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DEVELOPMENT OF BOILER TUBE MATERIAL SUPPLY CHAIN

Andritz Oy

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SAVONIA UNIVERSITY OF APPLIED SCIENCES

THESIS
Abstract

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Abstract

This thesis is an exploration into the boiler tube material supply chain processes of Andritz Oy from procurement to pressure part manufacturing. Critical topics within the supply chain process which require significant manual work were identified and explored in detail.

The aim of this thesis was to provide the desired deliverables for Andritz Oy, which were a comprehensive study and description of the current processes and the formation of concrete development ideas and recommendations concerning the topics covered. The possibility of implementing processes to reduce manual work was the priority regarding the development ideas.

The implementation phase of this thesis included extensive and frequent internal meetings and discussions. These discussions facilitated a deep understanding into the current processes and the intricacies associated with these processes. Furthermore, these frequent discussions provided an opportunity to continually review ideas formed during the thesis writing process. Development ideas were then formed based on analysis into the current processes along with ideas from the extensive literature review.

The deliverables from this thesis form materials which can be used for Andritz Oy’s internal use. Descriptions of current processes can be used as materials for orientation regarding these topics, and the development recommendations can be used as a platform for possible further discussion and implementation.

Keywords

Supply chain development, tube material, industrial boilers.

PREFACE

This thesis represents the culmination of several years of dedicated study, marking the conclusion of my engineering studies.

I would like to extend my gratitude to Andritz Oy for facilitating this thesis. Special thanks to Mikko Björn and Asta Aali for mentoring me through my thesis journey. In addition, I would like to thank Ari Jääskeläinen for guiding me through the thesis process.

Taneli Heiskanen. Kuopio. 11.5.2024

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1 INTRODUCTION

1.1 Background

Industrial boilers are a central part of various critical processes across industries such as power generation, manufacturing, and chemical recovery in pulp mills. The importance of reliable and efficient boiler systems cannot be overstated.

The longevity and functionality of industrial boilers rely heavily on the materials used in construction, especially the tube materials which form the core of the heat exchange mechanisms. These boiler tubes are subjected to extreme temperatures and pressures. They operate in corrosive environments and demand materials of exceptional quality and durability.

1.2 Rationale

The effectiveness of the supply chain for boiler tube materials is paramount for the successful execution of industrial boiler projects. Tube materials constitute a large part of the materials procured for boiler projects. Implementing good supply chain management strategies and procedures is essential for facilitating handling of both physical boiler tube materials and the flow of information among suppliers, manufacturing workshops, and the purchasing organization.

This thesis aims to investigate Andritz Oy's internal boiler tube material supply chain strategies from procurement to manufacturing and explore development ideas to reduce manual work in different phases of the supply chain.

The deliverables from this thesis are a comprehensive description of current processes and formation of development ideas based on analysis of the current processes.

1.3 Client Organization

This thesis was commissioned by Andritz Oy, specifically the Pulp & Power business segment of Andritz, which is responsible for products within the chemical recovery process and power generation in a pulp mill. These products include evaporators, white liquor plants, recovery boilers and various side stream products. The Pulp & Power business segment is also responsible for industrial power boilers. This thesis is an investigation into boiler pressure part tube materials, and it focuses on the products comprising these materials, recovery boilers, and power boilers.

Andritz Oy is a part of the international technology group Andritz, which provides solutions to clients in various industries. Andritz's four main industry sectors which they operate in are pulp and paper, metals, hydropower, and environment and energy. It is a global leading supplier of plants, equipment, automation solutions and services in these industries. *(Andritz Group)*

Concerning boilers, Andritz's main products in the power boiler category are PowerFluid CFB (Circulating Fluidized Bed) Boilers and EcoFluid BFB (Bubbling Fluidized Bed) Boilers. *(Andritz power boilers)*. In the recovery boiler category, the main product is the High Energy Kraft Recovery Boiler (HERB). *(Andritz chemical recovery boilers)*

Andritz provides their clients with customized solutions to their needs. The size and scope of boiler projects varies depending on clients' needs. This nature of differing projects requires a robust boiler tube material supply chain, as the tube material requirements change drastically depending on the project.

1.4 Detailed Scope and Limitations

In this thesis, three topics related to the boiler pressure part material supply chain are investigated. These topics were chosen because they were identified as areas which require significant manual work and could benefit from development ideas.

1. Development of Tube Inventory Documentation
2. Tube Material Certificate Exchange Between Tube Material Suppliers and Manufacturing Workshops
3. Development of Tube Material Unit Price Tracking System

This thesis approaches these topics from the purchasing organization point of view and how it deals with supply chain challenges within these topics. An extensive study and description of current processes is followed by an analysis of these processes. Development ideas are formed from the analysis of the current processes along with extensive literature research and internal discussions.

It is crucial to acknowledge the scope and limitations of this research. In examining the tube material supply chain, it is important to recognize the involvement of numerous stakeholders. It is essential to bear in mind that this research is confined to the perspective of the purchasing organization.

In addition, it is important to understand that Andritz has a vast global supply chain system. This thesis is limited to Andritz Oy's boiler tube supply chain processes from procurement and purchasing of tube materials to their delivery to manufacturing workshops within Europe. There are also other factions within Andritz which deal with boiler tube materials, however, they have their own processes. Examples of this include Andritz (China), which typically deals with industrial boiler projects in Asia, and Andritz TEP, which supplies their own catalogue of boilers to final customers.

This detailed scope enables a thorough study into Andritz Oy's boiler tube supply chain processes, free from the complexities of other departments within Andritz. This focused approach facilitates a deeper investigation, gaining more precise and concrete outcomes.

Furthermore, practical implementation of these development ideas is out of the scope of this research and may be considered as potential ideas for future implementation.

2 LITERATURE REVIEW AND BACKGROUND INFORMATION

The purpose of this literature review and background information is to explain the function and principles of tube materials in industrial boilers, and supply chain theory related to boiler tube materials. This lays the theoretical foundation for the investigation in this thesis. Understanding the tube materials and why certain materials are used are fundamental to understanding Andritz's internal boiler tube supply chain processes. Furthermore, theoretical knowledge on supply chain management, along with background information on Andritz Oy's supply chain network, serves as the base for forming development ideas concerning Andritz Oy's boiler tube supply chain processes.

2.1 Industrial Boiler Tube Material Principles

The basic function of an industrial boiler is to generate steam for industrial purposes. Scientifically, a boiler converts chemical energy in fuel into heat energy in steam. *(Rayaprolu, 2009, p. 3)*. This heat energy can then be further converted into electricity, which is common for industrial boilers. Recovery boilers are different in that they also have a function in the chemical recovery process of a pulp mill, converting concentrated black liquor into green liquor. *(KnowPulp, 2024)*.

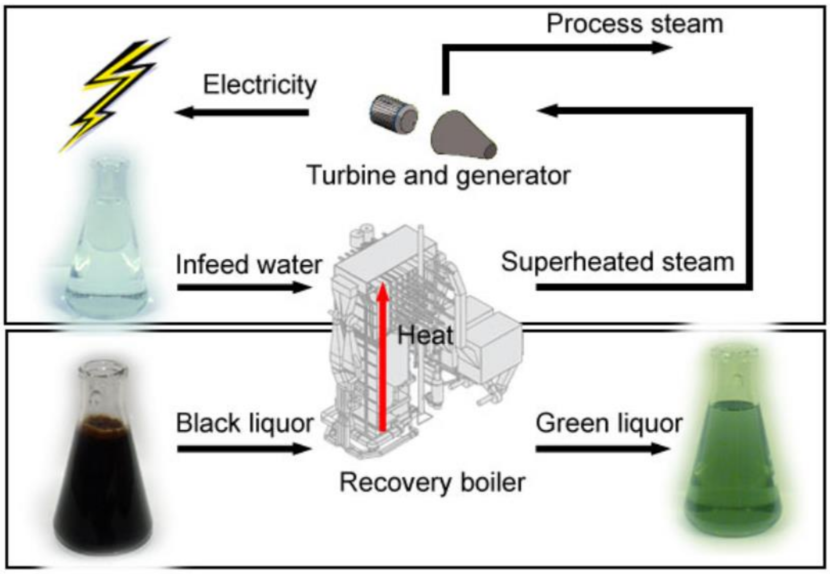

Figure 1 Functions of a Recovery Boiler *(KnowPulp, 2024)*

Figure 1 above shows the main functions of a recovery boiler. The two processes shown in the diagram are independent of each other, and the chemicals could be recovered without recovering the heat that is generated during the burning process. *(KnowPulp, 2024)*.

Tube materials form the bulk of the materials used in the heat exchange mechanisms in an industrial boiler. Boilers can generally be classified as fire tube boilers or water tube boilers, depending on the flow arrangement of water and the hot gases inside the boiler. In fire tube boilers, the hot gases flow within immersed boiler tubes, heating the surrounding water, whereas in water tube boilers, water flows through the tubes which are surrounded by hot combustion gases. *(Jayamaha, 2016, p.102)*.

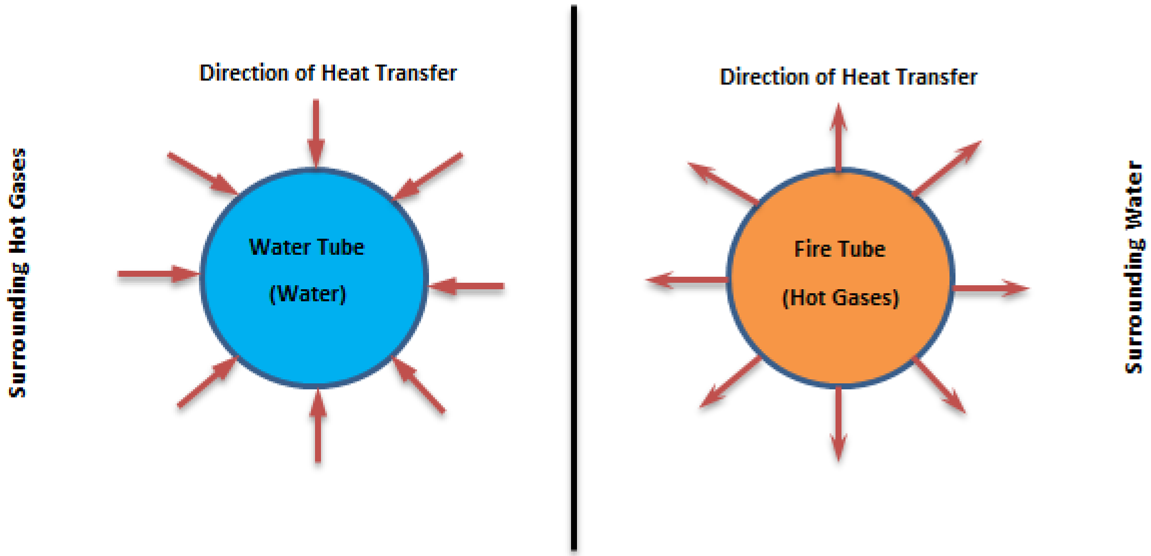

Figure 2 Water tube boiler vs Fire tube boiler *(Gasmaster)*

Figure 2 above shows a simplified diagram of the difference between a water tube boiler and a fire tube boiler.

Fire tube boilers are not viable at high pressures, therefore for industrial applications water tube boilers are used. Andritz's catalogue of power boilers and recovery boilers are all water tube boilers, therefore they are the focus for this thesis.

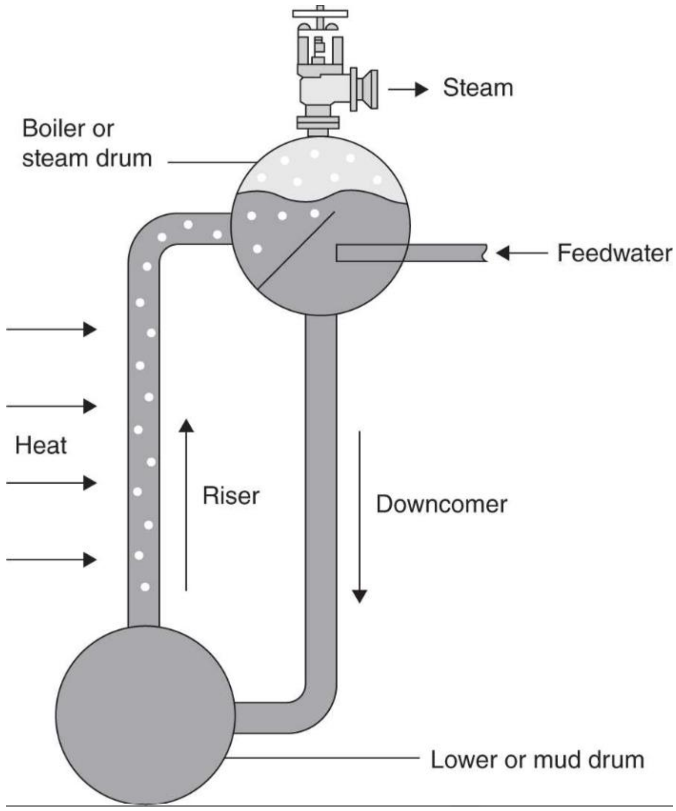

Figure 3 Simplified water circulation in a water tube boiler *(Jayamaha, 2016, p. 104)*

Figure 3 above shows a simplified diagram of water and steam circulation within the tubes of a water tube boiler. The diagram shows the basic principle of how steam is produced within the water tubes. This is an extremely simplified diagram and purely shows the principle of circulation within the boiler tubes. For example, this diagram omits the economizer, and superheaters, where tube materials are also used.

In a nutshell, feedwater is fed to the steam drum. This water has typically been preheated in an economizer which utilizes heat from the flue gases inside a boiler to preheat the water. Water then flows from the steam drum to the lower or mud dream, from where it is distributed into the tubes forming the wall of the boiler. Modern recovery boilers have a main inlet header instead of a lower drum, functioning as a single steam drum process. As the water is heated by the boiler, the mixture of water and steam rises back up to the steam drum. The steam drum is never full of water, and the reasoning behind this is that the steam drum has the important function of separating the steam from the water. Therefore, the steam and water mixture that has risen from the tubes, gets separated in the steam drum. The water that is left is reused in the process and the steam that has been separated typically flows into superheaters which then superheat the steam. The reason for superheating steam is to remove any water droplets from the steam, as they are detrimental to the turbines that the steam flows through after it leaves the boiler. *(Vakkilainen, 2005)*

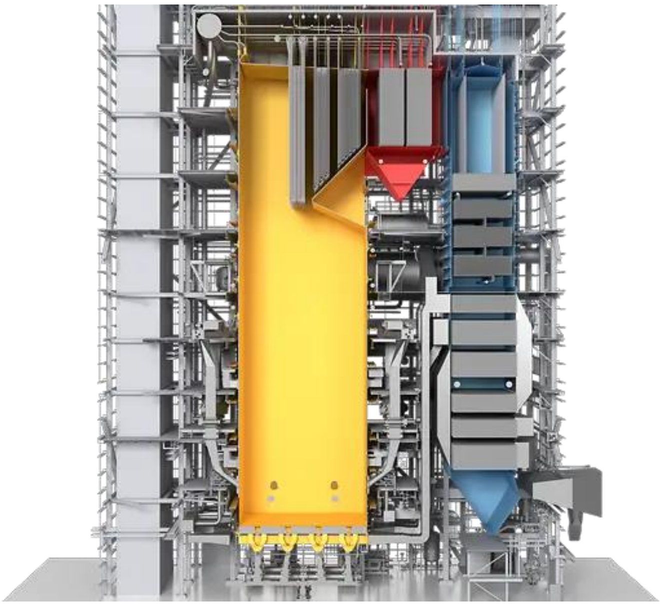

Figure 5 Power Boiler (BFB) Cross Section *(Andritz Ag, 2021)*

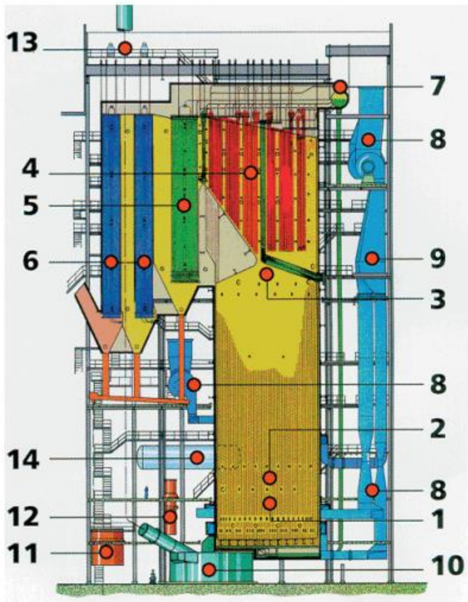

Figure 4 Recovery Boiler Cross Section *(Vakkilainen, 2005, p. 6-1)*

Figure 4 and Figure 5 above show a cross section of a typical BFB power boiler and a recovery boiler respectively. Designs of power boilers and recovery boilers are similar, however, there can be design variations depending on the size and scope of the boiler. From these diagrams, the main components requiring pressure part tube materials can be seen. Taking Figure 5 as the example, these components are the evaporative surfaces (2, 3 & 5), the superheating surfaces (4), and the economizers (6). *(Vakkilainen, 2005, p. 6-2)*

This is the basic principle of how steam and water flows within the tubes of an industrial boiler, and it explains the different parts of the boiler, where pressure part tube materials are required.

2.2 Tube Materials in Industrial Boilers

According to *(Rayaprolu, 2009, p. 167)*, materials employed in boiler making can be broadly classified into categories displayed in Figure 6 below.

Parts of a Boiler

S. No	Item	Description	Consisting Mainly
1	Pressure parts (PPs)	Pressure-holding parts, mainly FW, drum water, and steam	Drums, tubes, pipes, headers, tanks, forgings, and castings
2	Nonpressure parts (NPPs)	Fabricated items	Structure, flues and ducts, casing and hopper, tubular air heater (AH), cyclones, BRIL
3a	Bought-outs (BOs)	Equipments procured from others	Valves, mountings and fittings, soot blowers, attemperators, fans, electrostatic precipitator (ESP), rotary AH
3b	Firing equipment		Mills, burners, burner management system (BMS), stoker, feeders, air nozzles for fluidized bed combustion (FBC), hot gas generators
3c	Common BOs	Common for the total plant with one or more boilers	Feed pumps, deaerator, ash handling plant, coal handling plant, oil storage, P&H units, gas conditioning skid

Note: BRIL stands for bricks, refractory, insulation, and lagging.

Figure 6 Parts of a Boiler *(Rayaprolu, 2009, p. 168)*

Tube materials fall under the pressure parts category. Depending on the type and scope of boiler, the pressure parts category contributes to around 30 to 40% of the cost of a boiler plant. *(Rayaprolu, 2009, p. 167)*

The amount of pressure part tube materials required for a boiler varies drastically depending on the size and scope of the boiler. For example, one European recovery boiler, which is currently under construction, required 93 445 meters of pressure part tube materials and another recovery boiler required 121 118 meters of pressure part tube materials. These two recovery boilers are examples of typical European sized recovery boilers. However, on a global scale, they would be considered small, especially when compared to the significantly larger sized boilers commonly found in South America and Asia.

From Andritz's past projects, typically around 5 to 10% of the whole cost of a recovery boiler can be attributed to boiler pressure part tube materials. This cost encompasses everything, including shipping costs and installation costs. When looking purely at material costs, pressure part tube materials can be attributed to 20 to 40% of all material costs depending on the scope of the boiler. This is in line with the information from Rayaprolu' s Boilers for Power and Process book.

2.3 Specific Tube Materials Used in Boilers

Industrial boilers consist of different tube materials based on various factors such as operating conditions and the type of fuel being burned. The conditions contrast drastically when comparing the use of black liquor as fuel, and the use of other conventional fuels, such as coal. For example, kraft recovery boilers have higher rates of alkali metals and chloride in gaseous form than a coal fired boiler. *(Vakkilainen, 2005, p. 10-16)*. The intended fuel has the most profound effect on the size and shape of the boiler. *(Rayaprolu, 2009, p. 10)*.

Furthermore, within the boiler, different materials are needed at different areas of the boiler because of contrasting internal environments. For example, in a recovery boiler, the lower part of the furnace consists of composite tubes as they resist the very corrosive environment better than carbon steel. The upper part of the furnace, where the environment is not as corrosive, carbon steel tubes are used. *(Ek et al., 2009, p.330)*.

This subchapter will investigate some of the common tube materials used in industrial boilers, and where they are found within the boiler.

2.3.1 Carbon Steel Tubes

Carbon steel tubes are extremely common in industrial boilers. Carbon steel resists most corrosive conditions at oxygen rich conditions. Carbon steel also has excellent SCC (stress corrosion cracking) resistance, and it has lately been used as floor material in recovery boilers. *(Vakkilainen, 2005, p. 10-14)*.

Figure 7 Carbon steel furnace bottom *(Vakkilainen, 2005, p. 10-14)*

Figure 7 above displays a carbon steel furnace bottom.

Carbon steel is the most used tube material in industrial boilers. One of Andritz's European recovery boiler projects used 60 250 meters of P265GH carbon steel. This accounts to around 65% of all pressure part tube materials used in this project.

However, for recovery boilers, a disadvantage of bare carbon steel tubes is that they cannot resist black liquor burning on them, nor smelt contact, therefore highly alloyed composite tubes are used in the furnace lower levels. *(Vakkilainen, 2005, p. 10-14)*.

2.3.2 High Alloy Steel Tubes

Highly alloyed steel tubes are commonly found in the superheaters, especially in the secondary and tertiary superheaters. Primary superheater materials can be carbon steel, as they are protected from direct furnace radiation. These highly alloyed steel tube materials are used because of their weldability and corrosion protection properties. *(Vakkilainen, 2005, p. 10-16)*.

For example, in one of Andritz's recovery boiler projects, high alloy steel tube materials such as 10CrMo9-10, 13CrMo4-5, and 7CrMoVTiB10-10 were used in the superheaters.

There are also discrepancies concerning high alloy steel tube materials used in superheaters depending on whether a recovery boiler or a power boiler is considered. For example, austenitic stainless steels are widely used in power boilers, however, their use in recovery boilers is rather limited due to their susceptibility to SCC. *(Soodakattilayhdistys, 2004, p. 109)*

2.3.3 Composite tubes

Composite tubes are relatively new in the industry, and they are only applicable in recovery boilers. Composite tubes are not required in power boilers as the common fuels used in power boilers do not create the extreme corrosive environments that black liquor produces in recovery boilers.

Composite tubes refer to a tube that consists of an outer part of stainless steel and an inner part of carbon steel. The stainless-steel outer part allows for the tube to better resist corrosive environments, compared to a carbon steel tube. *(Ek et al., 2009, p. 330)*

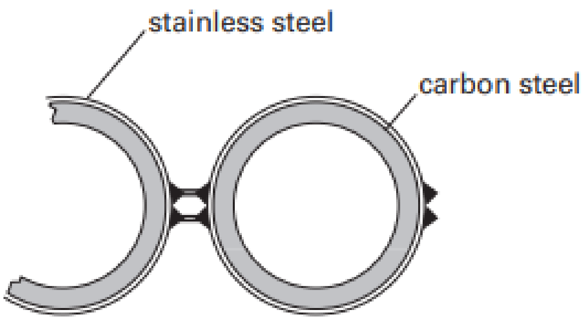

Figure 8 Cross Section of Composite Tube *(Ek et al., 2009, p. 331)*

Figure 8 above displays a cross-section of a composite tube, showing the outer stainless-steel part with the carbon steel inside part. The outer part's function is to protect the tube from corrosion, and the inner carbon steel part is the pressure bearing part of the tube.

The highly corrosive environment in the lower furnace of recovery boilers needs to be accounted for when making decisions on tube materials. Research in Finland has showed that Sanicro 38 (SAN38) composite materials had the best corrosion resistance among steels studied. *(Vakkilainen, 2005, p. 10-14)*. As a result, composite tubes such as SAN38/H11RN have been widely used in the lower furnace of recovery boilers in the industry.

For example, in one of Andritz's recovery boilers, composite SAN38/H11RN tube material was used for the lower bends on the front and rear furnace walls, and a small amount of tube material was used for the furnace floor. Composite P265GH material was used for the furnace walls. In another one of Andritz's recovery boilers, SAN38/H11RN and composite P265GH was used for the furnace walls. Furthermore, SAN28 tube material was used in the superheaters.

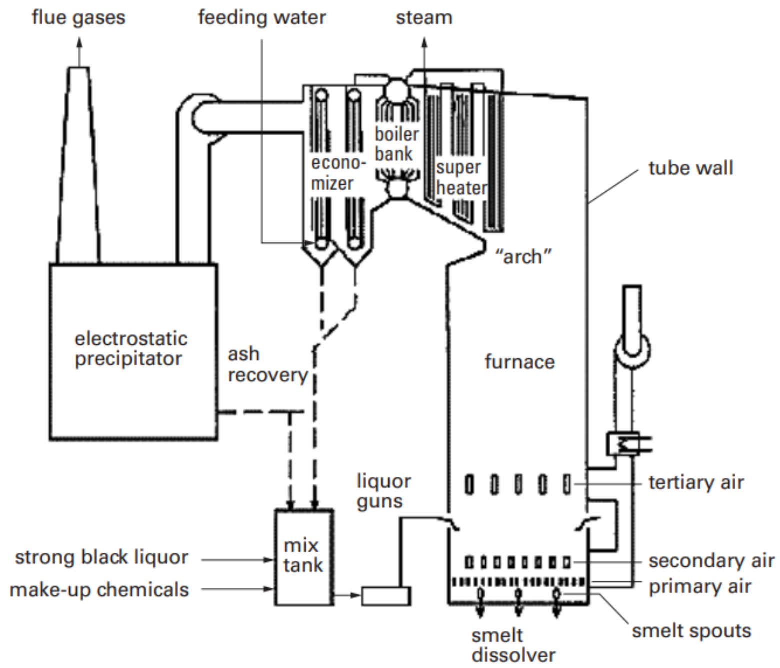

Figure 9 Schematic Diagram of Recovery Boiler *(Ek et al., 2009, p.315)*

Figure 9 above shows a schematic diagram of a recovery boiler. The area of the furnace where the composite tube material typically is found is the lower area of the furnace, up to the tertiary air ports.

2.3.4 Other Considerations Affecting Tube Material Selection

Additionally, price is a consideration that affects the materials used in boilers. Carbon steel has been an industry standard tube material for decades and it is preferred also for its relatively cheaper price compared to highly alloyed steel tubes and especially, composite steel tubes.

For example, comparing P265GH steel tubes with diameter 63.5mm and wall thickness of 6.3mm with SAN38/H11RN tubes with diameter of 63.5mm and 6.53mm, the stark difference in price can be seen. The SAN38/H11RN composite tube unit price is around 14 – 15 times the price of P265GH carbon steel tube unit price.

Another consideration that is critical is the dimensions of the tubes used in the boilers. Suppliers typically produce standard dimensions of tubes and ordering within these standard parameters usually also affects the price of the tubes. Furthermore, stock suppliers usually keep high stocks of the tubes in the dimensions that are popularly demanded.

2.4 Supply Chain Theory

As is stated in the detailed scope, this thesis explores supply chain processes within the specified scope. The scope includes supply chain processes from procurement and purchasing of boiler tubes from suppliers to the delivery of these materials to manufacturing workshops.

Supply chain management and development is at the core of the topic of this thesis. Andritz's supply chain network is extensive, with many stakeholders involved. For the purposes of this thesis, it is important to note that supply chain strategies and development ideas are approached from Andritz's purchasing organization's point of view. This distinction, along with supply chain management theory discussed in the following chapters, provides a comprehensive understanding of the principles behind Andritz's supply chain processes concerning boiler tubes.

2.4.1 Supply Chain Management

Supply chain management refers to the way in which materials and information concerning these materials are managed within the company. *(Van Weele, 2018, p. 251)*. In addition, *(Skjøtt-Larsen et al., 2007, p. 17)*, defines the concept of supply chain as the sequence of operations organized around the flow of materials from source of supply to their final distribution. There is significant overlap between logistics, procurement and purchasing. These can be seen as categories that fall under the umbrella of supply chain management, and these are the main topics within supply chain management regarding this thesis.

Within Andritz's supply chain network, there is significant communication between the purchasing organization and manufacturing workshops regarding information flow about tube materials. Andritz's pulp and power logistics organization coordinates the delivery of physical tube materials to the correct manufacturing workshops.

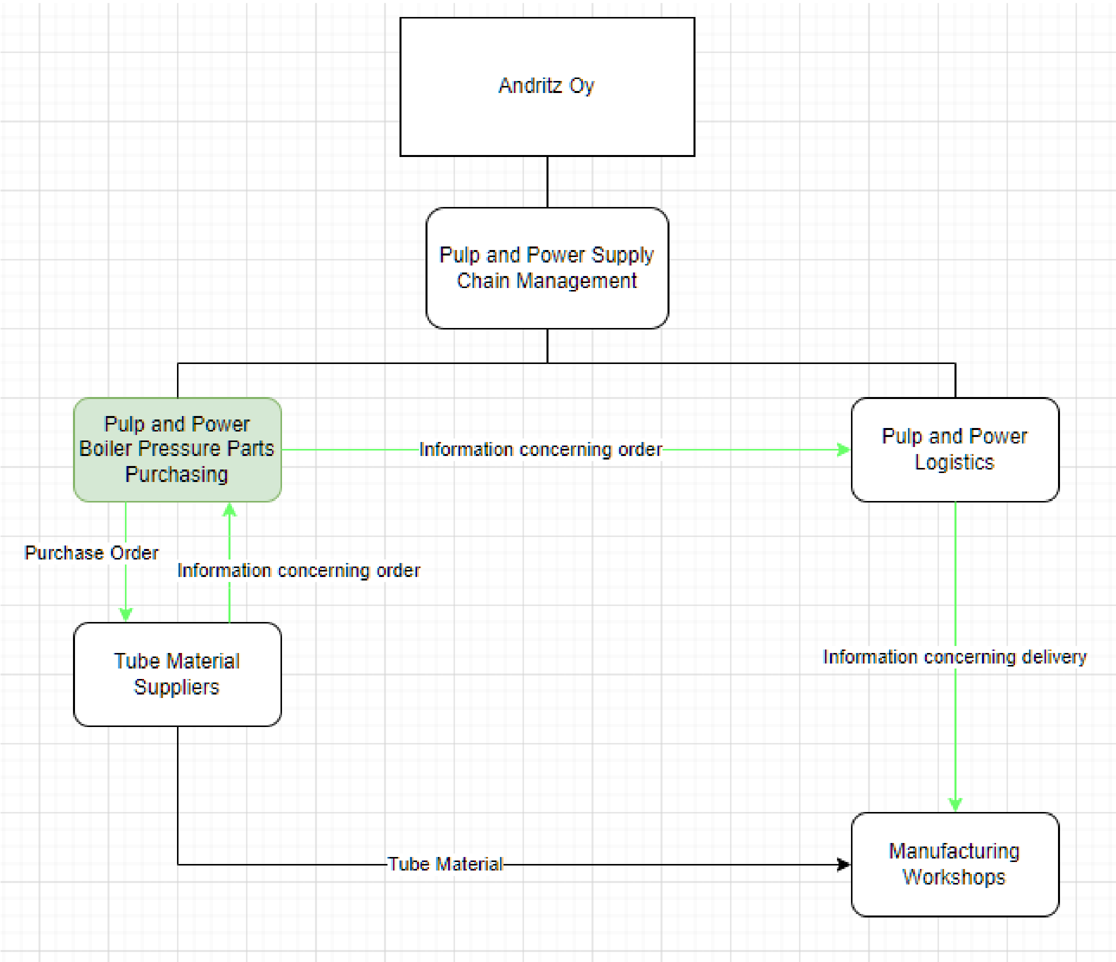

Figure 10 Andritz Boiler Tube Supply Chain Network *(Adapted from Andritz Internal Information)*

Figure 10 above displays a simplified supply chain network diagram for Andritz's boiler tubes, showing the main stakeholders. This diagram is simplified and adapted from Andritz's internal network diagrams. Regarding Andritz's boiler tube supply chain network, the four main stakeholders are the boiler pressure parts category purchasing department, the pulp and power logistics department, the tube material suppliers, and the manufacturing workshops. The purchasing organization is shaded in green to enhance clarity, as this thesis adopts the perspective of the purchasing organization. Information flow is depicted with green arrows, and physical boiler tube flow is depicted with black arrows. As indicated in Figure 10, the physical movement of tube materials happens between the tube material suppliers and manufacturing workshops, whereas the information flows between all stakeholders involved.

2.4.2 Supply Chain Challenges

The complex and intricate nature of supply chain networks makes them innately prone to various challenges. *(Drake, 2012, p. 20)*, identifies variability to be one of the biggest challenges within supply chain networks. Variability is seen in every supply chain network, and it necessarily adds to a company's supply chain costs. Variability is usually handled with two major strategies; carrying extra inventory or building agility and responsiveness to supply chain operations. *(Drake, 2012, p. 20)*. Variability is seen in Andritz Oy's tube material supply chain. Inventory carrying, especially concerning composite tube materials, is a strategy implemented heavily by Andritz Oy.

Vertical integration is another strategy that is utilized to tackle supply chain challenges. It is defined as a strategy that allows a company to streamline its operations by taking direct ownership of various stages of its production process. *(Hayes, 2024)*. Benefits of vertical integration include increased control over supply chain operations, easing coordination between different stages of the supply chain. However, firms need to be able to have the capacity for successful implementation of a vertical acquisition. *(Drake, 2012, p. 6)*.

Vertical integration is a strategy that Andritz has used concerning boiler pressure part manufacturing. Full ownership of Andritz Warkaus Works and implementation of Andritz TEP as fully owned Andritz workshop are examples of vertical integration.

2.4.3 Purchasing Organization

The purchasing organization is central to the procurement and purchasing of materials within a company. Procurement and purchasing are extremely important for manufacturing companies. The largest part of the cost of goods sold or sales revenues is taken up by purchased materials and services. Procurement costs make up approximately 50% of the cost of the final product. *(Van Weele, 2018, p. 12)*.

Purchasing organizations are structured to suit the purchasing needs of the company. In industrial sectors, purchasers often have a technical background, and are knowledgeable about the products they are responsible for.

Purchasing organizations can typically be divided into two distinct organizational structures: centralized structure, or decentralized structure. Centralization refers to global coordination, integration, and synergy across dispersed organizational units, whereas decentralization implies flexibility and adaptability to local conditions. Benefits of a centralized structure include pooled negotiation power, shared resources and knowledge, and increased coordination between different departments. On the other hand, decentralized structures take advantage of local knowledge of supply markets. *(Johnsen et al., 2019, p. 66)*.

(Johnsen et al., 2019, p. 66) suggests that organizations with a large portfolio of different purchase categories are often reluctant to be dictated by a central purchasing management structure as they believe they can obtain better deals themselves as they have superior local supply market knowledge. This is true in Andritz's case with many different industrial products, with different purchasing organizations for different product categories. Furthermore, there are different purchasing organizations for the same products in different areas of the world. For example, boiler tube materials purchasing for Asian boiler projects is coordinated from Asia, taking advantage of significant local market knowledge. However, there are centralization strategies being implemented to take advantage of Andritz's global supply chain network, with the goal of increasing coordination between the various purchasing organizations within Andritz. This combination of centralized and decentralized purchasing structures is known as a hybrid purchasing structure. *(Johnsen et al., 2019, p. 71)*.

2.4.4 International Logistics and Inventory Management

Logistics and inventory management are supply chain management topics that are present in this thesis. From a logistical point of view, Andritz is an international company. Concerning boiler tube material manufacturing in Europe, Andritz Oy utilizes various suppliers and manufacturing workshops around Europe.

International logistics processes are present in Andritz Oy's boiler tube supply chain, specifically concerning the physical movement of the materials around Europe, and the inventory management of these tube materials at Andritz Warkaus Works.

International logistics is distinct from domestic logistics as it deals with greater complexity, and more variables. A major factor that must be considered is the increased transportation costs. *(Czinkota et al., 1989, p. 448)*.

Inventory management is critical to Andritz's boiler tube material supply chain strategy, especially regarding composite tube materials. According to *(Czinkota et al., 1989, p. 438)*, inventory carrying costs can easily comprise up to 25 percent of the value of the inventories themselves.

Inventory can also be seen as a strategic tool. Decisions such as geographical location of inventory warehouses, centralization or decentralization of warehouses are critical. *(Czinkota et al., 1989 p. 440 – 447)*. For example, centralized logistics management centralizes the decision-making process and coordinates the global logistics processes, whereas decentralized logistics management can lead to greater local management knowledge and satisfaction. *(Czinkota et al., 1989, p. 446 – 447)*.

In addition, *(Harrison & van Hoek, 2011, p. 121)* suggests that in product environments where inventory costs are more important than distribution costs, centralized inventories are beneficial. This issue is present in Andritz's own boiler tube inventory management system, especially concerning the possibility of opening a composite tube inventory at Andritz TEP.

2.5 Andritz Oy Boiler Tube Supply Chain Network Background Information

This subchapter will explore critical information about Andritz Oy's boiler tube supply chain network. This information is necessary for the comprehension of the key elements of this thesis.

Within Andritz Oy's purchasing organization, boiler tubes fall in the category purchasing category. A category is defined as a group of products which are purchased within specific groups, indicating the company's most important spend categories. *(Van Weele, 2018, p. 216)*. Boiler tubes make up a significant part of an industrial boiler, necessitating a good procurement strategy for these materials. Procurement of these materials is specialized and distinct from other boiler components. Furthermore, the market is typically more volatile to price changes, with quotations for having shorter validity periods compared to other materials and components. Therefore, Andritz has identified this as an important category, for which they have designated a category purchaser.

For the purposes of this thesis, the boiler tube materials can be broadly classified into two categories. The categorization is made from a supply chain point of view, and they are defined by their availability and delivery times in the market. It is important to make this categorization because it forms the basis for the investigation into inventory management, as the reason a stock amount of compound tubes is kept is their relatively long delivery times.

1. Tubes that are readily available from suppliers with short delivery times

These include carbon steel tubes such as P265GH, and high alloy tubes such as 10CrMo9-10, with relatively low delivery times.

2. Composite tubes that have relatively long delivery times from suppliers

These include tube materials such as SAN38/H11RN, composite P265GH.

2.6 Conclusion of Literature Review

This literature review thoroughly examines boiler tube material theory, gaining the basis for the investigation from the materials point of view. Furthermore, an exploration into supply chain theory allows for a comprehensive outlook at the issue of this thesis.

Linking supply chain management theory and understanding physical boiler tube theory allows us to understand why certain supply chain decisions chain are made. Furthermore, this literature review facilitates an analysis into developments that can be made to supply chain strategies.

With the insights gained from the literature review, there is strong theoretical background, along with background information for the investigation part of the thesis.

3 CURRENT PROCESSES

This chapter describes the current processes with the three main topics of investigation.

This study into the tube material supply chain requires a description of the current supply chain processes. Understanding the current situation and the reason behind these processes allows for a comprehensive investigation into how these processes can be developed. Furthermore, tube materials are a critical component of industrial boilers, therefore the supply chain process for tube materials is integral to the success of a project.

In addition, it is critical to understand Andritz's manufacturing processes and policies to gain a deeper understanding into the supply chain process. In Europe, Andritz uses three main manufacturing workshops among others to manufacture different components for boilers (Andritz Warkaus Works, Andritz TEP, and SHI FW Energia Fakop). When Asian manufacturing is used, the manufacturing workshops are typically responsible for their own tube material supply. There are other workshops that are used; however, these three listed workshops form the bulk of the tube material manufacturing concerning boilers in Europe. It is important to make the distinction between Andritz's own workshops and independent workshops. These differences affect the relationship between Andritz Oy and the workshop.

Andritz Warkaus Works has been fully owned by Andritz since 2013 and manufacturing at a new facility commenced in 2022. *(History of Warkaus Works)*. Andritz TEP, formerly Duro Dakovic TEP, was founded in 1921 in Croatia and it was fully acquired by Andritz in March 2023. *(Andritz* *termoenergetskapostrojenja doo - andritz tep)*. SHI FW Energia Fakop was established in 1880 in Poland, and it is owned by Sumitomo SHI FW. *(Shi Fw Energia Fakop, 2020)*.

Naturally, Andritz Oy works in close collaboration with Andritz Warkaus Works. Andritz TEP is being gradually integrated into the Andritz group and the implementation of composite tube manufacturing at Andritz TEP is a concrete example of the integration. Previously, composite tube manufacturing was done exclusively at Andritz Warkaus Works. SHI FW Energia Fakop is used by Andritz Oy solely as a manufacturing workshop without other functions.

As stated in the earlier paragraph, these different levels of collaboration are important to distinguish, and it affects functions such as inventory management which will be reflected in the tube inventory section.

Andritz is a project-based organization, and the day-to-day activities are dictated by these projects. As a result, typically pipes are ordered and allocated directly to a project.

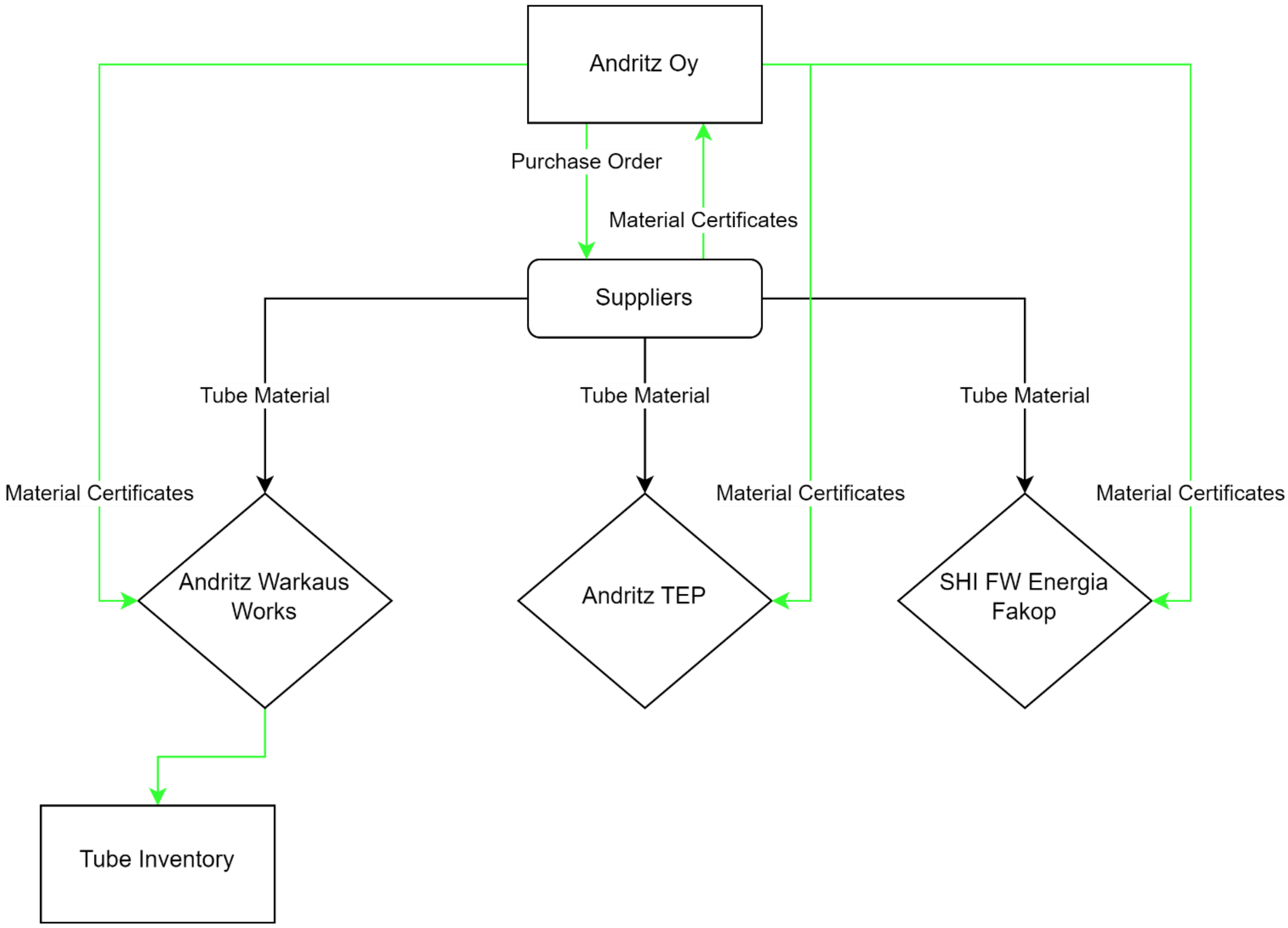

Figure 11 Tube Material Flow Chart

Figure 11 above shows a simple flow chart to display the current tube material supply chain process. The green arrows display movement of information, and the black arrows display physical movement of tubes.

Following the flow chart, the process starts from a purchase order made by Andritz to the supplier. (In reality, the supply chain purchasing process for tube materials begins earlier than this, however, it is out of the scope of this thesis.) The purchase order usually specifies to the supplier which manufacturing workshop the tube materials will be delivered to. The details of delivery from supplier to manufacturing workshop is handled between Andritz's logistics department and the suppliers. Once the materials are shipped to the workshops, the suppliers provide the material certificates to Andritz Oy. Andritz Oy then sends these material certificates to the relevant manufacturing workshop where the tube materials are being delivered.

As stated earlier, Andritz keeps an inventory of the tubes that are delivered to Andritz Warkaus Works. This is depicted in Figure 11 above. Currently, there is no inventory management at the other manufacturing workshops.

The flow chart depicted in Figure 11 above is valid for tube materials with relatively low delivery times (carbon steel tubes, high alloy steel tubes), whereby it is possible to deliver the materials directly to the manufacturing workshop working on the project. Composite tube materials have relatively long delivery times, and the material flow chart for these tube materials is depicted in Figure 12 below.

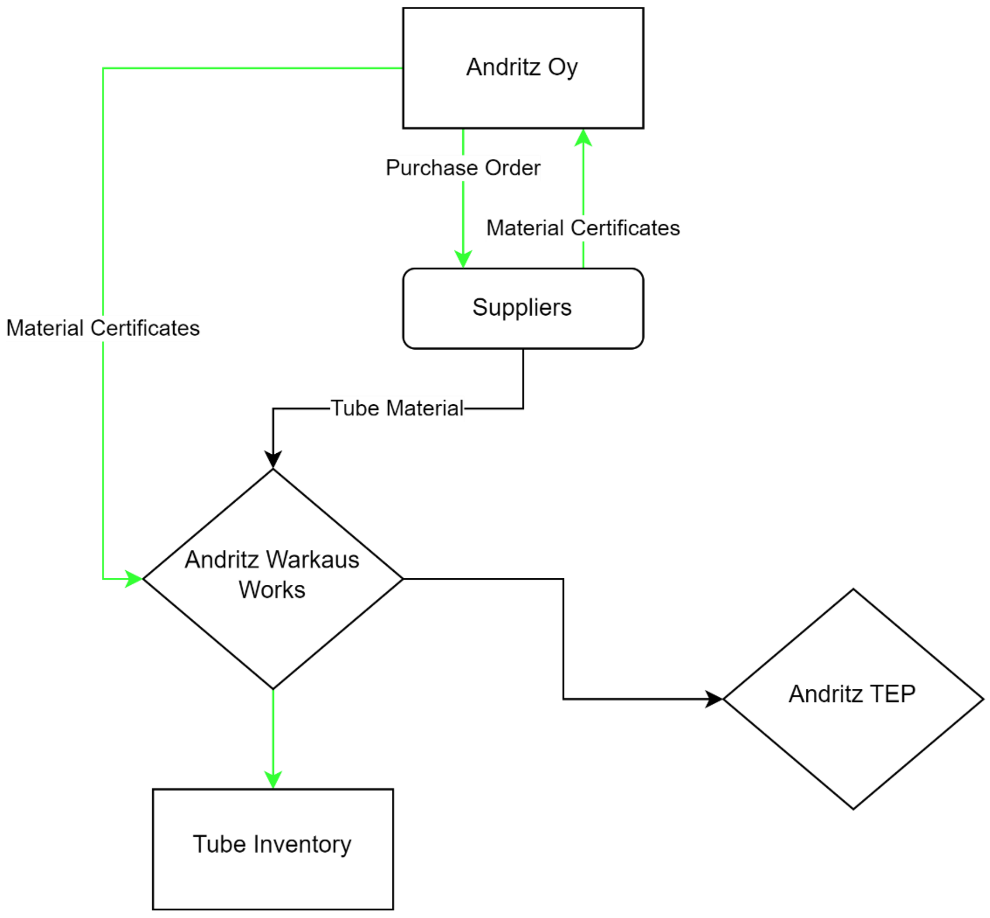

Figure 12 Composite Tube Material Flow Chart

Figure 12 above depicts the material flow chart for composite tubes. These tubes have a relatively long delivery time; therefore, a stock of these materials is kept at Andritz Warkaus Works.

Andritz Warkaus Works has traditionally been the only workshop doing composite tube manufacturing. However, with the ongoing integration of Andritz TEP, composite tube manufacturing has commenced there as well. For example, the composite tube manufacturing for one of Andritz's recovery boiler projects is currently being done at Andritz TEP.

Composite tube supply chain process is different from regular steel tube supply chain process as these materials are not directly allocated to a project. A defined level of stock inventory is kept, and materials are reserved to projects from this stock.

3.1 Tube Inventory Management System

Tube inventory management is a critical function from Andritz Oy's point of view. It contributes to the goal of maximizing profit along with minimizing waste. Currently Andritz Oy keeps an inventory of tubes at Andritz Warkaus Works and Warkaus Works' warehouse is central to the control and management of the tube inventory.

Concerning the other workshops that Andritz uses in tube manufacturing, there is not a tube inventory management system. This is due to the nature of Andritz not owning these workshops. The situation with Andritz TEP is currently being assessed, with the possibility of commencing inventory operations there.

As stated earlier, Andritz typically orders tubes directly to projects. In practice, this means that tubes are ordered directly from suppliers to be delivered to the manufacturers. The manufacturers differ depending on the project and what components are being manufactured. Tubes delivered to Fakop and Andritz TEP are not tracked after they have been delivered, and what these workshops do with unused tubes is not of concern to Andritz Oy. The situation may change in the future with Andritz TEP as they are fully integrated into Andritz. However, tubes delivered to Andritz Warkaus Works are monitored and inventory of these tubes is kept.

Furthermore, Andritz Warkaus Works is central to maintaining the stock of composite tube materials. Composite tubes are unique in that they have delivery times that are long, compared to other tubes. Therefore, the warehouse at Andritz Warkaus Works is extremely important, as a place to store these composite tubes. From a purchasing and logistics point of view, the management of the stock level of these composite tubes is critical. It is one of the key functions of the inventory management system for Andritz Oy. Composite tubes are significantly more expensive than normal carbon steel tubes that are used and therefore their inventory levels are closely managed to reduce waste.

Concerning composite tube materials, Andritz Oy's goal is to have 20 kilometers of 304L or equivalent tube materials, and 3 kilometers of SAN38/H11RN or equivalent tube materials. Currently, these composite tube materials have delivery times of 10 to 12 months, however, these delivery times can fluctuate and, in the past, the delivery times for these materials has been as high as 18 months. This stock amount of material is vital for Andritz Oy's boiler business, and this stock material can facilitate manufacturing of a few recovery boilers.

In this explanation of the tube inventory system, it is important to understand that Andritz Warkaus Works and Andritz Oy keep separate inventory lists of the tubes in different systems. The reason behind this is the differing goals of the inventory list. Andritz Warkaus Works' inventory list is designed to aid their manufacturing, whereas Andritz Oy's inventory list is designed to track the stocks of tubes and make tube material reservations for potential future projects. These differences in the primary goals of the inventory systems have led to distinct differences in how these inventory systems are managed and utilized.

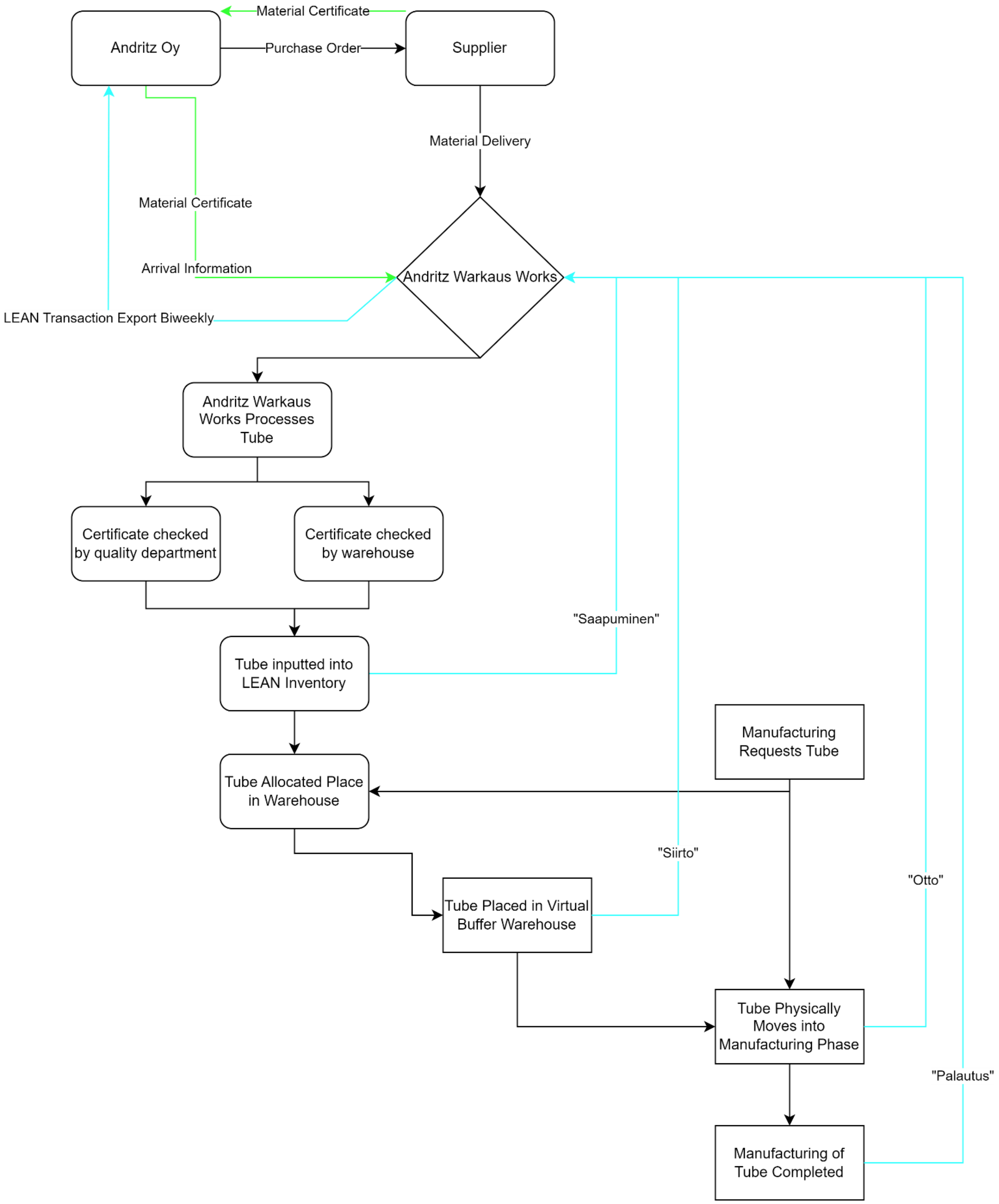

Figure 13 Tube Material Arrival Flow Chart

Figure 13 above depicts a flow chart of information and material flow when a delivery of tubes arrives at Andritz Warkaus Works. The green arrow shows the information flow from Andritz Oy to Andritz Warkaus Works, when a purchase order for tube materials is made. Conversely, the blue arrows show the flow of information in the other direction, from Andritz Warkaus Works to Andritz Oy. The blue arrows visually show the "phases" the tube materials are in during their handling process, which is reflected in the LEAN transaction list which is exported to Andritz Oy.

3.1.1 Andritz Warkaus Works Tube Inventory

Andritz Warkaus Works keeps their inventory in a system called LEAN. LEAN is Andritz Warkaus Works' manufacturing system, and it has an inventory tracking function built in. As the main function of the LEAN system is to aid manufacturing, the maintenance of the tube inventory requires substantial manual work.

To understand the full situation in the inventory management system, it is important to understand the physical movement of the tubes throughout the whole inventory management process. Following the flow chart in Figure 13, the different phases of tube material movement within the inventory management process is seen.

First, an order is made to a supplier, after which the tube materials are shipped to the Andritz Warkaus Works workshop. The warehouse at Andritz Warkaus Works processes these tubes, along with the quality department. The tubes are then placed in a physical storage place in the warehouse and the inventory list is updated in the LEAN manufacturing system. Andritz Warkaus Works stores the tube materials by the bundles that they arrive in. This information is reflected in the inventory information.

Then, when manufacturing requires a tube, they place an electronic request for the specific tubes in the LEAN system. The warehouse team then moves the tube materials into a virtual "buffer" warehouse. This buffer warehouse is strictly virtual, and its purpose is for the warehouse and manufacturing team to know that the tube material has been reserved for manufacturing. When manufacturing is ready for the tube materials, the materials are physically moved into the manufacturing workshop.

If there are left over tube materials from manufacturing, they are returned to the warehouse and inventory system.

3.1.2 Andritz Oy Tube Inventory

Andritz Oy keeps their tube inventory in an Excel spreadsheet. This tube inventory list consists of pipes for both capital and service projects. From the capital projects side, the inventory list is maintained by the category purchaser for tubes, Asta Aali.

The main goal of the inventory list from Andritz Oy's point of view is to maintain an updated inventory list with the capability to reserve tube materials for projects that come up. Furthermore, other Andritz departments globally can communicate with Andritz Oy to query about the possibility to use tubes from Andritz Oy's inventory. This function is typical with the service side of Andritz Oy, as they typically need small amounts of tube materials at short notice.

Row No	Type	Project	Order No.	Pos.	Tube Dia	Tube Wall	Layer	Base Material HT8 = SA213T22/ 10CrMo9-10 HT7=	SAP Material No.	Material Grade	Open Reservation [m]	Origin Reservation [m]	Intakes from Stock [m]	Free Capacity [m]	Warehouse Actual "m"
955	KAPITAL TASE	Tase	4503311034	20	63,5	6,53	SAN38	SAN38	131023251	Compound	25,00		2244,61	846,3	871,32
955	VARAUS	Cerrado	4503311034	20	63,5	6,53	SAN38	SAN38	131023251		25,00	25,00			
955	OTTO	Vestrock eväputki	4503311034	20	63,5	6,53	SAN38	SAN38	131023251				15,21		
955	OTTO	Kaukas tulppapaneelit	4503311034	20	63,5	6,53	SAN38	SAN38	131023251				38,03		
955	OTTO	Romutus	4503311034	20	63,5	6,53	SAN38	SAN38	131023251				469,29		

Figure 14 Andritz Oy Inventory List

Figure 14 above displays an excerpt from Andritz Oy's inventory list. This is solely an excerpt from one order of SAN 38 tube material, which is a composite tube that has been ordered to stock at Andritz Warkaus Works. The columns represent critical information about the tube materials, and the tube material information are inputted in different color codes on the rows.

Andritz Oy maintains their inventories by SAP order number. The reasoning for this is the ease in filtering which tubes are ordered for which projects. This is distinct from Andritz Warkaus Works, as they maintain their list in bundles and material number.

The rows with blue text indicate that this tube material is physically in the inventory at Andritz Warkaus Works' warehouse.

The rows with red text indicate "otto" which means that this material has been taken from the inventory into manufacturing. This can also refer to tube materials being shipped from the Andritz Warkaus Works warehouse to a different manufacturing workshop.

The rows with pink text indicate "varaus" which is the reservation of tube materials to projects. This is the most critical function of Andritz Oy's inventory management system and the premise for the whole system.

The rows with grey text indicate tubes that have been ordered but have not yet arrived at Andritz Warkaus Works' warehouse.

The Excel cell highlighted in green displays the actual amount of the specific tube material from the order number that is left in the warehouse.

The materials in the inventory can be split into two distinct categories, tube materials that are ordered to an Andritz Oy company balance (tase), and tube materials which are ordered directly to a project. Composite tube materials, such as the SAN38 tube material in Figure 14, are ordered to the company balance, whereas other tube materials are ordered directly to projects. The leftovers from previous projects are used in future projects where possible. This is commonly seen in service projects.

The composite tube materials which are ordered to the company balance require a cost shift when they are allocated to a certain project. This is one of the main functions of keeping a detailed balance of these materials, facilitating the allocation of costs to a project. The same principle applies when tube materials which were originally ordered for a different project are used.

3.1.3 Communication between Andritz Warkaus Works Inventory and Andritz Oy Inventory

Communication and exchange of information between these two inventory lists is critical for control and up to date maintenance of Andritz Oy's list.

Currently, a transactions list from the LEAN system is exported every two weeks and this list is sent to the tubes category purchaser, who updates Andritz Oy's list.

	A	B	C	D	E	F	G	H	I	J
1	Tap.tyyppi	Varasto	Tap.päivä	SAP-tilaus/positio	Määrä	Nim.nimi	Projekti	Aktiviteetti	Info 1	Tap.tunnus
2	Otto	PANDS	17/01/2024	4504091248-20	-11,3	SA210A1-D63,5-S6,35	501743	501743		128768
3	Otto	PANDS	11/01/2024	4504091248-20	-12	SA210A1-D63,5-S6,35	501743	501743		128020
4	Otto	PANDS	10/01/2024	4504091248-20	-186,11	SA210A1-D63,5-S6,35	501743	501743		127884
5	Otto	PANDS	08/01/2024	4504091248-10	-70	SA210A1-D63,5-S6,35	501744			127628
6	Saapuminen	LMNAND	19/01/2024	4503842007-20	32,7	SAN38/4L7-D63,5-S6,53				129134
7	Saapuminen	LMNAND	19/01/2024	4503842007-20	98,47	SAN38/4L7-D63,5-S6,53				129134
8	Saapuminen	LMNAND	19/01/2024	4503842007-20	125,94	SAN38/4L7-D63,5-S6,53				129134
9	Saapuminen	LMNAND	19/01/2024	4503842007-10	21,85	3R12/4L7-D63,5-S6,53				129134
10	Saapuminen	LMNAND	19/01/2024	4503842007-10	48,05	3R12/4L7-D63,5-S6,53				129134
11	Saapuminen	LMNAND	19/01/2024	4503842007-10	312,45	3R12/4L7-D63,5-S6,53				129134
12	Saapuminen	LMNAND	19/01/2024	4503842007-10	43,14	3R12/4L7-D63,5-S6,53				129134
13	Saapuminen	LMNAND	19/01/2024	4503842007-10	141,74	3R12/4L7-D63,5-S6,53				129134
14	Saapuminen	LMNAND	19/01/2024	4503842007-10	260	3R12/4L7-D63,5-S6,53				129134
15	Saapuminen	LMNAND	19/01/2024	4503842007-10	271,7	3R12/4L7-D63,5-S6,53				129134
16	Saapuminen	LMNAND	19/01/2024	4503842007-10	52,49	3R12/4L7-D63,5-S6,53				129134
17	Saapuminen	LMNAND	19/01/2024	4503842007-10	55,28	3R12/4L7-D63,5-S6,53				129134
18	Saapuminen	LMNAND	19/01/2024	4503842007-10	43	3R12/4L7-D63,5-S6,53				129134
19	Saapuminen	LMNAND	19/01/2024	4503842007-10	272,09	3R12/4L7-D63,5-S6,53				129134
20	Saapuminen	LMNAND	19/01/2024	4503842007-10	71,12	3R12/4L7-D63,5-S6,53				129134
21	Saapuminen	LMNAND	19/01/2024	4503842007-10	14,62	3R12/4L7-D63,5-S6,53				129134
22	Saapuminen	LMNAND	19/01/2024	4503842007-10	36,65	3R12/4L7-D63,5-S6,53				129134
23	Saapuminen	LMNAND	19/01/2024	4503842007-10	20,82	3R12/4L7-D63,5-S6,53				129134
24	Saapuminen	LMNAND	19/01/2024	4503842007-10	190,34	3R12/4L7-D63,5-S6,53				129134
25	Saapuminen	LMNAND	15/01/2024	4503842007-10	251,69	3R12/4L7-D63,5-S6,53				128314
26	Saapuminen	LMNAND	15/01/2024	4503842007-10	329,47	3R12/4L7-D63,5-S6,53				128314
27	Saapuminen	LMNAND	15/01/2024	4503842007-10	342,98	3R12/4L7-D63,5-S6,53				128314
28	Saapuminen	LMNAND	15/01/2024	4503842007-10	265,76	3R12/4L7-D63,5-S6,53				128314
29	Saapuminen	LMNAND	15/01/2024	4503842007-10	45,5	3R12/4L7-D63,5-S6,53				128314
30	Saapuminen	LMNAND	15/01/2024	4503842007-10	181,95	3R12/4L7-D63,5-S6,53				128314

Figure 15 LEAN Transactions exported to Excel from Weeks 2-3 2024

Figure 15 above shows a screenshot excerpt of the LEAN transactions list exported to Excel. This is the document used to communicate the inventory situation between Andritz Warkaus Works and Andritz Oy.

From Andritz Oy's point of view, there are 4 columns which are of use. Tap.tyyppi, SAP-tilaus/positio, Määrä, and Nim.nimi.

Tap.tyyppi displays the type of transaction, of which there are four options. These are related to the movement of the tubes, detailed in the Andritz Warkaus Works chapter. Saapuminen refers to the arrival of the tube into both physical storage and the inventory list. Siirto refers to the transfer of the tube from storage into the manufacturing virtual buffer storage. This can be thought of as the manufacturing reserving the tube. Otto then refers to the physical movement of the tube from storage into manufacturing. There is also Palautus which refers to tube material that has been returned from manufacturing. Typically, this is tube that is left over from manufacturing that can then be used in another project.

SAP-tilaus/position refers to the SAP order number that Andritz Oy has used to make the purchase of the tube. This piece of information is extremely important as this is the way that information from this transaction list is filtered and updated into Andritz Oy's inventory list. As stated before, Andritz

Warkaus Works stores the tubes by bundles, whereas Andritz Oy keeps their inventory list by SAP order number. Therefore, from the list above, we can see that row 9 to 30 in Andritz Warkaus Works' inventory list, with each row referring to one bundle, corresponds to one row in Andritz Oy's list.

Määrä refers to the quantity of tubes in meters.

Nim.nimi refers to the name of the tube and the dimensions of the tube. For example, from row 9 we can see that the tube that has arrived is 3R12/4L7, which is a composite tube, with outside diameter of 63.5 mm and wall thickness of 6.53 mm. In Andritz Oy's inventory list, the names and dimensions of each tube are displayed in different columns which eases filtering when searching for specific tubes.

The other columns that are exported from the LEAN system are used for Andritz Warkaus Works' internal manufacturing processes and are not needed for Andritz Oy's applications.

3.1.4 Difference Between the Inventory Systems

There are differences between information displayed Andritz Oy's inventory list and Andritz Warkaus Works' inventory list. These differences occur from differing goals for the inventory list.

The biggest difference is how the information about the storage of tube materials in the warehouse is reflected in the respective inventory management systems. Andritz Warkaus Works stores the tube materials in the bundles that they arrive in, which is reflected in their inventory management system. Whereas Andritz Oy, stores the information about these tube materials by order number, displaying which project the tubes are allocated to. The exception to this is composite tube materials, which are ordered to stock rather than directly to a project.

Another difference is that the LEAN system has the whole name of the tube and dimensions of the tube in the same cell, whereas Andritz Oy's system has the dimensions separated from the tube name.

A further example of differences is the SAP-tilaus/positio column and the projekti column. These columns are defining the same thing, the project that this bundle of tubes is used for. For example, in row 2, the SAP-tilaus/positio is 4504091247-20 and the projekti is 501743. The projekti number is solely for the purpose of the manufacturing at Andritz Warkaus Works, and Andritz Oy has no use for this number, and the SAP-tilaus/positio is solely for Andritz Oy's purpose to know what project the tubes are being used for. These two numbers correspond to the same project, yet they have no connection to each other in terms of communication. This currently causes significant manual work as each Andritz Warkaus Works project number needs to be manually allocated to the Andritz Oy project.

(Internal Meeting, 2024, Boman T, Aali A, Heiskanen T)

3.2 Material Certificates

Material certificates are an integral part of the boiler tube material supply chain. Functions such as documentation, quality assurance, traceability, and compliance are critical things that material certificates enable. Therefore, the supply chain strategy concerning handling material certificates from suppliers to manufacturing workshops is extremely important.

This chapter covers the current process of transferring material certificate information between tube material suppliers and manufacturing workshops.

3.2.1 Material Certificate Transfer Current

Currently, Andritz Oy receives the material certificates from suppliers upon delivery of a tube material order. The material certificates are then manually sent from Andritz Oy to the relevant manufacturing workshop, along with Andritz Oy's quality department for documentation purposes. There is substantial manual work in connecting the correct material certificate to the correct tube materials, and then sending the information to the manufacturing workshops.

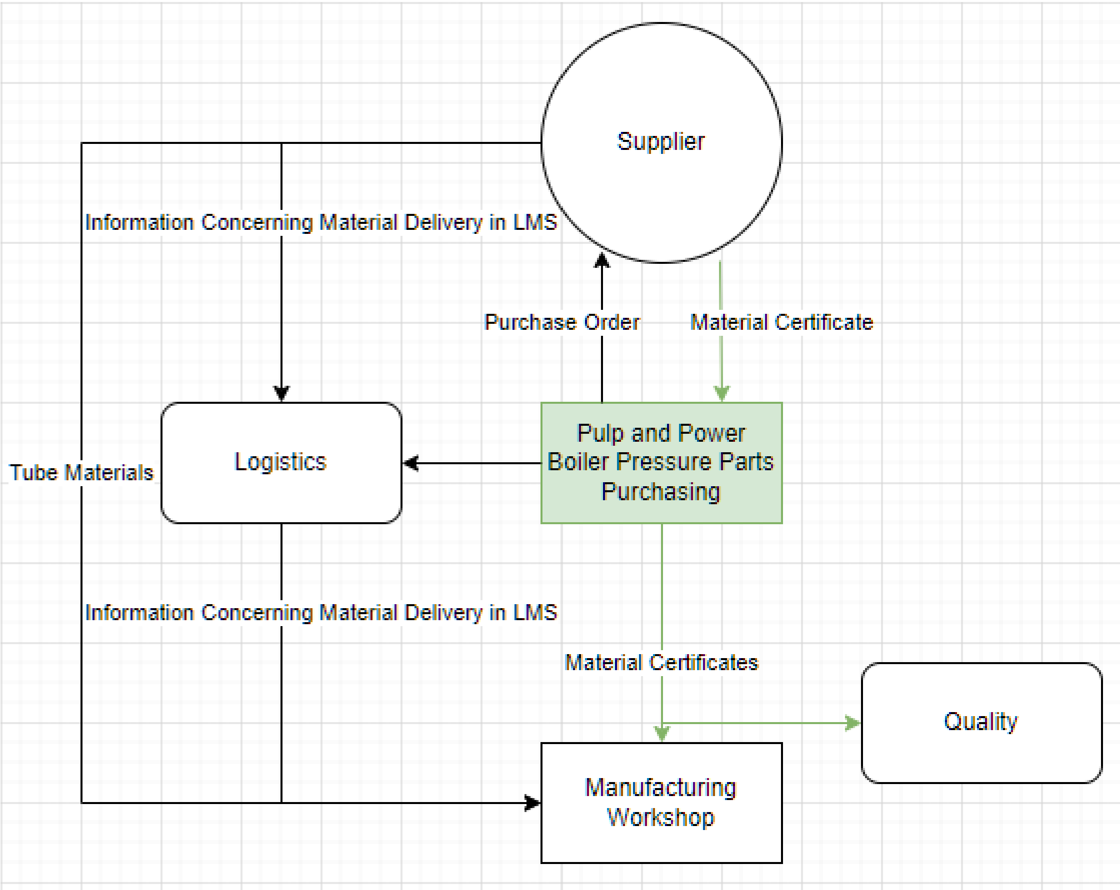

Figure 16 Material Certificate Flow Chart

Figure 16 above is a simplified flow chart visually displaying the information transfer of the tube material certificates between the different stakeholders. This is depicted by green lines. The information concerning the material delivery moves via Andritz Oy's logistics department. They utilize a system called LMS in aiding their communication with suppliers and manufacturing workshops. LMS is a communication tool used by Andritz Oy's logistics, expediting, and quality departments. Its significance regarding tube material certificate information transfer becomes apparent in exploring development ideas.

The situation becomes more intricate when tube materials from the same order is delivered to multiple manufacturing workshops. This is because each tube material certificate needs to be connected to the correct bundle of tube materials. Then, the corresponding tube material certificates need to be sent to the corresponding manufacturing workshop where the tube material is delivered. The amount of manual labor is compounded by the fact that a large tube material order can have a significant number of material certificates.

The material certificates are critical documents for Andritz Oy for the documentation and compliance of the tube materials. Andritz Oy needs to be able to trace the tube materials from production of the tube, through suppliers and manufacturing workshops, to the final customer. The tube material certificates are an integral part of the documentation for the quality department.

3.2.2 Andritz Warkaus Works Material Certificate Information Transfer

As with the tube material inventory, there is a different procedure concerning the material certificate transfer between Andritz Oy and Andritz Warkaus Works compared to the other manufacturing workshops. When tube materials are delivered to Andritz Warkaus Works, the information concerning the delivery and the material certificate information is inputted to an Arrivals Excel document by Andritz Oy. This system facilitates Andritz Warkaus Works' warehouse to have information concerning a tube material delivery without exchange of emails between Andritz Oy and Andritz Warkaus Works.

Regarding the material certificates, there is a mutual Microsoft Teams channel between Andritz Oy and Andritz Warkaus Works where the tube material certificates are stored. From this Microsoft Teams channel, both Andritz Warkaus Works and Andritz Oy can find the tube material certificates and use them for their respective needs.

3.2.3 Tube Material Certificates Documentation

Andritz Oy Pulp and Power Purchasing compiles all material certificates concerning tube materials in one folder. This is folder is enclosed within the mutual Microsoft Teams Channel with Andritz Warkaus Works.

In addition, Andritz Oy maintains an Excel document summarizing the relevant information regarding the material certificates saved.

There is no standardized way of saving the material certificates in the folder, which has led to different ways of naming the material certificate files. This is exacerbated by the fact that the material certificates concerning Andritz Oy's service projects are saved in the same folder.

3.3 Tube Material Unit Price Tracking System

Maintaining accurate records of tube material unit prices is extremely important for Andritz Oy. It enables the estimation of tube material costs and the tracking of price trends. In addition, it facilitates the sharing of price information with the sales department, as tube material prices can have a significant effect om the overall cost of a boiler project.

Furthermore, tracking prices of composite tube materials is important, as they are ordered to stock. This approach allows Andritz Oy to estimate optimal timing for placing orders.

3.3.1 Tube Material Unit Price Tracking System Current

Prices about tube materials are gathered from purchase orders and RFQs (Request for Quotations). The bulk of price material information comes from quotations. Andritz Oy does not have a standardized RFQ template. The most common way quotations are provided by suppliers is by email or in an Excel file.

The information regarding tube material unit prices is maintained in an Excel file. The information gathered from quotations and purchase orders are inputted manually.

4 ANALYSIS

This chapter covers the analysis of the current processes and frameworks concerned with the supply chain topics covered in this thesis. Understanding the current processes is crucial in identifying areas of improvement. This analysis forms the foundation for proposing recommendations and development ideas.

4.1 Tube Material Inventory Management System

On the surface, the tube inventory management system seems simple. A coordinated system to track tube material consumption and inventory, however, beneath the surface lies a deep and complex web of processes which results in the current situation. There are many steps that can be identified as points for potential mistakes which leads to more manual work to fix.

This thesis is an investigation from Andritz Oy’s point of view, but it is important to understand the effects that Andritz Warkaus Works’ processes have on the inventory management system. Andritz Warkaus Works plays a critical role in the handling of the physical tube materials and compiling of inventory information. It is important to understand that Andritz Warkaus Works is manufacturing orientated, and their systems are geared to aid their manufacturing processes. The LEAN system used by Andritz Warkaus Works is their manufacturing system and they express information in different ways than Andritz Oy in their purchasing process.

This analysis of the current tube inventory management system aims to analyze the current processes, identifying areas of development.

4.1.1 Andritz Warkaus Works Inventory Management System

The current inventory management system stems from the coordination between Andritz Warkaus Works’ warehouse and Andritz Oy. The two processes have been developed independently from each other and the compatibility of the two systems is fundamental to the process.

The Andritz Warkaus Works system has a significant influence on the processes of the Andritz Oy inventory management system. The communication procedures are directly derived from how to convey information between Andritz Warkaus Works and Andritz Oy.

The current system at Andritz Warkaus Works requires considerable manual work. As detailed in Figure 13, there are many spots from where information flow is compiled, at the different phases within the inventory management system. Furthermore, the processing of arriving tube materials is a manually intensive task, as material certificates need to be verified by both the quality department and the warehouse. This often results in tube materials being inputted into the inventory management system before these steps have been completed, whereby the confirmation of material certificates happens after the tubes are already in the system.

The development areas in Andritz Warkaus Works' inventory management processes are outside the scope of this thesis. However, if a review of their processes is made, Andritz Oy must be a part of the development discussion. Joint development discussions would lead to better cooperation and deliverables that would benefit both parties.

4.1.2 Andritz Oy Inventory Management System

Andritz Oy's current inventory management system is manually resource intensive as all the functions of the system need to be controlled by someone. The main functions such as tube material reservations need to be manually updated and maintained. Furthermore, the system is only familiar to few people within the Andritz Oy organization, and the system requires a learning curve to get accustomed to the intricacies. This makes the system extremely fragile to personnel changes. It is extremely important to make the system less dependent on manual work and more accessible to users that are new to the system.

In addition, there are format problems in the inventory list with a lack of a standardized form of documenting tube material information. This increases difficulty when filtering and finding information about tube materials.

Development options must be explored, especially concerning how the information from Andritz Warkaus Works' LEAN export can be processed better.

4.1.3 Effect of Differences

At the crux of the situation is the differing priorities of Andritz Warkaus Works and Andritz Oy. These differing priorities lead to different philosophies on handling the inventory management. Examples of these differences are explored in the description of the current processes and these differences affect the whole system.

Andritz Oy prioritizes enabling tube material reservations for projects, particularly those involving composite tube materials. This is the reasoning behind having a distinct inventory management system from Andritz Warkaus Works, as their LEAN manufacturing system does not accommodate reservations. The importance of the system cannot be overstated; it prevents over-reservation of tube materials and facilitates estimations for ordering composite tube materials to stock.

Andritz Warkaus Works' priorities are in manufacturing, and this is reflected in the priorities of auxiliary functions such as inventory management. Their inventory system is solely a module of their manufacturing system, not a system specifically designed for inventory management. For example, the simple fact that Andritz Warkaus Works stores the tube materials in bundles causes communicational differences between Andritz Oy and Andritz Warkaus Works. In the LEAN inventory export, several rows of tube material information can reflect a single row in Andritz Oy's inventory list because of this difference. From Andritz Oy's point of view, the way the tube materials are stored is of no concern, rather, the most important information is the tube material specifications (dimensions, material, etc.) and the total amount of tube material in meters.

Andritz Oy's inventory list does not have the capability to store the tube material information in bundles, as there would be too many rows in the Excel file. The inventory system would become extremely confusing with rows for bundles of tubes along with rows for tube material reservations.

An example of this confusing information flow is the siirto function of the LEAN inventory system. This function has caused problems in communication between Andritz Warkaus Works and Andritz Oy. The function is solely used by Andritz Warkaus Works' manufacturing and warehouse for their communication. Fundamentally, Andritz Oy does not care whether the tube materials are in storage or in a manufacturing virtual buffer storage. Rather, Andritz Oy is concerned with whether the tube materials are physically in storage or not. Therefore, the siirto function is negligible for Andritz Oy, and the inclusion of this information has caused unnecessary confusion for Andritz Oy.

Furthermore, currently the siirto function causes extra manual work from Andritz Warkaus Works' side. This is because the siirto function doesn't physically move the tube materials into production, rather the materials are placed in a virtual storage. Naturally, this has no implication in the physical stock of material, however, within the LEAN inventory system, an event is documented. Therefore, the responsible person for the LEAN inventory system must account for these siirto events in the LEAN Excel export that is sent to Andritz Oy.

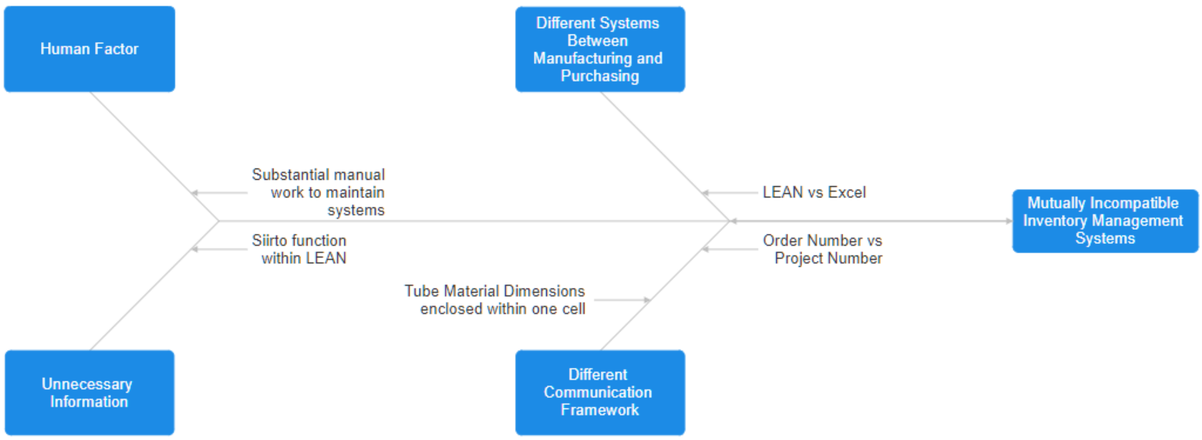

Figure 17 Fishbone Diagram for Tube Material Inventory Systems

The fishbone diagram illustrated in Figure 17 above visually displays the main causes that have led to the current incompatibility between the two inventory management systems. These causes form the basis for identifying the areas of development.

The examples covered in this analysis, along with the other differences between the inventory lists causes an environment where information can be easily misinterpreted, and miscommunication is commonplace. Increased cooperation to find solutions to communication problems requires substantial commitment from both parties.

4.1.4 Shared Inventory List

Sharing an inventory list seems like a good solution to the communication problems. The inventory list would be in one place, reducing risks of miscommunication and misinterpretation. A centralized inventory list would also streamline the responsibility of maintaining the list, which would differ from the current situation where there are multiple people responsible for different parts of the whole inventory management system. However, it is likely that implementation of a shared inventory list would cause more problems than solutions.

Integrating a shared inventory list would require extensive collaboration between Andritz Oy and Andritz Warkaus Works. The differing priorities of the organizations makes a shared inventory list unfeasible. For example, Andritz Oy's requirement to be able to make tube material reservations is not possible in Andritz Warkaus Works' LEAN inventory system. In addition, there would be a lot of information included within the system that does not benefit both parties. Furthermore, Andritz Warkaus Works has inventories of other tubes that are not related to Andritz Oy's operations. A better approach would be to tackle the communicational problems between the systems, rather than integrating them together.

4.1.5 Andritz TEP Inventory

The integration of Andritz TEP into a fully Andritz owned and operated manufacturing workshop brings up questions concerning boiler tube materials. Things such as how to monitor the consumption of tubes in manufacturing, especially concerning the composite tubes.

Currently, the composite tube materials are exclusively ordered to Andritz Warkaus Works' warehouse, where they are kept in stock. When Andritz TEP requires composite tube materials for a project, the tubes are shipped from Andritz Warkaus Works. There are ongoing discussions concerning opening a tube warehouse at Andritz TEP.

There are positives and negatives concerning the possibility of opening a composite tube material inventory at Andritz TEP.

The simplest short-term solution is to keep a centralized inventory at Andritz Warkaus Works, and this is the current process. Further benefits of a centralized inventory at Andritz Warkaus Works are the implementation of a centralized distribution center for composite tube materials, especially if more manufacturing workshops are acquired by Andritz, or more workshops are implemented into composite tube manufacturing. In addition, the relatively high prices of composite tube materials need to be noted. Centralized inventories are usually more beneficial for highly priced materials. Ideas such as maintaining an inventory of carbon steel and highly alloyed tubes at Andritz TEP, while establishing a centralized inventory of composite tubes at Andritz Warkaus Works, may present promising strategies for future consideration.

On the other hand, currently in Europe, Andritz only owns and operates two manufacturing workshops. With this situation, it could be beneficial in the long-term to open an inventory warehouse at

Andritz TEP. Implementation of an inventory at Andritz TEP could bring cost savings, especially with transportation costs of the tube materials. Shipment of materials directly to Croatia is cheaper than shipping of the materials via Varkaus. Furthermore, implementation of an inventory system at Andritz TEP can be seen as a new project and a possibility to implement new strategies developed to ease inventory management problems that are currently present in Andritz Warkaus Works' inventory. However, it is important to understand that implementation of an inventory management system at Andritz TEP would require extensive cooperation between Andritz TEP and Andritz Oy.

4.1.6 Tube Inventory Management Analysis Conclusion

The current inventory management system is an amalgamation of processes over time. Whenever challenges emerge, they are addressed with specific fixes, and when new issues arise, new solutions are made. This continual adaptation leads to a chain of processes that become ingrained into the system, and a situation where things are done "because they have always been done that way". It is extremely important to maintain a significance and purpose behind actions; otherwise, processes can become confusing and lose effectiveness, potentially becoming redundant.

The situation at Andritz TEP is a potential topic for future consideration, especially as discussions about inventory management are ongoing.

4.2 Material Certificates

The current situation requires manual work in handling the multitude of material certificates related to a delivery of tube materials. The most time-consuming task is connecting the correct material certificate to the correct delivery of materials. This is compounded in situations where tube materials from the same order are sent to multiple different manufacturing workshops.

Formation of a system whereby material certificates are transferred directly between tube material suppliers and manufacturing workshops would be ideal. This would eliminate Andritz Oy as the middleman in the material certificate transfer process, minimizing points of data loss and streamlining the supply chain process associated with tube material certificates. However, it is important that Andritz Oy also receives the materials as they are necessary in compiling documentation for the quality department and final customer.

The current process used between Andritz Oy and Andritz Warkaus Works is better than the process used between Andritz Oy and the other manufacturing workshops, as all the material certificates can be found in the same place.

The best solution from Andritz Oy's point of view is a process whereby tube material certificates would be sent directly to the manufacturing workshops along with the corresponding tube materials.

In addition, the unstandardized way of saving the material certificate files causes unnecessary confusion when trying to locate files. Especially, if more shared folders are implemented, a standardized form of naming the material certificates needs to be agreed.

It is important to understand the wider implications of material certificates as they are extremely important with many different parties requiring the material certificates for different reasons. Whilst this thesis focusses on working to improve the process between suppliers and manufacturing workshops, the requirements of other stakeholders must be acknowledged.

4.3 Tube Material Unit Price Tracking System

The current unit price tracking system in Excel is extremely unorganized, with prices inputted manually from supplier quotations and purchase orders. The unstandardized way they are inputted causes problems when filtering for specific tube material prices. Furthermore, as the quotations from suppliers are unstandardized, manual work is required to gather the tube material price information from the quotations.

Standardization strategies such as a standardized template for RFQs to suppliers are potential ideas to consider in development. This would facilitate implementation of automation strategies into the current tube material unit price tracking system. However, it must be considered that this would require the suppliers' cooperation in providing quotations within Andritz's template. Difficulties can arise because of this as suppliers are accustomed to giving quotations according to their own frameworks.

5 DEVELOPMENT

The development ideas formed are one of the key deliverables from this thesis. This chapter examines the development ideas regarding the topics covered. Things such as advantages and disadvantages, and overall feasibility of the development ideas are explored. Development ideas draw from analysis of the problems with the current processes along with perspectives formed from the theoretical background.

5.1 Tube Material Inventory Management System

Analysis of the current inventory management system has identified major areas of development. The amount of manual work is substantial, and these development ideas arise from the goal to reduce manual work.

The development of the tube inventory management system can be conceptualized in two distinct ways: development of existing processes and establishment of new processes.

Developing on existing processes includes improving communication frameworks and reducing the amount of excess information transferred between Andritz Warkaus Works and Andritz Oy. This requires significant cooperation between the two organizations. Furthermore, development ideas for Andritz Oy's inventory management system will be explored.

Establishment of new processes will investigate different ways of obtaining information about the tube materials. Creation of new processes must have the main goals of the inventory management system as a priority, these being making reservations for projects, and tracking and filtering the quantity of tube materials in the warehouse.

5.1.1 Development of Existing Processes

The main priority of development of existing processes is improving the communication framework between Andritz Warkaus Works. This is essential for further development ideas concerning the tube inventory management system. The main problems are the different codes used by Andritz Warkaus Works' manufacturing and Andritz Oy.

The most important changes to the communication framework are as follows:

1) Separation of dimensions of tube materials into individual cells in the LEAN transaction report
2) Use of the same project number between Andritz Oy and Andritz Warkaus Works
3) Combination of multiple rows with the same SAP order number and position into one single row
4) Implementation of identical format between Andritz Warkaus Works LEAN transaction report and Andritz Oy inventory management list.
5) Exclusion of unnecessary information in communication between Andritz Warkaus Works and Andritz Oy

These development recommendations are dependent on the desire for cooperation between Andritz Warkaus Works and Andritz Oy. The changes to the communication framework would allow for implementation of layers of automation to Andritz Oy's inventory management system.

The first three recommendations are critical as they are the elements that cause the most manual work. These are non-negotiables from Andritz Oy's point of view and without these changes, automation methods cannot be applied. The fourth recommendation would significantly aid the communication between both systems, easing the implementation of automation processes. Furthermore, omission of unnecessary information would decrease the overall confusion during communication.

5.1.2 Improving Andritz Oy Inventory Management System

Andritz Oy's inventory management list is an area identified for development, especially in reduction of manual work. The reduction of manual work is reliant on cooperation with Andritz Warkaus Works; however, steps can be made to develop on Andritz Oy's current system and prepare for possible implementation of automation processes.

Recommendations for development of Andritz Oy's inventory list are as follows:

1) Formulation of a standardized template for inserting tube material information into the inventory management system
2) Material certification link to each row in the list
3) Analysis of how automation can be implemented if format changes are made.

Currently there is no standardized method for inserting tube material information into the inventory management system. This has developed into a situation where tube materials are inserted into the system in disorganized manner.

A standardized template for inserting tube materials into the inventory management list must be formulated. The idea for this is to make a separate Excel sheet in the list with standardized examples for how to insert the tube material information.

Material certification transfer from tube material supplier to manufacturing workshop was another topic investigated in this thesis. The second development recommendation links this topic with the tube material inventory topic, whereby the material certificates for the specific tube materials would be embedded as a link into specific row.

A preliminary investigation into automation techniques has been performed during this thesis. The main topic concerning automation techniques has been how to interpret and transfer the data automatically from the LEAN transaction report to Andritz Oy's inventory management list. It is important to understand that for automation techniques to be implemented, the recommendations stated in chapter 5.1.1 are prerequisites. Particularly, the implementation of the first four recommendations listed.

If these changes are executed, implementation of automation techniques, within the current system, such as using VBA (Visual Basic for Applications) to automatically copy data from the LEAN transaction report to Andritz Oy's inventory management list are possible. VBA is a programming language native to Microsoft Office applications, and it can be used to scrape data from one file to another. *(Kenton, 2024).*

Furthermore, during the investigation into the LEAN manufacturing system, it was discovered that there is a possibility to export the LEAN transaction report into a csv (comma-separated value) file. A csv file is a text file in a specific format that allows data to be saved in a table structured format. *(Johnson, 2022).* If the critical formatting changes discussed are made, it would be possible to import an exported LEAN transaction report csv file directly to Andritz Oy's inventory management list in Excel.

5.1.3 Automation Possibilities

The other approach to exploring development ideas was examining the possibility of creating completely new processes to monitor the inventory of tube materials. The development ideas explored are automation orientated, with the aim of reducing manual work concerning the management of tube material inventory.

The recommendations for new automated processes are as follows:

1) Scanning system for tube materials
2) Automated tube material warehouse

Implementation of a tube scanning system was one of the ideas formed from the analysis of the current situation. The idea for this system stems from the communication problems between Andritz Warkaus Works' LEAN manufacturing system and Andritz Oy's inventory management system. A tube material scanning system would bypass the LEAN system from Andritz Oy's point of view.

The proposed system involves the assignment of a distinct code to each bundle, which would then be scanned. These codes would contain information regarding the tube materials. Additionally, each tube in the bundle would need to be scanned. Subsequently, information from the scanned bundles would automatically be transmitted to Andritz Oy's inventory management system. This would instantly give Andritz Oy the information regarding the arriving tube materials, rather than the delay from the Andritz Warkaus Works' processing of the tube materials and the biweekly LEAN transaction report. The tube materials would then be scanned again when they are taken from storage into manufacturing.

This automated scanning system would ease the manual workload from Andritz Oy's point of view, however, it would increase the manual workload on Andritz Warkaus Works' side, as the individual tubes from each bundle would need to be scanned both when they come into the warehouse, and when they leave into manufacturing.

The other automation method recommended is a fully automated warehouse. Concerning boiler tube materials, Andritz's biggest tube material suppliers implement fully automated warehouses. The advantages of such a system are clear, and it would significantly reduce manual work needed in maintaining tube material inventories. However, it is important to understand the factors limiting the possibility of implementing such a system. Firstly, it requires significant monetary investment and approval from the upper management of both Andritz Oy and Andritz Warkaus Works. Secondly, implementation of an automated tube material warehouse at Andritz Warkaus Works would be difficult because of the relatively small scope of the Andritz Warkaus Works tube material warehouse. The cost benefit will not be as large when compared to larger warehouses. It is critical to consider that boiler tube materials only constitute a fraction of Andritz Oy's business, whereas for tube material suppliers implementing these automated systems, tube materials constitute a large fraction of their business.

5.2 Material Certificate Exchange Between Tube Material Suppliers and Manufacturing Workshops

The goal of the development ideas concerning material certificate information transfer from suppliers to manufacturing workshops derives from minimizing the role Andritz Oy plays as a "middleman". Unlike tube materials that are supplied directly to the manufacturing workshops, material certificates are supplied to the manufacturing workshops from the suppliers via Andritz Oy.

The development ideas regarding easing the material certificate transfer between tube material suppliers and manufacturing workshops are in the primal stages. These development ideas should be investigated further as there is potential for implementation of improved processes.

The recommendations for development of material certificate information transfer are as follows:

1) Investigation and analysis of whether LMS system can be used to transfer material certificates.
2) Investigation into implementation of a shared material certificate folder between Andritz Oy and manufacturing workshops
3) Standardization of material certificate document names

As stated in the current processes, Andritz Oy's logistics department used a system called LMS to communicate and coordinate information concerning the logistics of materials between different phases of the supply chain. The LMS system's main functions are outside the scope of transferring material certificate information between suppliers and manufacturing workshops, however, the functions built into the system enable files to be attached to orders.

Within the system, suppliers and manufacturing workshops are given limited access. Both suppliers and manufacturing workshops can upload documents and files into the LMS system, however, a direct link between the tube material suppliers and manufacturing workshops is not possible. The suppliers and manufacturers are only able to access their own orders. There is a caveat concerning Andritz workshops, such as Andritz Warkaus Works and Andritz TEP, whereby they could directly access information from the tube material suppliers.

The process would work with the tube material certificate files saved in a designated folder. A link to the folder is then attached to the material delivery in the LMS system, whereby the manufacturing workshop can access the material certificates.

Suppliers and manufacturing workshops can be given access to the LMS system for their own orders. However, for direct link from suppliers to manufacturers is not possible. Someone at Andritz Oy needs to be able to link the mat certs from supplier to the correct order to manufacturing workshop.

In the best-case scenario, all tube material certificates concerning a specific order would be received from the tube material suppliers in a standardized form, whereby these material certificates could be saved into one folder, which could be linked to the relevant manufacturing workshop in the LMS system.

(Internal Meeting, 2024, Natunen N, Heiskanen T)

The second development recommendation approaches the topic from implementation of a shared folder between Andritz Oy and the manufacturing workshops. This is the current process between Andritz Oy and Andritz Warkaus Works.

Implementation of a system like this would reduce the information transferred by email, and a standardized form of transferring information about tube material certificates between Andritz Oy and the relevant manufacturing workshop would reduce confusions in communication.

This framework would require a separate shared folder with all the different manufacturing workshops. This results in the relevant manufacturing workshops having access to the corresponding tube materials.

The third recommendation of standardizing the naming of material certificate document names can be implemented instantly. Especially concerning the different ways tube material certificate files are saved between Andritz Oy Capital and Andritz Oy Service.

5.3 Tube Material Unit Price Tracking System

The recommendations for development of the tube material unit price tracking system are as follows:

1) Implementation of a standardized template for inputting price information into the unit price tracking system
2) Implementation of a standardized tube material RFQ

The first development recommendation can be implemented instantly. A standardized template providing clear instructions for how to input tube material price information should be made directly into the existing Excel file.

The second development recommendation would allow for more automation, reducing manual work. For example, if suppliers give their quotations into a standardized Excel template, the same types of automation approaches discussed in Chapter 5.1.2 can be implemented. However, it is important to understand that this would require cooperation from the tube material suppliers, as they are accustomed to their own processes of providing quotations. This development recommendation can be seen as a topic for discussion between Andritz Oy and tube material suppliers.

6 CONCLUSION

Supply chain networks are inherently complex webs including many different stakeholders. This is also true for Andritz's boiler tube material supply chain. It is important to note that this research is a comprehensive review of a small part of the whole supply chain network. Precise development and improvement of processes within small parts of supply chain networks aids the development of the whole supply chain network.

This thesis has brought to light problems relating to the current processes. Things such as over reliance on manual work can be detrimental, especially in cases where only a few people are responsible and knowledgeable about a certain function, such as the inventory management system.

This thesis has covered the processes concerning tube material inventory management, tube material certificate transfer between tube material suppliers and manufacturing workshops, and tube material unit price tracking. Tube material inventory management was the main topic of investigation in this thesis as it is seen as the most critical process needing improvement.

Specifically, this chapter covers the definitive next steps concerning the topics covered. From this thesis, it is important to identify concrete steps to take in terms of developing the current processes. These concrete decisions have been made with thorough analysis of current processes and through internal discussions.

6.1 Tube Material Inventory

The concrete recommendation for development of the inventory management system is changes in the LEAN system and Andritz Oy system to become mutually intelligible. Specifically, recommendations 1 to 4 from Chapter 5.1.1 must be implemented so that automation processes can be fulfilled. If these recommendations are fulfilled, implementation of automation processes discussed in Chapter 5.1.2 is possible.

Along with these changes aiding the communication between the systems, recommendations 1 to 3 from Chapter 5.1.2 concerning the improvements on Andritz Oy's inventory management system should be implemented. Implementation of these development ideas is less complicated and can be done immediately, as these are internal improvements. These improvements will make the current inventory list easier to understand. In addition, brainstorming of more automation ideas can take place during and after the process of this thesis and it is an important step to take considering a situation where such automation processes can be implemented.

Naturally, the best solution for development of the inventory management system is implementation of an automated tube material warehouse, however, the difficulties of implementing such systems are discussed in Chapter 5.1.3. The ideas explored in the chapter can be thought of as ideas for future consideration.

6.2 Material Certificate Exchange Between Tube Material Suppliers and Manufacturing Workshops

The concrete recommendation for development of the material certificate information transfer between tube material suppliers and manufacturing workshops is implementation of a standardized manner of saving the tube material certificate files. This internal development process can be implemented immediately, and it simplifies possible implementation of the other recommendations discussed in Chapter 5.2.

The other two development ideas explored in Chapter 5.2 can be seen more as preliminary ideas that would require further investigation into the feasibility of implementing such processes. Currently, the best solution would be implementation of a shared folder between Andritz Oy and the manufacturing workshop, where tube material certificates would be stored.

6.3 Tube Material Unit Price Tracking System

The concrete recommendation for development of the tube material unit price tracking system is implementation of a standardized template within the current system, with detailed instructions on how to input price information.

The other recommendation idea of creating an Andritz Oy standardized RFQ is a possible idea for future implementation. This would require cooperation and communication between Andritz Oy and the tube material suppliers.

7 EVALUATION

This thesis has been an evolving process from inception to completion. It has been a continual learning process from understanding of current processes, analyzing these processes to then forming concrete development recommendations for Andritz Oy. Proactive and continual discussions with Andritz Oy during the writing of this thesis have guided the thesis towards a direction beneficial to both Andritz Oy and the author. In addition, strong background information and understanding of the complexities and intricacies of Andritz Oy’s supply chain processes concerning boiler tube materials have facilitated a successful study.

The aims set at the beginning of this thesis have been met. The literature review along with comprehensive descriptions of the current processes provide a clear understanding of the topic and serve as the theoretical background. Deep analysis of the current processes identified the problem points concerning the topics, and precise development recommendations were formed from the analysis.

This thesis has investigated the inventory management as a main topic and the other topics as side topics. Inventory management was seen as the most critical thing needing improvement on processes to reduce manual work. This was a deliberate and considered mutual decision between the client organization and the author. Identification of this topic as the main problem topic enabled a deeper examination into the current processes and the problems faced. This led to a deeper analysis into the current processes, resulting in more precise development ideas that can be implemented.

It is important to understand that the nature of taking one topic as the main topic has affected the study into the other topics, especially concerning exploring further development ideas. Studying each topic as its own thesis may have facilitated deeper investigation into each topic. However, in the case of this thesis, it is important to note the urgency and topical nature of the tube material inventory topic, especially with the possibility of opening a new tube material inventory at Andritz TEP.

8 FURTHER STUDY

This thesis has brought a multitude of potential ideas for further study. The research done in this thesis has brought to light the main pain points regarding the topics covered. Each topic could have been covered as their own thesis. This thesis provides thorough background information and can be utilized as a resource for further study into these topics. For example, the implementation of automation techniques explored in this thesis regarding the tube material inventory is an exciting potential area of future study. Furthermore, investigation into the possibility of incorporating other systems within Andritz Oy, such as the LMS system, to aid in material certificate information transfer is a possible avenue for future study.

During the process of writing this thesis, novel points of view have been uncovered. Familiarization with the processes have allowed for comprehensive and concrete formation of ideas. Further knowledge about the topic over an extended period enables intricate detailed ideas for development, which is a positive regarding future study.

One specific intriguing topic of further study briefly discussed in this thesis is the possible implementation of a tube material inventory at Andritz TEP. Ideas formed in this thesis can provide a background study and provide information and recommendations regarding the opening of a tube material inventory.

Furthermore, understanding the role that the topics covered in this thesis play in the larger supply chain network concerning boiler tube materials opens more ideas into potential future study. For example, deeply analyzing how developments within these supply chain topics affect other parts of the supply chain, or analyzing other parts of the supply chain from different perspectives are all possible ideas. However, it is important to understand the scope of a bachelor’s thesis. Deeper and broader exploration of supply chain topics covered in this thesis can be viewed as potential topics for a master’s thesis.

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