\ blockstacking = 24 + 25 = 49\ m^2$$

To determine the area, we need for pallet racking we must make some assumptions. First, we assume that we have 3 shelves. Meaning that we need a length of 14 pallet positions, to be able to store at least 40 coils of aluminum. Second, we assume that the floor space needed is equal to the total size of the pallets that are stored on the floor.

$$Area\ for\ storage\ using\ pallet\ racking = 1.2 * 1 * 14 = 16.8\ m^2$$

Then, we need space for the forklift truck to be able to operate. For *selective pallet racking*, we need accessibility from the side of the racks, based on the length of the lane and the space needed for the forklift truck, we need 74.55 $m^2$, see Figure 4.8.

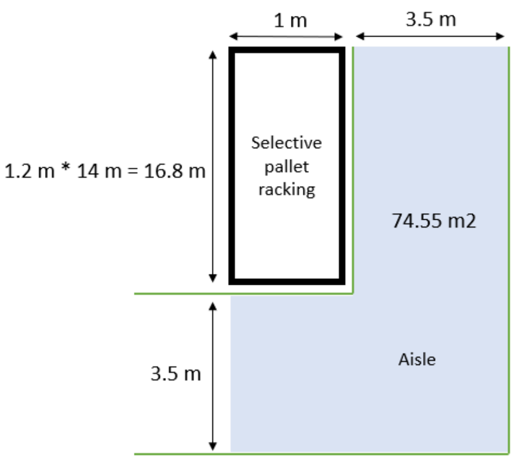



*Figure 4.8 – Area needed for selective pallet racking*

$$Total\ area\ needed\ for\ selective\ pallet\ racking = 16.8 + 74.55 = 91.35\ m^2$$

For *pallet flow racking* we need accessibility from two sides, the front and the end. This requires two times 12.25 $m^2$, see Figure 4.9.

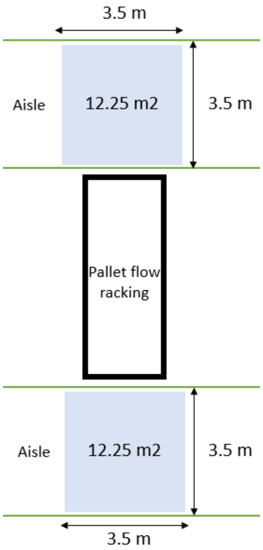



*Figure 4.9 – Area needed for pallet flow racking*

$$Total\ area\ needed\ for\ pallet\ flow\ racking = 16.8 + 25 = 41.8\ m^2$$

These results show that the area we need for pallet flow racking is significantly lower than selective pallet racking mainly since selective pallet racking requires access from the side of the racks. Furthermore, the area needed for pallet flow racking is lower than using block stacking. When dealing with space limitations, the storage area need might be an important aspect to consider.

### 4.2.3 Improving the picking process

Section 3.3.4 identified that the bottlenecks during the picking process comprise a missing method to replenish aluminum at both conform lines and the fact that aluminum is not identifiable when packaging is removed. Again, forklift truck drivers have limited possibilities to decide what aluminum to pick for the production process. Therefore, the forklift truck driver should receive information about what aluminum to pick (supplier) and where it is located. This information depends on the production order characteristics. For example, when we produce a relatively small conductor, we prefer a different aluminum supplier than when we produce a relatively thick conductor. We first provide information on what aluminum to pick. Then, we discuss how the forklift truck driver is informed about what aluminum to pick and consequently how the aluminum is made identifiable at the conform line. Lastly, we discuss alternatives for the long term.

**Picking information**

When we start a new production order, the machine operator receives a document that includes the details of the production order. For example, the conductor variant and length to be produced are provided. Currently, this document does not state which aluminum supplier to use. However, in the improved storage system, we need information about what aluminum supplier to use for a production order. Therefore, we need to provide the machine operator with a document that states exactly what aluminum supplier to use when a specific conductor variant is produced.

First, we classify aluminum suppliers based on the quality of aluminum that they deliver. We rank them from A, the best, to C, the worst. The classification is shown in Table 4.10 and is based on observations and data gathered by process improvement engineers at TKF. Also, the number of coils received per supplier as percentage of the total number of coils received is added.

| Supplier | Quality Ranking | Coils received as % of total coils received YTD-May 2022 |
|---|---|---|
| 1 | A | 6% |
| 2 | A | 37% |
| 3 | B | 50% |
| 4 | C | 7% |

*Table 4.10 – Classification of aluminum suppliers*

In Section 3.2, we stated that preferably good quality aluminum is used for producing aluminum conductors with smaller sizes since these are more sensitive to artifacts. Therefore, we need to make a distinction between “thick” and “thin” conductors. The classification of conductors, based on their size, is shown in Table 4.11. Furthermore, we have added the number of coils per class as that have been used for production as a percentage of the total number of coils used.

| Conductor Variant | Size classification | Coils used as % of total coils used YTD–May 2022 |
|---|---|---|
| < 630 mm2 | Thin | 52% |
| ≥ 630 mm2 | Thick | 48% |

*Table 4.11 – Classification of aluminum conductor size*

From Table 4.10 and Table 4.11, we see that most thin conductors can be produced with A quality aluminum and that all thick conductors with B quality aluminum. Note that the total number of received coils is almost equal to the number of coils used (4 more received than used). We state that conductors with a size < 630 mm2 are preferably produced with A rank quality. If that is not possible, aluminum with quality rank B can be used. If both A and B suppliers are not available for production, the planner must be informed, to see if there are possibilities to switch between production orders.

Then, to produce conductors with a size ≥ 630 mm2, suppliers with quality rank C are used. If no supplier with quality rank C is available, a supplier with quality rank B can be used. If both are not available, the planner must be informed to possibly switch production orders.

For this process, cooperation between the machine operator and the forklift truck driver is important, since the machine operator knows what aluminum is needed and the forklift truck driver knows what aluminum is available. We provide a method on how to inform forklift truck drivers about what aluminum to pick and where to store it.

**Picking**

The first alternative to inform forklift truck drivers is an informing board next to both conform lines and along the driving path. The board contains two parts. Each part is dedicated to one intermediary storage position. In Section 3.3.3, we mentioned that the intermediary storage positions serve as storage next to the production lines. In this alternative, we, for example, mark one intermediary storage position with the number “1” or give it a color. The other intermediary storage position is marked with the number “2” or another color. This ensures that the intermediary storage positions are differentiable. Next to each intermediary storage position on the board, a card can be placed by the machine operator. This card contains the supplier_ID and the color of the supplier from which aluminum must be picked. To clarify, the machine operator has a document that links a conductor variant of a production order to a supplier.

Next, a card with the relevant supplier is placed on board next to the position where the forklift truck driver should place the aluminum coil. This is a signal for the forklift truck driver to pick the relevant aluminum and store it at the indicated position. Immediately after the forklift driver has picked and stored the aluminum, the card is removed from the board, such that the forklift truck driver knows that no aluminum must be picked now. Figure 4.10 shows a possible design together with the relevant components of a board. For the operation of this alternative, the board must be clearly visible to forklift truck drivers. Also, all stakeholders should be made familiar with this method. The advantages and disadvantages are shown in Table 4.12.

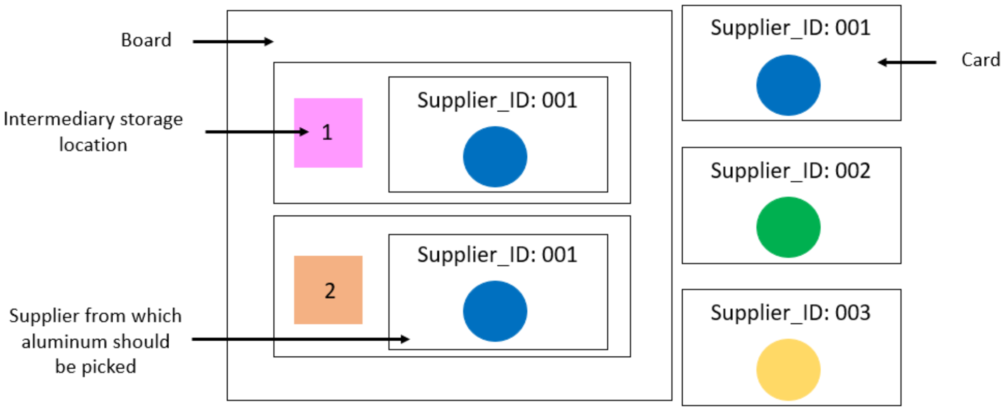



*Figure 4.10 – Potential design of information board for forklift truck driver*

| **Advantages** | **Disadvantages** |
|---|---|
| Clear overview of what aluminum to pick | Increase in work for the machine operator |
| Clear overview of where to pick aluminum | Hard to anticipate on changing production order |
| Improve picking accuracy | Chance of downtime |
| Low investment | |
| Easy to implement and understand | |

*Table 4.12 – Picking using an information board: advantages and disadvantages*

**Identifying aluminum**

Aluminum stored at the intermediary storage position is removed from its packaging, including the label, by the machine operator. From that moment, aluminum from the different suppliers looks the same and is not identifiable. Resulting in a lack of knowledge about what supplier is used for production. Therefore, we need to find a method that ensures the ability to identify aluminum.

To identify aluminum without packaging, we again evaluate a method that uses an information board. Compared to the information board for picking aluminum directed to the forklift driver, this information board is directed to the machine operator. This method again works with cards containing supplier information. The barcode on the labels of the aluminum stored at the intermediary storage position is scanned by the machine operator. Next, a label is printed that contains the color related to the supplier and the LE-number and barcode of that specific aluminum coil. Figure 4.11 shows a possible design for this label.


*Figure 4.11 – Potential design of label*

This label is attached to a card and placed on the board. The moment an aluminum coil is moved onto the supply reel, the card on the board of the concerned supplier is moved to the supply reel it is placed on. This means that every supply reel should be assigned a number, for example use a marker to write down a “2” on the supply reel. Thereafter, when aluminum on a supply reel is used for production, the card of that supplier is moved to the right and scanned by the machine operator. This way we exactly know the characteristics of the aluminum that is used. This method also prevents production with two different suppliers. After scanning, the inventory level of that supplier reduces with one. An example of a board that can be used for this method is shown in Figure 4.9. The advantages and disadvantages of this method are provided in Table 4.13.

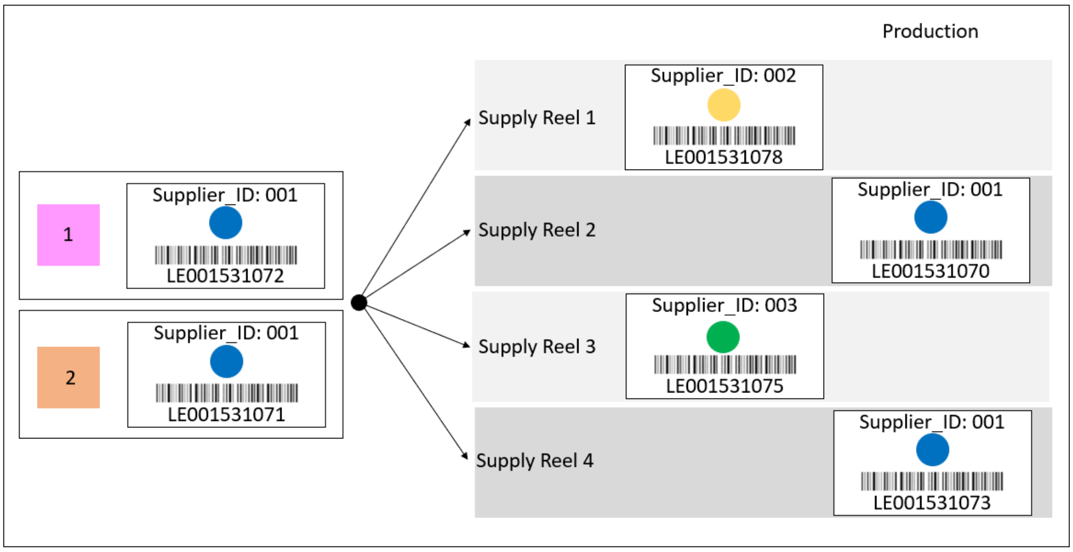



*Figure 4.12 – Potential design of board to identify aluminum suppliers*

| **Advantages** | **Disadvantages** |
|---|---|
| Clear overview of aluminum suppliers and locations | Increase in work for machine operator |
| Improve picking accuracy | Prone to mistakes |
| Low investment | |
| Easy to implement and understand | |
| Allows traceability | |
| Prevent production with two different suppliers | |

*Table 4.13 – Identifying aluminum using an information board: advantages and disadvantages*

**Alternatives for the long-term**

An alternative that enhances traceability throughout the entire storage system is radiofrequency RFID. In the literature review in Section 2.2, we mentioned that RFID technology stores an identification number and other information on a microchip attached to an antenna. This ensures up-to-date tracing of raw materials as they move from receiving to production. RFID systems consist of four elements:

1. A unique identification number linked to a coil.
2. An identity tag that is attached to the coil with a chip that stores the identification number and other information.
3. RFID readers and data processing systems that receive signals from the tags and process the data linked to the tags.
4. Databases that store the information

The technology has lots of advantages, e.g., better accuracy than manually scanning, better use of labor and fewer administrative and other human errors. However, it is also quite an investment. The costs of implementation can range from ten thousand euros to hundreds of thousands of euros, dependent on the complexity of the system (Smart et al., 2010). In the future, it might be a relevant technology to consider when TKF aims to use full traceability. At this stage, the level of traceability for aluminum that is required to operate successfully does not need RFID and can be achieved by using less complex and lower-cost alternatives.

## 4.3 Conclusion

This chapter has answered research question 3: *"Which storage- and traceability approaches are most suitable for TKF?"*. Regarding traceability, we determined that we are mainly interested in information about the available aluminum and the aluminum that is used for production. Then, to improve the storage system, we viewed each process within the system separately. The receiving process aims to improve the registration and identification of aluminum. Information to be registered is the supplier, quantity and storage location. Since we are interested in the complete traceability of aluminum coils, one unique identifier is assigned to each aluminum coil. This unique identifier is linked to the information by a barcode. This barcode is included on a label that is attached to each aluminum coil. Furthermore, the supplier should be denoted on the label such that forklift drivers know where to store the aluminum. To facilitate a smooth operation of the storage process, storage locations can be marked with colors, such that they are easily recognizable. Lastly, methods using a combination of a board and cards are provided to pick the correct aluminum from the correct supplier and trace what aluminum supplier is used for production.

# 5 Solution

This chapter provides the improved storage system for aluminum in which aluminum is adequately allocated to production and COPQ is reduced. First, Section 5.1 provides a Standard Operating Procedure for the receiving, storage and picking of aluminum. Furthermore, this section answers research question 4: *"What is the impact and feasibility of the chosen storage- and traceability methods for TKF?"*. Then, in Section 5.2, the implementation plan is provided. Lastly, this chapter is concluded in Section 5.3.

## 5.1 Standard Operating Procedure (SOP)

This section provides a Standard Operating Procedure (SOP) for the storage system of aluminum at TKF. The SOP provides employees at TKF with a framework for performing required activities to ensure a successful operation of the storage system. Since this research makes a first attempt to organize the storage and traceability process to reduce COPQ, providing an SOP is a perfect fit. Besides that the SOP aims to reduce COPQ, it is also essential for starting to measure KPIs: storage accuracy, picking accuracy and scrap rate. This information will help measuring performance, and easily identifies opportunities for further improvements and COPQ reduction.

The SOP is based on the solutions found in Chapter 4 for the bottlenecks in the storage system. By implementing a standardized storage system, a better insight into the COPQ is obtained, which enables performing accurate data analysis to reduce variation and COPQ. First, Section 5.1.1 provides the SOP for the receiving process. Also, the impact of the SOP and its feasibility are discussed. Second, Section 5.1.2 provides the SOP for the storage process. Again, impact and feasibility are discussed as well. The same is done for the picking process in Section 5.1.3.

### 5.1.1 SOP: receiving

For the receiving process, we have divided the SOP into three parts: inspection, registration and unloading and labeling. The three parts succeed one another, meaning that first the SOP for inspection should be followed, thereafter the SOP for registration and lastly the SOP for unloading and labeling. Each of them is discussed now.

**Inspection**

The inspection is the first task to be performed when a truck containing aluminum arrives at TKF. The goal of the inspection is to identify obvious damages to the aluminum. Consequently, we can determine whether to accept or reject the delivery. By inspecting the aluminum, we prevent production with aluminum that is damaged. This reduces the COPQ. The inspection takes place at the goods receiving depot and is managed by the goods receiving employee. The SOP is shown in Table 5.1.

The SOP for inspection is easily understandable, does not require any additional costs, and can be implemented fast. This means that the newly designed SOP can be easily converted into a working system.

| SOP Receiving: Inspection | | | |
|---|---|---|---|
| Topic | Inspection of Aluminum Arriving in Trucks | SOP-number | 001 |
| Location | Goods Receiving Depot | Date | 28-06-2022 |
| Actor | Goods Receiving Employee | | |
| 1. A truck containing aluminum coils arrives at the goods receiving depot at TKF.<br>2. The goods receiving employee performs a preliminary inspection of delivery documentation to confirm:<br>• Quantity matches the number on documents<br>• Coils are not obviously damaged<br>3. If damages have occured during transit: goods receiving emloyee contacts warehouse manager before unloading. | | | |

*Table 5.1 – SOP Receiving: Inspection*

**Registration**

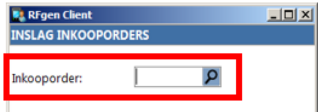
Immediately after the inspection is finished, the next task, registration, is started. During the registration, the aim is to correctly store relevant data of the received aluminum in the WMS, such that we have a clear overview of the available aluminum at TKF. This information is used to determine the correct storage location and to adequately allocate aluminum to production. Consequently, this will reduce COPQ. The registration takes place at the goods receiving depot and is managed by the goods receiving employee. The SOP for the registration is provided in Table 5.2.

The SOP for registration requires more effort than the SOP for inspection. Since multiple actions need to be performed before the SOP is operationalized, some time will pass by. For example, we suggest that in the WMS a link is made between the receiving order and supplier, such that the supplier is registered. Also, a field in the WMS should be added that automatically links a supplier to a color. However, if immediate action is taken, these adjustments can be implemented quickly. Furthermore, this SOP requires some additional costs for labels and colored stickers. Both labels and colored stickers cost around €0.01 per label/sticker. We have 12 coils in one truck, meaning that the costs are €0.24 per truck. In Q1 of 2022, around 1360 coils arrived at TKF. This means that the total label and sticker costs would have included $€0.24 * 1360 = €326.40$. Additional labor costs are negligible. Compared to the COPQ in Q1 of 2022, €X, these costs are relatively low. Lastly, the SOP is easily understandable. Together, this shows that putting a little effort into implementing the SOP is a feasible working method.

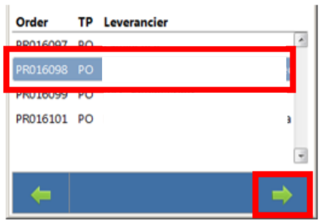
| SOP Receiving: Registration | | | |
|---|---|---|---|
| Topic | **Registration of Arriving Aluminum** | SOP-number | 002 |
| Location | **Goods Receiving Depot** | Date | 26-06-2022 |
| Actor | **Goods Receiving Employee** | | |

1. In the main menu, navigate to the **Inslag Inkooporder** tab and click on the **Checkmark**.


2. Enter the **Inkooporder**. You can:
   - Click on the magnifier
     OR
   - Type the inkooporder code




3. Select the correct inkooporder by cross-checking against inkooporder code on the shipping documents. Click on the **Arrow** or press enter.




4. A detailed window appears with information about the selected order, including the quantity that has been ordered and the quantity that is already received. Press enter.


5. Enter the **Received quantity**. Press enter.


6. Enter the number of pallets in one truck. Press enter.

7. The received order is now registered. Labels are automatically printed for each coil.

8. Add a colord sticker, based on the supplier, to each label. Give label to forklift truck driver who will unload the truck.


*Table 5.2 – SOP Receiving: Registration*

**Unloading and labelling**

When registration is completed, the truck with aluminum moves to the unloading point. At the unloading point, the aluminum coils are first unloaded from the truck and then labeled by the forklift truck driver. Labelling aims to make aluminum coils identifiable, which makes it possible for deciding on the correct storage location and to trace the aluminum throughout the storage system. Indirectly, a correct storage location and traceability reduce COPQ, since aluminum can then be properly allocated to production. The SOP is provided in Table 5.3.

The SOP for unloading and labeling is easily understandable, does not require additional costs and can be implemented fast. Therefore, this SOP is a feasible working method.

| SOP Receiving: Unloading, Labelling | | | |
|---|---|---|---|
| Topic | Unloading and Labelling of Aluminum | SOP-number | 003 |
| Location | Unloading Point | Date | 28-06-2022 |
| Actor | Forklift Truck Driver | | |
| 1. Receive labels of aluminum coils from receiving employee.<br>2. Unload the aluminum coils from the truck and temporarily place them at the unloading point.<br>• Handle all coils with care<br>• Avoid unloading during rain<br>3. Label the aluminum coils. Place lables in such a way that they are clearly visible. | | | |

*Table 5.3 – SOP Receiving: Unloading and labelling*

### 5.1.2 SOP: storage

For the storage of aluminum, the aluminum is moved from the unloading point to storage locations by the forklift truck driver. In Section 4.2.2, we determined the storage location assignment policy for the storage of aluminum at TKF. We decided that the shared policy, which only dedicates storage locations to an aluminum supplier when the first position of that location is occupied, is the best fit. A proper storage location assignment policy will reduce COPQ since it allows to pick of a specific supplier for production based on the production order characteristics. For the storage, traceability is also an important factor, since this allows for a clear overview of the available aluminum. The SOP for the storage is shown in Table 5.4.

For clarity, we make a clear distinction between storage location and storage position. A storage location is a lane on the floor that contains multiple storage positions. At TKF, currently three storage locations exist. Two storage locations have 14 storage positions. The third storage location has 12 storage positions.

The SOP for the storage is possibly the hardest SOP to implement since it requires quite some explanation for the forklift truck driver. Since multiple scenarios exist within the storage location assignment policy, it can be hard to come to grips with the policy for forklift truck drivers. Therefore, forklift truck drivers must get an extensive explanation of the policy and how to store the aluminum. However, the most important point of the policy, is that each storage location can only contain aluminum from one supplier.

Besides an extensive explanation, this SOP requires effort to design, purchase and place the boards with location names and barcodes. However, by putting the effort in, we expect that this SOP is understandable and possible to implement in a relatively short time.

| **SOP Storage** | | | |
|---|---|---|---|
| Topic | **Storage of Aluminum** | SOP-number | 004 |
| Location | **Unloading Point & Storage Location 1, 2, 3** | Date | 28-06-2022 |
| Actor | **Forklift Truck Driver** | | |

1. Check the color on the label of the received aluminum and check the storage locations ALU opslag 1, ALU opslag 2 and ALU opslag 3. There are two options:

    1) All storage positions at a storage location are **empty**
        → Store the received aluminum coils at the empty positions at the empty storage location with labels facing forward.

    2) **Not** all storage positions within a storage location are **empty**
        There are two options.
        a. The color on the labels of the received aluminum coils **match** the color on the labels of the aluminum at one (or more) storage locations.
            → Store the received alminum coils at positions within these locations that matches the color on their label.

        b. The color on the labels of the received aluminum **does not match** the color on the labels of the aluminum at the storage locations.
            Two options exist:
            i. There is a **match** in color between aluminum at two (or more) storage locations.
                → Merge the aluminum from these storage locations with same color on the labels. Move aluminum to positions from least occupied to most occupied location.
                → Store the received aluminum at the empty (or more) location that is created.
            ii. There is **no match** in color between storage locations.
                Is there a storage location with less than six coils?
                → **Yes.** Contact Logistics Manager to look for a location at TKF to temporarily store these coils. Move these coils to this location. Then, store the received aluminum at the empty storage location that is created.
                → **No.** Contact Logistics Manager to look for a location to temporarily store the received coils. Store the received coils at this location.

2. When received aluminum is stored at its storage position, scan the barcode on the label of the aluminum cooil. Next, scan the barcode in front of the storage location.

*Table 5.4 – SOP Storage*

### 5.1.3 SOP: picking

When aluminum has been stored, the next process is picking. In Section 4.2.3, we provided methods on how to pick the correct aluminum and how to make the aluminum identifiable such that we exactly know what aluminum is used for production and what quantity is still in inventory. These methods are used in the SOP. For the picking process we have divided the SOP into three SOP: providing picking information, picking and traceability. Each of them is discussed.

**Picking information**

Information on what aluminum to pick for the forklift truck driver is provided by the machine operator. In Section 3.3.3, we mentioned that each conform line has four supply reels, that supply the machine with aluminum. At most 2 supply reels are in use at the same time. The moment when one supply reel is out of aluminum, another supply reel is used. We propose that instead of always placing aluminum directly onto a supply reel when empty, that 2 supply reels always stay empty until we know what aluminum to produce with. Then, the machine operator decides what aluminum is needed to be picked and informs the forklift truck driver. The aim of the SOP for providing picking information is to use the correct aluminum supplier for production. That way, artifacts are prevented and COPQ is reduced. The SOP for picking information is provided in Table 5.5.

This SOP requires extensive explanation to the machine operator. Also, planners must be informed sufficiently. Low additional costs are required for this SOP to be operationalized. The costs comprise a board and cards. So, with a detailed explanation for stakeholders, this SOP is easy to implement and thus a feasible method for ultimately reducing COPQ. It should be noted, that for this SOP to work, first the before mentioned SOPs must be implemented successfully.

| SOP Picking: Information | | | |
|---|---|---|---|
| Topic | **Picking Information** | SOP-number | 005 |
| Location | **Conform lines 1 and 2** | Date | 28-06-2022 |
| Actor | **Planner & Machine Operator** | | |

1. Machine operator receives production order document.
2. Production order document states the conductor that is produced. Machine operator selects supplier that should be used for production based on received information about match between conductor variant and supplier.
3. 2 supply reels are in use. 2 supply reels are empty. Check:
   a. The current production order **can be finished** with the available aluminum on the supply reel.
      → Look at document of the next production order, and select card of that supplier.

   b. The current production order **cannot be finished** with the available aluminum on the supply reel.
      → Select card from the supplier of the current production order.
4. Inform the forklift truck driver about the aluminum that is needed:
   → Place selected card on the board next to the conform line. The numbers on de board indicate storage position next to the conform line. Place the card next to a storage position that is currently empty.
5. Once the forklift driver has picked the aluminum and placed it at the position indicated on the board, remove the card from the board.
6. The aluminum coil that is picked can be placed on an empty supply reel, when two supply reels are empty. Place the coil should on the supply reel behind or in front of the supply reel that currently contains the least aluminum.
7. When aluminum on a supply reel has been used completely, such that only two supply reels are occupied, return to step 3.

*Table 5.5 – SOP Picking: providing information*

**Picking**

When information is provided on what aluminum to pick, the forklift truck driver picks the aluminum. The aim of the SOP for picking is to inform forklift truck drivers how to know what aluminum to pick, when to pick, and where to place it. A correct picking procedure, ensure that production goes smoothly and that the correct aluminum is used for production. The SOP for picking is provided in Table 5.6.

The SOP for picking is easy to implement. Instructions need to be provided to the forklift truck driver but are easy to understand. Furthermore, no additional costs must be made, meaning that this SOP is a feasible working method.

| SOP Picking | | | |
|---|---|---|---|
| Topic | Picking Aluminum | SOP-number | 006 |
| Location | Storage Location 1, 2, 3 | Date | 28-06-2022 |
| Actor | Forklift Truck Driver | | |
| Process | | | |
| 1. Regurlaly view the information board next to conform lines 1 and 2.<br>2. When a card with supplier informtion is placed on the information board, it is a signal to pick aluminum.<br>3. Look at the color stated on the card on the information board. Pick aluminum that has the same color on its label from storage. Place the aluminum at the position that is indicated on the information board. | | | |

*Table 5.6 – SOP Picking*

**Traceability**

Once aluminum has arrived at the conform lines it is important to be able to keep tracing the aluminum, such that we know exactly what aluminum is used for production. However, at the conform line the packaging including the label is removed, which makes it hard to trace the aluminum. We discussed a method in Chapter 4 on how to solve this problem. The exact steps to be taken, are provided in the SOP in Table 5.7.

The SOP for traceability requires detailed instructions to the machine operator. Great accuracy and understanding of the SOP are needed for this traceability method to succeed. Furthermore, a board is needed for the operation of the SOP. Also, a label printer, only printing the barcode is sufficient, needs to be placed. Both require some costs. The costs for the board, depend on the type of board that is chosen. For example, a magnetic whiteboard with frame costs between €200 - €400, depending on the size. The estimated costs of a label printer are between €100 - €200. Compared to the COPQ these costs are relatively low. With good instructions, this method is easy to implement in a short period.

| SOP Picking: Traceability | | | |
|---|---|---|---|
| Topic | **Traceability of Aluminum at Conform lines** | SOP-number | 007 |
| Location | **Conformline 1 and 2** | Date | 29-06-2022 |
| Actor | **Machine Operator** | | |

1. Forklift truck driver places aluminum coil next to the conform line.
2. Scan the barcode on the label of the aluminum coil. A label is printed.
3. Attach the label to a card and place it on the board at the position that the coil is currently standing.
4. Remove the packaging from the aluminum coil.
5. When the forklift truck driver moves an aluminum coil onto an empty supply reel, move the card of that aluminum coil on the board aluminum forward to the supply reel that it is placed on.
6. When the aluminum coil is used for production, move the card forward again under "production". Also, scan the barcode on the card to register LE-number in CIQ, such that data linked to LE-number is registered.

*Table 5.7 – SOP Picking: Traceability*

## 5.2 Performance of SOP

In Section 5.1, we provided an SOP on how the storage system for aluminum can be improved such that COPQ is reduced. Currently no accurate data analysis can be performed which makes it difficult to predict an expected reduction in COPQ. However, the SOP allows to get better insight into COPQ, because variation within the system is eliminated. In turn, this makes an accurate data analysis possible, which can be used to reduce COPQ. Furthermore, the performance of the SOP can be evaluated by using KPIs. In Section 3.3.5, we mentioned three KPIs that relate to COPQ: storage accuracy, picking accuracy and scrap rate. The first two could not be measured yet. However, the SOP allows to measure both. Therefore, performance of the SOP and the proposed solution can only be determined after implementation. Since implementation lies out of the scope of this research, we cannot say anything about the performance. However, for TKF to determine the performance after implementation, we will provide an explanation on how the two KPIs should be measured.

*Storage accuracy* – In Section 3.3.5, we mentioned that the storage accuracy determines the percentage of aluminum coils stored at correct location. The SOP primarily focusses on storing aluminum of different suppliers separately. After implementation we know exactly at what location aluminum is stored. This also gives us information on the aluminum that is stored at a location. When we find that multiple suppliers are stored at the same location, we can say that aluminum is stored inaccurately. The accuracy can then be determined by counting the number of aluminum coils that are not of the supplier stored first at the specific location. Measuring the storage accuracy is essential for determining the performance of the SOP. Which can be used to (further) reduce COPQ. Preferably the storage accuracy should be close to 100%.

*Picking accuracy* – In Section 3.3.5, we referred to picking accuracy as the percentage of coils that have been accurately picked from storage. More specifically, we mean that the correct aluminum has been picked from storage such that the correct aluminum can be used for production. After implementation of the SOP, we can trace exactly what aluminum is used for production. This allows us to determine whether he assigned supplier to production order is in fact used for the production order. When that is not the case, the picking of that specific coils is inaccurate.

## 5.3 Implementation Plan

The SOP consists of multiple parts that are correlated and collectively contribute to reducing and getting insight into COPQ. Therefore, it is important that all SOPs are implemented step-by-step. In this section, we provide the actions that need to be taken to successfully operationalize the SOP, in other words, we provide the implementation plan. For each action, we assign the priority and an actor. The priority shows the sequence in which the steps need to be taken. The actor is the person who is responsible for fulfilling the action. The actor is also responsible for training new employees and ensuring that the SOP is used and stays up to date. Table 5.8 shows a step-by-step approach for the implementation of the SOP.

We find that most actions in the implementation plan are facilitators for a successful implementation. Figure 5.1 shows for each activity how much effort is needed and the impact they have on the implementation of the SOP. We define the impact as the expected effect that an action will have relatively on a reduction in COPQ. The effort is defined as the expected time that must be invested relatively to perform an action. We see that the actions 1-12, individually do not take much effort and do not have high impact. However, they are necessary to successfully make an impact with actions 13-15.

| Priority | Action | Actor |
|---|---|---|
| 1 | Link the purchase order automatically to the aluminum supplier in WMS. | WMS Administrator & Logistics Manager |
| 2 | Assign a color to each aluminum supplier. | Logistics Manager |
| 3 | Link the aluminum supplier automatically to the assigned color in WMS. | WMS administrator & Logistics Manager |
| 4 | Purchase stickers of the colors that have been assigned to the aluminum suppliers. | Logistics Manager |
| 5 | Design and print/purchase boards, which are placed at storage locations. The boards contain the name of the storage location and a unique barcode. | Logistics Manager |
| 6 | Add an input for the storage location of an aluminum coil in WMS. | WMS Administrator |
| 7 | Design, print and buy components needed for information board. | Industrial Engineer |
| 8 | Provide conform lines 1 and 2 with a label printer. | Industrial Engineer |
| 9 | Mark/color intermediary storage positions at conform lines 1 and 2. | Industrial Engineer |
| 10 | Design, print and buy components needed for traceability board. | Industrial Engineer |
| 11 | Inform planners about supplier selection for a production order. | Industrial Engineer & Planner |

| | | |
|---|---|---|
| 12 | Provide conform lines 1 and 2 with information document about match between conductor variant and supplier. | Industrial Engineer |
| 13 | Inform goods receiving employees on SOP. | Logistics Manager & Goods Receiving Employees |
| 14 | Inform forklift truck drivers on SOP. | Logistics Manager & Forklift Truck Drivers |
| 15 | Inform machine operators on SOP. | Industrial Engineer & Machine Operators |

*Table 5.8 – Implementation plan for SOP*

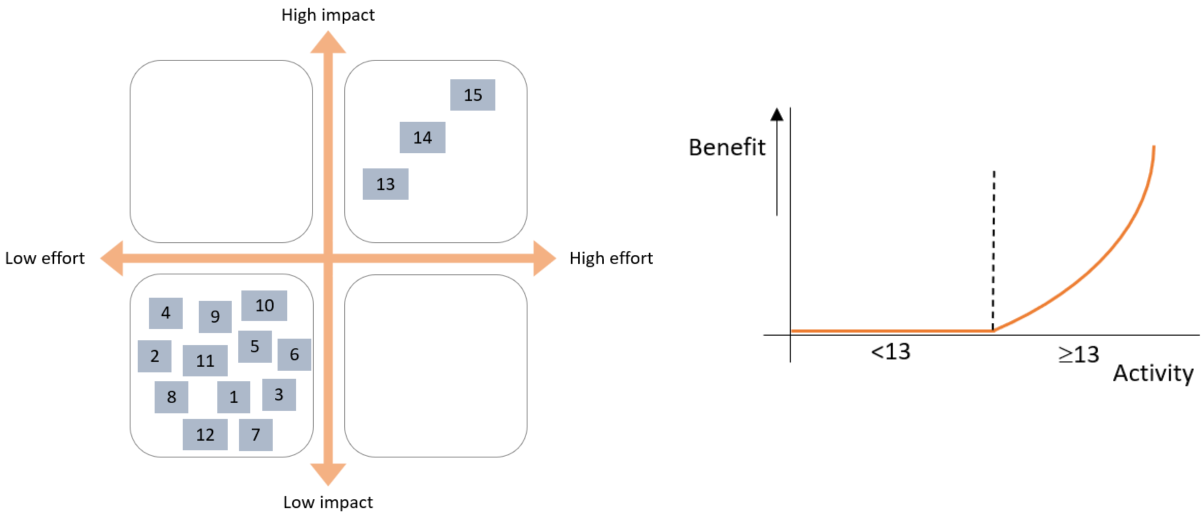



*Figure 5.1 – Impact and effort of the actions needed to be taken to implement the SOP*

Besides a step-by-step approach for implementing the SOP, another factor plays a crucial for a successful implementation. Namely, all stakeholders should accept the SOP. Without acceptance, implementation will not be successful. Therefore, acceptance must be created by (1) informing stakeholders on why this change in working method is needed and (2) a well-working and clearly defined SOP. Furthermore, by creating acceptance, the performance of the improved storage system is likely to be better, since actors will understand the method better, resulting in fewer mistakes in terms of storage accuracy and picking accuracy. Ultimately this will reduce the scrap rate and thus COPQ.

At this stage, the working methods used within the SOP, have been presented to relevant stakeholders, like machine operators, forklift truck drivers and the logistics manager. The first responses were positive.

Furthermore, it is important to assure that the quality of the SOP is controlled. We suggest that Industrial Engineers at TKF are responsible for evaluating the SOP regularly. Directly after implementation, the Industrial Engineer checks on the SOP and its operation weekly to determine whether activities are done as advised and to determine whether a revision of the SOP is necessary. Once the operation of the SOP runs smoothly, the number of checks can be reduced. However, it remains important to regularly evaluate the performance, since circumstances are frequently changing meaning that it might be necessary to slightly change the SOP.

## 5.3 Conclusion

This chapter has provided an SOP for the storage system for aluminum at TKF. Also, research question 4 has been answered: *"What is the impact and feasibility of the chosen storage- and traceability methods for TKF?"*. We determined that the expected impact of the SOP is improved picking accuracy and storage accuracy. We expect that when aluminum is adequately allocated to production, the COPQ is likely to reduce. However, we cannot say with certainty that COPQ reduces, but with the standardized storage system we have made the system measurable, which provides a better insight into COPQ and the storage system. This insight can be used to reduce COPQ. Furthermore, the implementation of the SOP has relatively low costs and can be implemented in a short amount of time if the effort is put in. For the SOP to be successful, an extensive explanation of the working method is required for the stakeholders. When this is done, the SOP with methods for the receiving, storage and picking, is a feasible method. Lastly, we have provided an implementation plan for the SOP.

# 6 Conclusions and Recommendations

In the last chapter of this research, we provide an answer to the main research question. In Section 6.1, we discuss the conclusion of this research. Then, based on the conclusion and research goal, recommendations to TKF re explained in Section 6.2. Lastly, in Section 6.3, we discuss the limitations of this research and make suggestions for further research.

## 6.1 Conclusion

In Chapter 1, we identified that the core problem at TKF was a lacking storage- and traceability method for the storage of the raw material aluminum that led to a suboptimal allocation of aluminum to production, which resulted in COPQ. Therefore, we formulated the following main research question:

"*How can TKF improve the storage method and traceability of aluminum such that aluminum can be adequately allocated to production and COPQ can be reduced?"*.

To answer this question, we divided the main question into smaller research questions. Together these will answer the main research question.

In Chapter 2, a literature review has provided insight into the structure and organization of storage systems and traceability methods in general. Also, multiple methods for designing storage systems or traceability methods have been presented.

In Chapter 3, we analyzed the current situation of the storage system and traceability of aluminum at TKF through observations and interviews with employees. The data and information collected during this analysis have been used to identify bottlenecks within the system that resulted in a sub-optimal allocation of aluminum to production. These bottlenecks were:

- Lack of registration of received aluminum
- Lack of identification of received aluminum
- Missing storage location assignment policy
- No method for replenishing aluminum at the production line
- No identification possible of the aluminum when packaging (incl. label) is removed

In Chapter 4, we identified approaches on how to solve the bottlenecks that were found. First, the requirements of TKF were determined. Consequently, we provided alternatives to solve the bottlenecks. These alternatives were evaluated based on their characteristics and the requirements of TKF, which led to the best-fit alternatives to solve the bottlenecks. The bottlenecks and their solutions are shown in Table 6.1.

| Bottleneck | Solution |
|---|---|
| Lack of registration | Unique identifier for each coil linked to supplier, received quantity and storage location |
| Lack of identification | Place label containing barcode and color that visualizes supplier on each coil |
| Missing storage location assignment policy | Adopt shared policy |
| No method for replenishing | Use information board that displays picking information |
| No identification when packaging is removed | Use information board that states relevant information of label |

*Table 6.1 – Storage system bottlenecks and their solutions*

In Chapter 5, the solutions have been merged into an SOP for the storage and traceability of aluminum. Also, an implementation plan is provided. When the SOP is successfully implemented at TKF, aluminum can be adequately allocated to production. The SOP for the storage system of aluminum at TKF allows for the collection of accurate data about storage accuracy, picking accuracy, scarp rate, and supplier used for production. Even though we are not able to verify that the COPQ reduces when the SOP is implemented, we have the possibility to gain a better insight into the COPQ which results in improvement opportunities. Therefore, we conclude that the SOP is an improved storage and traceability method that ensures that ensures an adequate allocation of aluminum to production which either immediately or in the future reduces COPQ.

## 6.2 Recommendations

Based on the conclusion and the aim of this research, we provide an overview of the recommendations to TKF.

To achieve a reduction in COPQ, the first recommendation to TKF is to start implementing the SOP. The step-by-step approach to implement the SOP is provided in Chapter 5. The activities in the SOP are solutions for the bottlenecks in the storage- and traceability process of aluminum and ensure that aluminum can be adequately allocated to aluminum. This is likely to result in a reduction of the COPQ either immediately or in the future. We provide this report to my company supervisors. It is their task, to provide the relevant information to the specific actors.

Second, we recommend to frequently talk to stakeholders that are affected by the SOP. Stakeholders, for example machine operators and forklift truck drivers, should be informed about the purpose of the changing working method. Also, their thoughts about the SOP are important for potentially improving the SOP. By involving them, they are more willing to change their working methods.

Third, we recommend TKF to start collecting and analyzing data. The SOP eliminates variations within the storage system and consequently provides data that can be used for data analysis. We propose to collect data about the storage accuracy, picking accuracy, scrap rate and supplier that is used for production. This data allows to get an even better insight into the COPQ. Which can be used to find opportunities to reduce COPQ (further).

Lastly, for the long term, we recommend looking into alternative storage methods. For example, a pallet racking system for the storage of aluminum. A pallet racking system might have several benefits among which, a lower floor occupation and better accessibility.

## 6.3 Limitations and Future Research

In this section, we address the limitations of this research and how this results in possibilities for future research.

During this research no or little data has been available regarding the storage and traceability process. However, the SOP that is provided to TKF is a solid base for starting to measure data. In this research we have made a first attempt to get insight into COPQ, data that is collected can be used to get an even better insight. Therefore, in future research we propose to focus on the analysis of the data and improve the SOP, such that COPQ can be reduced (further).

Furthermore, this research is performed as a graduation assignment for which the duration is set at ten weeks. This means that limited time is available to research all possibilities to reduce COPQ. When more time is available other factors that contribute to COPQ can be further researched. In Chapter 1, we already identified that converting machine settings might influence the COPQ. Therefore, a suggestion for future research is to investigate the effect of converting machine settings on COPQ. Another suggestion might be about how the production planning and scheduling, keeping in mind aluminum availability for example, can be improved such that we reduce the number of times that the machine settings must be changed. Also, an inventory control policy is an interesting subject for further research.

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# Appendices

## Appendix A Example Calculation COPQ

*This Appendix has been removed from the public version due to confidentiality*