Material Flow of Castings Analysis: Cost and Logistics Dimensions

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Description

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Abstract

The need for the research came from commissioning company's transmission plant. A renovation was planned and demand for transmissions was expected to grow, so adjustments to the material flow (if any) should have been decided. Since the base parts of transmissions were castings, their material flow was in the core of logistics in the plant. Thus, the research was devoted to the casting's material flow.
The research was focused on the castings warehousing solution and costs associated with them, and the layout analysis and improvements based on the material flow of castings. Warehousing solution consisted of three options: outsourced storage, building own warehouse, and mixed option. Each one of them implied different type of costs. As for the second part of the Research, current layout and future layout were analyzed using a simulation software and compared to each other. Improvements were suggested and both layouts were analyzed with the simulation of improvements implementation.
The result of the research was Costs calculation tool made in Excel and extensive analysis of the layout and improvement suggestions. The tool allowed to compare the costs of the three warehousing options and to check the costs of the options with adjusted input data. The analysis of the layout and suggested improvement were provided to the commissioning company to be considered during renovation.
Due to time and resource limitations, the research covered general outlook of the situation. There-fore, parts of the research could be studied in more details. The results of the research were a good base for commissioning company to make the decision and choose the direction of further research.

Keywords/tags (subjects)

Logistics, material flow, warehousing, intralogistics, castings, simulation, layout, costs calculation

Miscellaneous (Confidential information)

Appendices and data about commissioning company and its operations is confidential information and removed from public thesis. The basis for secrecy is Confidentiality agreement between the Authors and the commissioning company.

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1 Table of Key Terms

Term	Definition/description
3PL	Stands for "Third party logistics" which means an outsourced business that takes care of the buying companies logistics operations
ad hoc	Another phrase for very urgent shipment in the logistics world
AGV	Automated Guided Vehicle, in this case, guided by induction wire
Automation	Process following a predetermined set of steps using little or no human force
Blue collar	Classification of people who are considered working class/workforce.
Bottleneck (production)	the longest operation done in the production
Castings	Molten metal poured into a mold to form an object once cooled
Collar	Wooden packaging made up of 4 sides that fit on top of a pallet to form a barrier, helping to keep items in place
Days-on-hand (DOH)	Quantity of parts that cover demand for given number of days
Economic order quantity (EOQ)	The most cost-efficient quantity of material per order
Entreprise resource planning (ERP	Logistics management system that includes integrated database for company operations
FMS	Flexible manufacturing system
Forklift	Truck that is used for lifting, moving and lowering items
Frozen zone (schedule)	Timeframe when plan cannot be changed (e.g. in production plan, in order plan, etc.), typically expressed in weeks
GSM	Stands for "Global system for Mobile communication". This is essentially internet for mobile phones
JIT	Acronym for Just In Time, a production model
Layout	Structure of something, the way of arrangement
LCA	Low cost automation, technology that creates automation using existing processes
Lean principles	Concept aimed at improving efficiency
Material flow	The way that material follows within certain period of it's lifecycle (e.g. in production)
Material handling	Moving material between points (e.g. warehouse, production points, etc.)
Minimal order quantity (MOQ)	Minimal quantity of material that can be ordered (minimal quantity of material per order)
Mixed research method	Research method that partially combines quantitative and qualitative ones
Multi-modal	Term used to describe different modes or methods to accomplish something
Pallet racks	Type of shelves that are designed for storing pallets
Plagiarism	Usage of another person's work pretending it is your own
PMTS tool	Acronym for Predetermined Motion Time System, used to determine the amount of time it takes to complete a work operation down to the human movement
Primary data	Data that originally comes fom the research case
Production strategy	Method used for production that require certain arrangements
Qualitative research method	Research method in which textual data is used
Quantitative research method	Research method in which numerical data is used
Research	Process of gathering information about particular topic and data analysis with the purpose of gaining a better and/or new understanding of an existing phenomenon or new discovery
Research method	A way of conducting the research (incl. type of data used, way of data gathering and analysis)
ROCE	Acronym for Return on Capital Employed, a financial term to determine a company's profitablity and capital
ROI	Return on Investment (explain more)
SAP	ERP software
Secondary data	Data that originates from previously conducted research case
Subassembly	A unit designed to be incorporated to a larger product but is assembled separately beforehand
Transmission	part of vehicle that changes the speed and direction using gears
Warehouse utlization rate	Part of warehousing space that is planned for usage to avoid overfilling
Warehousing	Process of keeping material in a storage
White collar	Classification of people who are working in an office/professional environment
Wi-Fi	Stand for " Wireless Fidelity". Is a system used to connect electronic devices or computers to the internet without the need of wires
Work-in-progress (WIP)	In terms of material: material that is still inside ongoing production process

2 Introduction

What is material flow and why is it important? And what about castings? How do these two things relate to each other? To answer these questions, we need to understand what they are in a nut-shell.

Material flow is an important part for a production company. A production company manufactures its products using materials; hence it is important that the material is moved from workstation to workstation in an efficient way. The efficient flow of material means that the faster a product is produced, the quicker a production company can cover its costs. There are different ways to pre-sent material flow, depending on what the given task is asking. Figure 1 uses a flow diagram to show material flow. (visTABLE, 2023)

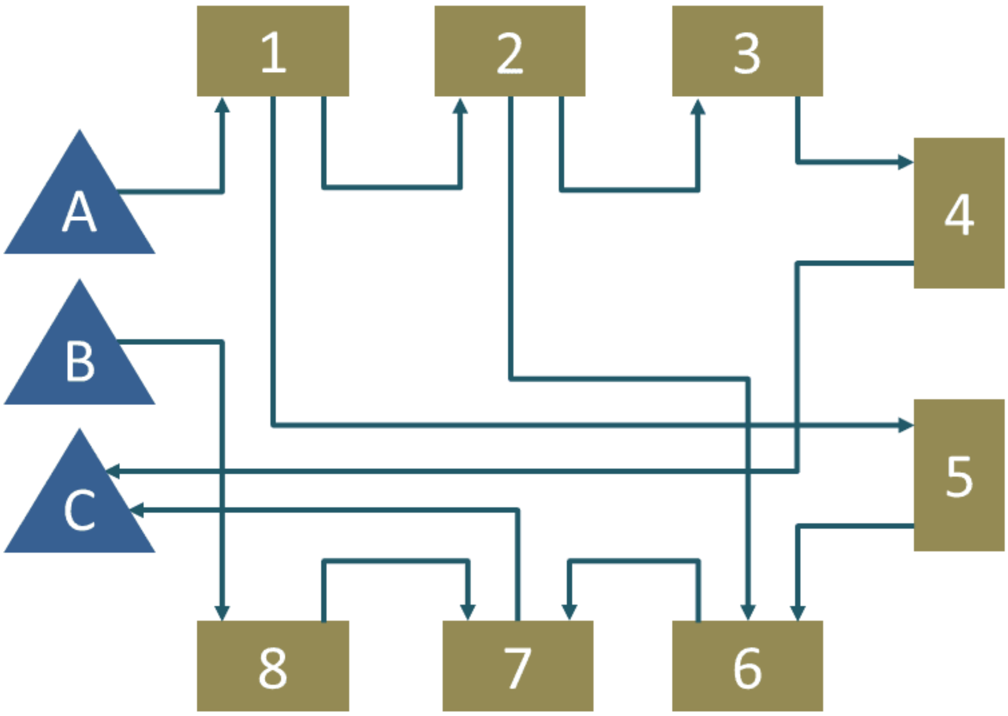

Figure 1. Material Flow (flow diagram) (visTABLE, 2023)

Castings on the other hand is material that is formed from a mold using molten material such as metal. Once the molten metal is poured in the mold of the desired product, it is then cooled so that it solidifies, this process can be seen in Figure 2. After the molten metal has solidified, it will then be removed from the mold and cleaned to remove any excess material to form the final casting product. (Kumar, 2023)

Figure 2. Molten metal being poured into mold (bernier cast metals inc., 2023)

There are several ways to approach the planning of material flow, internal and external material flow. This thesis covers both. And the way these two topics relate to each other is that they are both crucial in ensuring a smooth operation for the transmission plant of the commissioning company. The castings used in the transmission plant are not the final product, they need to under-go machining and washing to remove any debris or foreign items caused by the machining process, beginning its journey to being a complete tractor transmission ready to be assembled at the commissioning company assembly plant. (Material Flow Manager, 2023, adapted)

The base part of the transmission are castings. Therefore, their material flow should be prioritized since it is the only material utilized throughout the whole production process. The transmission plant is undergoing developments which is a good chance to re-evaluate the material flow and if there are ways to optimize it better. Allocating the investments in development wisely is also one of the targets of the study.

2.1 Commissioning Company

Hidden in public version.

2.2 Background

The need for the topic came from the Material Flow Manager at the commissioning company. The company is currently undergoing development and are applying for investments. This thesis would help support the final decision for some of the developments and the different scenarios based on the findings. There are a lot of examples that have been discussed during our first interview with the Material Flow Manager. That said, we aim to give a clearer understanding with the data gathered as to what a solution could look like, to the current problem.

To understand the problem the transmission plant will need to be broken down to the basics of how it operates. General layout of the transmission plant can be seen in Figure 3. First, the castings are sent to the transmission plant from the external warehouse. Once in the transmission plant, the castings either get stored on pallet racks close to the intake doors or go directly to machining.

After the castings have gone through the machining phase, they need to go through a washing machine to remove all the excess debris and liquid that have come from the machining process. Once the machined product has been washed, it goes for assembly. After the transmission has been assembled, the transmission is tested and brought to the next step.

From the interview, and after speaking in person to the Manager, the Authors found out that there are a few problems with the current situation. One of the problems is, volume of machined material will increase, and we cannot move the machines from where they are currently. Another problem is that there is very limited storage for castings at the moment. There are a few pallet racks in the castings intake area, some castings being stored in the casting storage and some even outside. The problem with storing castings outside, especially in Finland, is that the weather is so harsh in the winter months. This means that the castings develop small layer of rust when left outside for 1 day. When the castings develop rust, they need to be quality checked again and need to be re-worked. This all adds up to more time and effort spent even before the casting has been used. One other problem mentioned is that the cleanliness of machined items is an issue.

Overall, there are a few topics here that helped form our research questions. There is also a good base knowledge of how the transmission plant works, as well as the general flow of material.

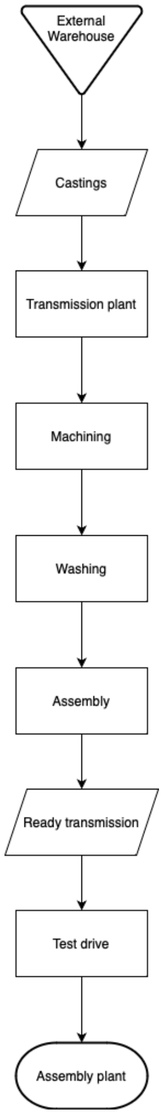

Figure 3. Transmission plant process flow (Interview with commissioning company, 2023, adapted)

2.3 Target

Targets of this thesis as discussed together with Senior Manager Manufacturing Engineering and Production System and Manager Material Flow Planning are that the authors create a simplified model proposal which optimizes the material flow of castings.

Authors are also tasked with finding the storage costs, material handling costs of the current transmission plant vs. the investment required. (Material Flow Manager, 2023)

3 Overview of research methods

Research is the process of gathering information about particular topic and data analysis. Both with the purpose of gaining a better and/or new understanding of an existing phenomenon or new discovery. (Cambridge University Press, 2023) Research consists of multiple steps (adjustments relevant to this study are stated in brackets):

1. Stating the research problem (research topic)
2. Creating the concept of the research (choosing research methods)
3. Choosing/creating data collection instrument (tools used in the research)
4. Research sample selection (areas of focus, research questions and limitations)
5. Research proposal (topic proposal and thesis plan)
6. Data collection (literature review and collection of data in the commissioner company)
7. Data analysis
8. Reporting (Kumar, 2019)

Steps 1-5 are related to research planning. The report has the problem reflected in the topic and description (Step 1); research methods (Step 2) are covered in the section 3.210 of the report; tools (Step 3), and research questions and limitations (Step 4) are discussed in the sections 3.1. Research proposal (Step 5) has a supporting function in the research conduction and, therefore, is not covered in the final report. Steps 6-8 are the operational parts of the research. Data collection (Step 6) and data analysis (Step 7) are fully covered in the report (Step 8) in Chapters 4 and 5 and are the main focus of this project.

3.1 Research questions and limitations

Defining the research questions and limitations is one of the steps of the research process. It is necessary to clearly state (with prior clear understanding) what the research is about, and which questions must be answered in the end. The authors gathered background information about the problem and the target was set by the commissioner company. Based on that, the following research questions have been defined:

1. What would be the best casting storage solution?
    a. Investment in internal warehousing in transmission plant premises

    b. Outsourcing to 3rd party logistics company

    c. Mixed solution

2. How to reorganize the layout of the transmission plant to maximize the efficiency of castings material flow?

However, there are numerous cause-and-effect links in supply chain, and the project has time limits, so research limitations need to be defined as well. The authors have decided that the following aspects will not be covered in the research:

- Obtaining parts from the supplier (including purchasing process, packaging instructions, and transportation of the parts from the supplier to the factory / company's external warehouse)
- Production planning
- Production method choice (the equipment is chosen by the commissioner company)

3.2 Research methods

There is a countless number of research problems, and each requires its own individual approach. It depends not only on the sort of problem, but also on the desired outcome and final purpose of the research conclusion. Thus, different research methods exist and involve various research methods and approaches.

Commonly, there are three main research methods: quantitative, qualitative, and mixed. As the titles suggest, quantitative method operates with numbers, qualitative with words and descriptions, and mixed method combines them both.

The summary of the main points about quantitative and qualitative methods are presented in Table 1. (Carrie Williams, 2007, p.65-72) However, they and mixed method are covered in a more detailed way in the following sections of the report (3.2.1, 3.2.2, and 3.2.3 respectively).

	Quantitative	Qualitative
Study model	Hypothesis	Formulation
Features	Numbers, statistics	Words
	Objectivity	Subjectivity
	Generalization	Purposefully useful
	Deductive reasoning	Inductive reasoning
	Specifics	High involvement of the researcher

Table 1. Quantitative and Qualitative research summary (Carrie Williams, 2007, p. 65-72)

3.2.1 Quantitative research method

An analysis can be called quantitative when the collected data is numerical. The data collection process needs to be done in advance to allow enough time for planning the questions (data range to be collected) and ensuring that the range indeed could match the data needed. Software is very well applicable in this research method, as the data is easy to structure, and advisable to simplify the data analysis process (e.g. in case of hypothesis testing). A lot of tools exist for analysis of numerical data, the most common of which would be the statistical analysis and hypothesis testing. (Pickard, 2017, p. 283-310)

Since the data consists of numbers, it is easy to categorize, compare and sort the information. It doesn't involve feelings and opinions, and therefore, it is objective and could be generally applicable. At the same time, in the data collection process specific range is studied and possible conclusion options could be often pre-determined. One more feature of the quantitative research method is that the reasoning is deductive (from the general to the particular). (Carrie Williams, 2007, p. 65-72)

3.2.2 Qualitative research method

Unlike quantitative research, qualitative one is aimed at formulating the new theory using inductive reasoning (from particular to general). Data collected in terms of qualitative research is not numerical, but textual and in-depth. Besides, analysis of initially collected data could require a new data collection. Basically, the main point of qualitative research is to get the full understanding of the phenomenon and word a theory, explaining the studied phenomenon or it's certain features. Since it involves a non-numerical data, analysis comes down to finding connections and patterns in the data, formulating the theory and evaluating if and how the theory works in the context of the phenomenon. (Pickard, 2017, p. 267-281)

Of course, such method requires high involvement of the researcher: as a participant or observer of the phenomenon. Because of that and the initial data being interpretation of the researcher or interviewees, it is impossible to completely exclude possibility of bias interfering with the results making them subjective. However, it allows to take some humanity into consideration which could be rather useful depending on the researched phenomenon. (Carrie Williams, 2007, p. 65-72)

3.2.3 Mixed research method

Both quantitative and qualitative research methods have their own advantages and disadvantages and areas where they are better suited. In case the researcher would like to see statistics and general patterns of the phenomenon, quantitative methos should be chosen. In case, more in-depth understanding is needed, then the qualitative research would be a better option. However, sometimes, especially in the extensive research projects, there is a need for both. That's where mixed method steps in.

The main point of the mixed method is to emphasize strength and mitigate weaknesses of the above-mentioned research methods. It allows the researcher to collect both kinds of data (e.g. in the survey), perform statistical and in-depth analysis for the appropriate scopes of data, use both inductive and deductive reasoning – so conduct comprehensive research of the phenomenon. (Carrie Williams, 2007, p. 65-72)

3.2.4 Research method chosen for this project

To sum up, three main research methods are distinguished: quantitative, qualitative, and mixed. Quantitative method involves analysis of numerical data, making it more objective and general. Textual data can be analyzed with qualitative method; thus, it allows to get a more in-depth understanding of the studied phenomenon. Mixed method is a combination of the above-mentioned research methods, utilizing the strengths of both and mitigating their weaknesses.

For our research the authors have chosen the mixed method. That way the authors could get a better understanding of commissioner needs and wishes; make precise and objective calculations (quantitative part) and, at the same time, take into account real-world experience (qualitative part) to find balanced solution. Since the research covers particular case of commissioner company, the Case Study approach is applicable here.

3.3 Data collection

The data collection process for this report can be divided into two parts: theoretical (literature review) and practical (data collection in commissioner company). Information gathered in the first part is classified as Secondary data and in the second part – Primary data. The difference between these two types of data used in research is in the origin of information. Primary data comes directly form the particular research case, while secondary data has been gathered previously for other purposes. (Cambridge University Press, 2023)

3.3.1 Secondary data

At first glance it seems that primary data should come first, however, it’s called primary for a different reason (because of the original source, not because of the order it should appear, in the research). When looking deeper and comprehending the definition, it still may seem that secondary data is not that relevant and has only a slightly supportive function. However, due to certain benefits that secondary data provides, literature review still comes first in research, making secondary data the base for the research rather than a slight support.

There is an extensive amount of information available about different phenomena. Nowadays, technologies make the information especially easy to access. It would be only logical to start the research by checking the relevant data that is already available instead of discovering the same information on one's own. Primary data collection is very time-consuming and sometimes requires spends, and the possibility to use secondary data is beneficial in a time and money perspective. (Gilbert A. Churchill & Iacobucci, 2005, p. 167-170)

Apart from time saving and cost reduction, secondary data also helps specify the primary data needed. Thus, it allows the researcher to choose a more appropriate way of collecting primary data. Besides, the researcher can immerse his/herself into the studied phenomena better when collecting the secondary data, getting a better understanding of the issue and more knowledge about possible cases, therefore, conducting a better analysis of the primary data and gathering more insights from it. (Gilbert A. Churchill et al., 2005, p. 167-170)

However, secondary data has certain disadvantages. Since the data has been collected for purposes other than the research (according to the definition of secondary data), it might not be perfectly compatible with the current research. For example, the phenomena can be measured using different scale and units, or the information might not be valid anymore due to the gap in time between the data collection and the current research. Another issue is accuracy of the data. Initial data collection and analysis consists of several steps performed by human, therefore, creating a probability of errors. One more thing to be aware of and careful about using the secondary data in the research is to detect if the data in the source is, in its turn, taken from secondary or primary source. Several secondary sources in the chain decrease accuracy and crucial matter-changing details could be left out. (Gilbert A. Churchill et al., 2005, p. 167-170)

3.3.2 Primary data

As opposed to secondary data, primary data fits the research case better, but requires time and may incur costs. Since the data is collected specifically for the research case (according to the definition of the primary data), the process is unique and designed for the particular case meaning various options for data's content and collection method. The primary data obtaining techniques can be categorized as either communication or observation. There are not that many general strengths and weaknesses for the primary data collection, but the techniques can be evaluated in the following aspects:

- **Versatility**

  Possibility to collect different kind of data; easier to achieve in communication, but possible in observation.

- **Speed and Cost**

  Communication faster, but more expensive, while observation is cheaper, but slower.

- **Objectivity and Accuracy**

  Strength of observation, as the outcome is not related to respondents' interpretation.

(Gilbert A. Churchill et al., 2005, p. 202-214)

3.4 Data collection and analysis tools used in this research

First, the authors collected the secondary data in the Literature review section 4 of the report. Multiple sources were used for secondary data collection (see References). Sources were found online (Google, Google Scholar, Janet library) and in books.

Next, the authors proceeded with the primary data collection. It was done with the use of interviews and observations during visits to commissioner company. Main sources of communication were Outlook (emails), Teams (messages and meetings) and face-to-face meetings.

For the data analysis the authors utilized MS Office programs (Excel, Word), and visTABLE simulation software. VisTABLE simulation software is described in more details in Chapter 0.

3.5 Ethics

With this chapter the authors confirm that the research will follow the main principles and guidelines mentioned in the chapter.

The main ethical principles of a research are reliability (research is done with proper quality level), honesty (research is transparent), respect (for the people involved), and accountability (for example, for the future use of the research results). It is essential that confidentiality of the data is respected in the research results. Potentially relevant risks must be recognized and avoided. Researchers must be impartial and open-minded to ensure objective results of the research. Secondary sources and contribution of other parties must be acknowledged (e.g., as proper references). Research results must not be fabricated or falsified. Besides, plagiarism is not allowed in the research. (ALLEA - All European Academies, 2017)

Since the research includes cooperation with relevant people, additional principles apply to the research. Participation in the research is voluntary and anonymous with possibility to leave the research at any moment without consequences. Participants have the right to know the content of the research and data processing. Privacy of the participants is ensured with the confidentiality agreement. (Finnish National Board on Research Integrity TENK, 2019)

The authors have been in close contact with employees of the commissioning company and received data and help from them throughout the research process. However, the names of the employees are excluded from the public version, as well as all the confidential information (data about the commissioning company and it's operations).

The second research question is related to the layout analysis and, therefore, majority of the research implemetation devoted to the second research question consists of confidential information. Therefore, most of it had to be removed from the publc version of the thesis – otherwise, it would be unethical to publish confidential data about commissioning company and it's operations.

4 Literature review

In this chapter of the report the Authors proceed with secondary data gathering. The studied topics are chosen in accordance with the research questions and limitations stated in section 3.1 of the report.

4.1 Castings

This section breaks down the basics of castings and how they are manufactured. The production process and nature of castings lead to special requirements which increase lead time from order to delivery. It must be considered from material management point of view. Proper planning of castings (e.g. sufficient safety stock) must reduce risk of running out.

Castings being discussed are metal naturally, as we are analyzing the transmission of a tractor. Metal castings can be split either by the type of metal (ferrous and nonferrous) or by the way the mold is made. They can be viewed in detail below, Figure 4 and Figure 5 respectively. Figure 4 shows the castings grouped by metals and Figure 5 shows the different types of molds that are associated with castings. (Campbell, 2015, p. 529)

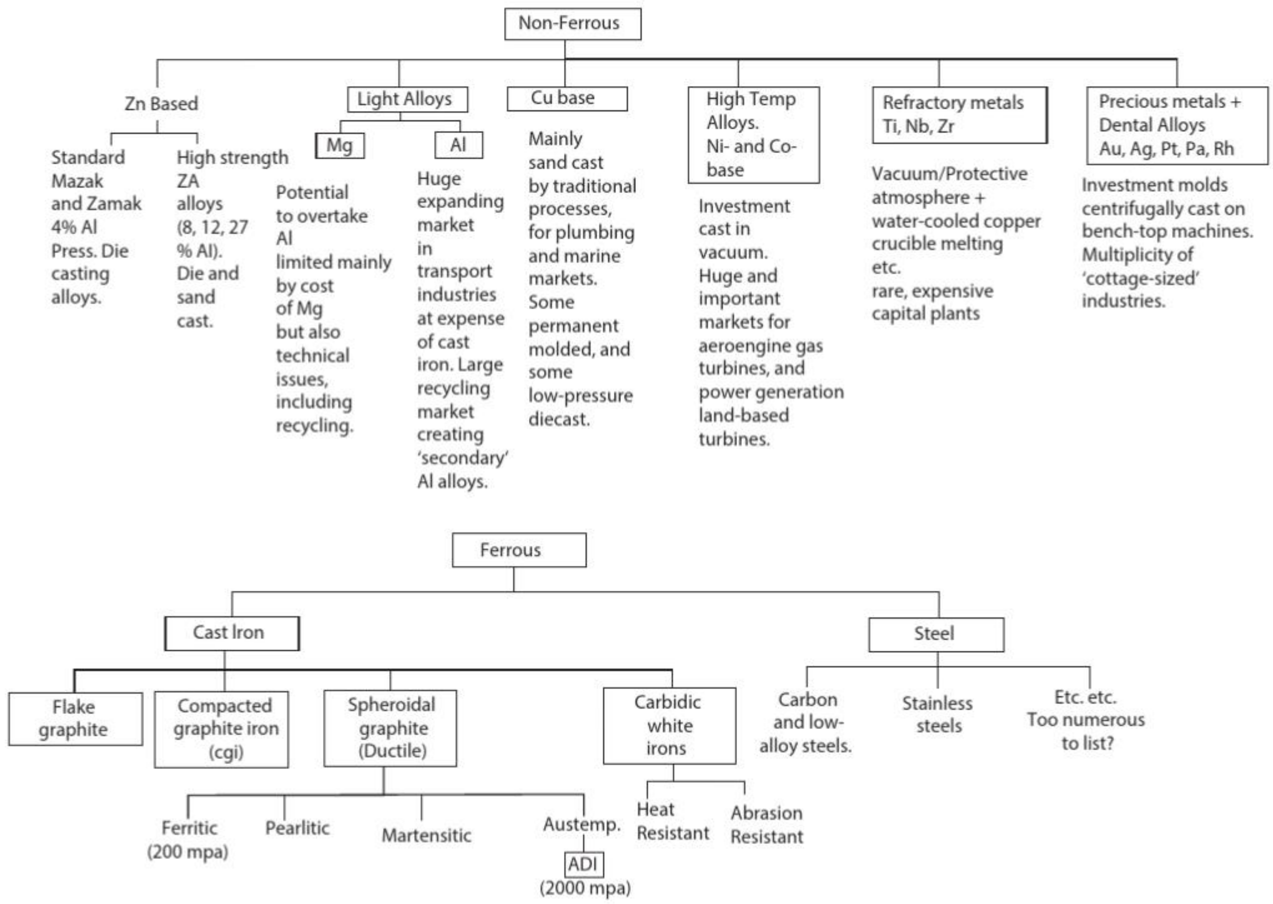

Figure 4. Castings categorized by metal (Campbell, 2015, p. 529)

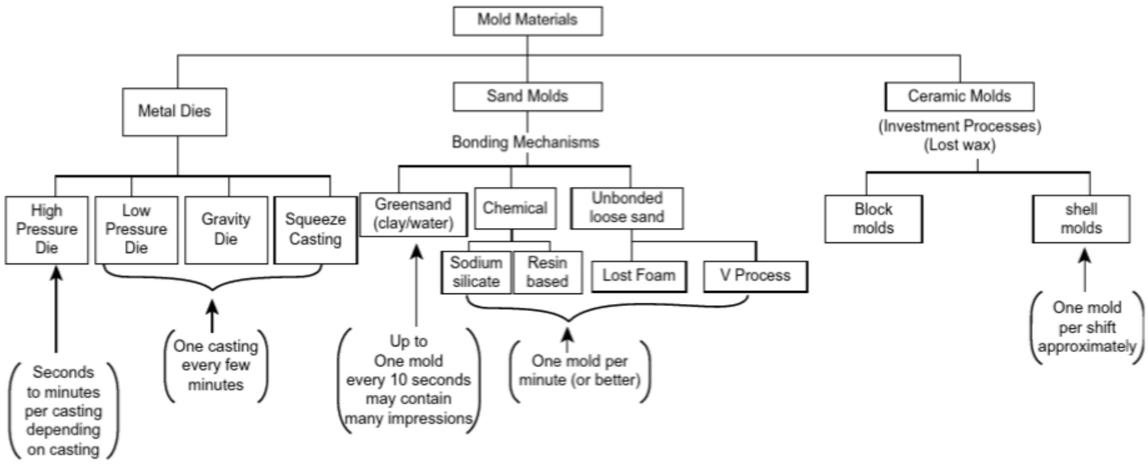

Figure 5. Castings categorized by molding type (Campbell, 2015, p. 530)

To create castings there are 5 steps in the process, although there are only 5, there are many different options to these 5 different steps. This creates a problem to summarize the casting industry, but the following processes have been chosen for their good balance of features. The 5 processes are as follows:

1. Melting
2. Moulding
3. Casting
4. Solidification control
5. Postcasting processing operations

(Campbell, 2015 pg. 530)

Although this may seem a simple process, it is not. According to Campbell the weakest link in these processes are phase 1 and 3. This is due to the fact that they have been chosen poorly, only based on the fact that they have huge productivity and low costs. The problem with the metal casting industry is the pouring of the liquid metal, this creates unwanted damage as the liquid aided by gravity accelerates to damaging speeds. In order to eliminate this, minimizing the amount of pouring in foundries is essential, as well as designing a correct casting technique. Campbell does however mention that foundries are successful on eliminating the process of pouring throughout. (Campbell, 2015) pg. 530

As castings are very sensitive parts, manufacturing should follow the common rules of castings production precisely. Otherwise, the casting will not be of sufficient quality. Melt is the base for a casting, so the bad quality of the melt can cause problems from the very beginning. The surface of the moulded melt must be at rest: even small wavelets can cause faults (like denser parts inside the casting). That reason makes it necessary to ensure that the velocity of the melt flow must not exceed 0,5 m/s. Another nuance of the melt flow is that it must always be in motion while the mold cavity is being filled. Otherwise, the metal starts hardening at a lower level than required which leads to faults. Air bubbles are not allowed as well, and they can get in the melt flow or through the sides of the mold cavity. When the liquid is hardening it becomes solid and starts taking less space. Therefore, there might be a need for the feeding process which takes a long time and is aimed at compensating this volume difference. Another issue that could damage castings during production is convection. Convection is a physical phenomenon that occurs when matters of different temperatures are involved (heat transfer flow). Convection causes instability and can significantly affect quality of a casting. One more problem that metal compositions are subjected to is segregation. It can lead to a different metals' proportions in different parts of a casting. Various factors influence the significance of segregation, and the goal is to minimize it. One more minor but essential idea is to add location points to castings, this minimizes further machining mistakes related to locating the part in space. Location points must be physically present on a casting, it is not convenient to have it at a virtual centerline or so. (Campbell, 2015, p. 535-638)

After the casting is produced, there can be residual stress present. It acts in such a way that a casting may tear into pieces or snap causing quality issue, equipment damage, or even safety issue. In order to test it, two lines on a central bar (with length L) are scribed and the distance between the lines is measured. Then the bar is cut between the lines, ends of the cut spring apart and the distance is measured again. Difference between the distances (ΔL) is calculated. (Campbell, 2015, p. 613-631)

Hooke's law (specific form, expressed in terms of strain and stress):

$$E = \frac{\sigma}{\varepsilon}$$

E – Young's modulus (constant which depends on the metal in question)

σ – stress (in this case residual stress)

ε – strain

Strain can be expressed via L and ΔL:

$$\varepsilon = \frac{\Delta L}{L}$$

Combining the two equations, the formula for assessing residual strain is:

$$\sigma = E * \frac{\Delta L}{L}$$

(Campbell, 2015, p. 613-631)

The castings manufacturing process has a lot of nuances and even a small deviation in process may dramatically affect the quality of parts. The process requires a lot of time and customer must be prepared for possible delays due to quality issues.

4.2 Material flow

Every object has a certain life cycle. In the beginning there is raw material, then it is transformed into the final product via production, then the final product is being used, and the final stage is disposal where the product could end up in a waste facility or be recycled, turning it back into raw material. Basically, material flow is all the phases that a material goes through during its life cycle. Of course, material flow is scalable, so it can be studied/analysed in the context of a particular company. Since this research case directly involves material flow, it is necessary to present an overview of material flow topic.

Generally, logistics doesn't bring any additional value to the product (with specific exceptions, of course, like wine and cheese that could still develop while they are being stored). Of course, it is impossible to get rid of logistics operations completely (nothing with efficiency coefficient of 100% exists, despite being so desirable), and therefore, the goal is to minimize time and costs spent on warehousing, movement, inventory, etc. Material flow analysis is one of the main tools to achieve this goal.

Lean organization of material flow is very beneficial in different ways. Usually, it includes standardization of processes that leads to clarity and time savings. Well-planned material flow results in more efficient space usage. Moreover, it leads to optimization of inventory, so good planning helps to avoid having unnecessary working capital. All those areas are closely related to time and costs, thus, to achieve efficiency and flexibility in production and to reduce waste a company needs to analyze and optimize their material flow. (4flow, 2023)

4.2.1 Lean principles and waste

In the end every business has one goal: to gain profit in order to develop further and keep functioning. Efficiency is one of the key factors influencing business profitability. Implementation of lean principles and waste elimination in the material flow are aimed at efficiency improvement, and thus, better profitability of the business. Material flow improvement is one of the goals of this research, that's why lean principles and wastes are discussed in this section.

Since *Profit = Price – Cost*, in order to increase profit, price should be increased, or cost should be decreased. However, major increase in price may have a negative effect on competitiveness and demand, so it is not a strategically good way to gain profit. This leaves the option of minimizing costs as preferrable. The key factor in this case is efficiency, and lean principles are aimed at enhancing it. (Santos, Wysk, & Torres, 2006, p. 1-10)

Several types of waste are defined in the lean principles. Some of them are closely related to material flow. They are inventory (including raw material, Work-In-Progress (WIP), and final product), transportation (internal material movement), defects, and inactivity (downtime and waiting time). Implementation of lean principles to material flow is a great way to minimize the waste and negative impact from it. (Santos et al., 2006, p. 1-10)

The biggest impact comes from inventory (discussed in Chapter 4.4.1) in comparison to other waste types. It consists of raw material safety stock, WIP, and some stock of the final product. When companies are planning their production, the forecast is made using statistics and market analysis. However, forecasts are always wrong, so a buffer or safety stock is necessary to keep some level of flexibility for the production. Besides, demand may vary between different time periods (e.g. due to seasonality of the product) and keeping inventory of final product needs to be considered to make production rates smoother (with no significant deviation between time periods). Moreover, raw material is procured in batches determined by packing quantity and Minimal

Order Quantity (MOQ). Therefore, from a purchasing perspective, keeping inventory of raw material can be economical. (Kumar S. A., 2007, p. 42-48)

The main ideas of lean manufacturing are the following: to find the problem (and the root cause), to adjust the process and eliminate/minimize the problem and maintain it. Key idea is also that this process needs to be repeated regularly to ensure continuous improvement. Table 2 is a list of lean principles and tools that can be used for improvement.

As said previously, the castings production process is difficult and must follow a lot of rules to reduce risk of having a quality issue. Therefore, it is not easy to follow lean principles for the part of supply chain that involves castings. It is a challenge that comes from the nuances of following castings requirements. This is the reason why castings require special attention in the supply chain.

Lean principles and tools	Explanation	Purpose
JIT	Just-In-Time production principle	Minimization of inventory, production only according to demand, obtaining resources right before production
5S	Sort (seiri) Set in order (seiton) Shine (seiso) Standardized or visual control (seiketsu) Sustain (shitsuke)	Workspace organization and cleaning
5Why	Why *problem* ? *Reason1* Why *Reason1* ? *Reason2* Why *Reason2* ? *Reason3* Why *Reason3* ? *Reason4* Why *Reason4* ? *Reason5*	Extension of the cause-and-effect links for root cause determination
PDCA	P - plan D - do C - check A - act	Continuous improvement cycle
DMAIC	D - define M - measure A - analyze I - improve C - control	- Six sigma steps - Improvement process
FMEA	Failure Mode and Effects Analysis	Tool for quality control and failures minimization

Table 2. Lean principles and tools (Santos et al, 2006, p. 88-89, 110-113, 149-165; Goetsch, 2013, p. 293-294, 375-376)

4.2.2 Overview of layout types

Organization of the layout is one of the main topics of the research. In order to be able to classify the layout, existing in the case company, and its features, overall knowledge of the layout types is needed. Therefore, overview of the layout types needs to be discussed in the research.

The layout of the factory defines material flow and, thus, efficiency of production. That is why it is crucial to plan (after implementation it is problematic to change) and organize.

As stated previously, logistics almost never adds value to the product, but is unavoidable in production. Therefore, operations like material handling and material movement need to be minimized – which is one of the aims of a layout. It also affects equipment utilization rate (and investments consequently), personnel utilization rate, production lead time and flexibility of the production line. In a sum, a well-planned layout helps costs and time reduction significantly. (Kumar S. A., 2007, p. 42-48)

A good layout needs to include all the “participants” of the production process (people, equipment, material, etc.). The distance that material covers between production stages and material handling need to be minimized, and the layout needs to be compact as well as taking as little space as possible. Companies need to operate in a changing world and have to meet changing requirements, production principles, production volumes, business development, etc., so the initial layout needs to be flexible to allow adjustments without major reconstruction involving significant investments (costs- and time-wise). Last but not least, safety must be ensured in the good layout. (Kumar S. A., 2007, p. 42-48)

The initial layout is set up when the factory is being built up. However, when the factory is already operating the need for layout reorganization may occur. Naturally, the situation where the factory is moving to another building is a good time for rearrangement. The new layout should be made according to previous experience as well as new needs and requirements that come with the development and extension. However, location change is not the only reason for layout modifications. Layout adjustment should also happen when a new piece of equipment is being installed to ensure utilization at maximum flexibility. Otherwise, further problems with material flow can occur which will be more costly than equipment set-up (with layout adjustment) in a long-term perspective. Generally, in case the initial layout doesn’t work well, it requires changes. WIP is one of the problems with material flow that could be a good indicator of issues with layout where reorganization is required. (Santos et al., 2006, p. 18-26)

Even though each factory is an individual case, with its own requirements, dimensions, and conditions, layouts generally follow a certain logic or idea. Generally, five types of layouts are distinguished: functional (process), cellular (group), line (product), combined (combination), and fixed position (project type) layout. Summary of the features of different layout types is shown in Table 3.

Layout	Key features	Advantages	Disadvantages
Functional (process)	- similar machines grouped together - batch production - different flow for different products - several orders at the same time	- high equipment utilization rate - flexibility - diversity	- increased manual material handling - high WIP - high lead time
Cellular (group)	- equipment for product families grouped together - various products in small batches	- low material handling - low WIP - high equipment utilization rate - flexibility	- only applicable when possible to divide products into product families
Line (product)	- equipment for product grouped together (in the production sequence) - e.g. conveyor line - sufficiently high production volume of the product	- low WIP - min. material handling (with automation possibility) - low production lead time - possibility for bottlenecks elimination	- low flexibility - series system reliability - high initial investments
Combined (combination)	- functional (process) + line (product) - tailored items (with small adjustments like size)	- flexibility - min. material handling (with automation possibility)	- very high initial investments - specific application conditions
Fixed position (project type)	- material in fixed position - components, labour, equipment, etc. delivered to the location - used when building singular huge product (e.g. ship)	- very high flexibility - low initial investments - possibility to do large works	- not applicable for serial production - no possibility for automation

Table 3. Summary of the main layout types (Kumar S. A., 2007, p. 43-44)

Functional (process) layout

The point of a functional layout is that similar equipment (with the same function), is grouped together. The raw material is moved to one group of machines, then to the next one and so on. This all depends on the processes it must undergo to become the final product. Because of that, different products have different material flows. (Kumar S. A., 2007, p. 43-44) Figure 6 is an example of the functional layout.

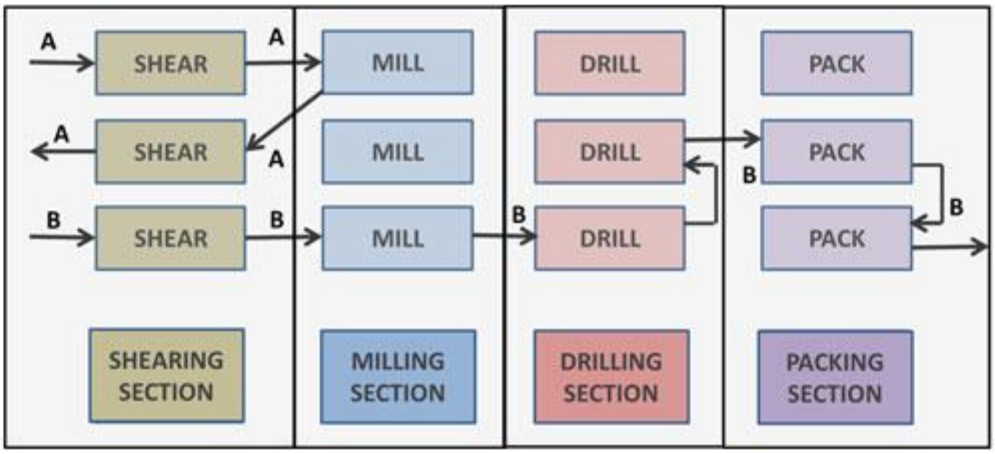

Figure 6. Functional (process) layout (AVCI, 2023)

One of the main features of the functional layout is flexibility, which makes it especially suitable for batch production and manufacturing of various products by order. Due to the versatile material flows, there can be several orders in the production at the same time leading to high equipment utilization rate (thus, lowering initial investments), but, at the same time, increasing WIP and production lead time. Besides, a lot of manual material handling is required to move material between different production stages. (Kumar S. A., 2007, p. 43-44)

Cellular (group) layout

Cellular layout also involves grouping the equipment, but with a different logic than functional one. This layout is based on the final products – similar products make a product family, and each gets its own production cell where all the necessary equipment is grouped. This allows the factory to produce tailored products in small batches (e.g. same T-shirts (product family), but in different sizes), adapting to diverse customer demand. (Kumar S. A., 2007, p. 46-48)

Material flow of products from the same family is a carbon-copy. Only small adjustments inside each production cell are needed. A correctly implemented cellular layout leads to low material handling, low WIP, high equipment utilization rate and efficiency, and product diversity without compromising production lead time. However, it is only beneficial in the case when different products are made and product families can be defined. (Kumar S. A., 2007, p. 46-48)

Line (product) layout

Implementation of line layout means grouping equipment for particular product manufacturing and placing it in the same order as the production sequence goes. Then the material flow for a product is a line. The most famous example of a line layout implementation is Henry Ford's conveyor assembly line. Since the whole production line is aimed at manufacturing one product, the production volume needs to be sufficiently high, otherwise it would not be economical. (Kumar S. A., 2007, p. 44-45)

Production flows logically and smoothly with such a layout. There is no need for temporary storage, and inventory level in production is low. Material handling is minimized and can be automated, since the material flow doesn't change. There is a possibility to eliminate bottlenecks, making relatively low production lead time even lower. (Kumar S. A., 2007, p. 44-45)

However, this layout requires high initial investments and is not flexible after installation: change in product might require renovation and reorganization of the layout. Besides, reliability of the system can be classified as a series, meaning that breakage (or other issue) of one machine leads to stopping the whole production line, and the lead time is determined by the longest operation done in the production (bottleneck). (Kumar S. A., 2007, p. 44-45)

Combined (combination) layout

A combined layout is a combination of functional (process) and line (product) layouts. The equipment is grouped according to the function it performs, and then these groups are placed in line according to production sequence of product. This layout is useful when the same kind of products requires small adjustments (as long as the production steps are the same). Example of such an adjustment is size. (Kumar S. A., 2007, p. 45)

Basically, combined layout is balancing between functional and line layouts: it is more flexible than line layout (in terms of final product features), but material handling is still relatively small and there is still room for automatization (e.g. conveyors or AGVs). (Kumar S. A., 2007, p. 45)

However, extra flexibility comes with even higher initial investments (comparing to the line layout). Therefore, it is only profitable to use such a layout in rather specific conditions (requirement for high production volume of tailored product). (Kumar S. A., 2007, p. 45)

Fixed position (project type) layout

Fixed position (project type) layout refers to the certain location of work where the base material stays. Everything else needed (other components, workers, equipment, etc.) is delivered to the location. This layout is used when a single piece of something large is built. Typically, such layout is used in the shipyards. (Kumar S. A., 2007, p. 46)

The layout enables execution of large works and is efficient with heavy materials (thus, high material handling and transportation costs). Of course, this layout is not meant to work well in serial production. It is useful for unique projects, so flexibility is very high, leaving no room for processes standardization and automation. At the same time initial investments are low. (Kumar S. A., 2007, p. 46)

4.2.3 Overview of production strategies

Choice of layout is closely related to the production strategy. Since the research implementation will be conducted in a case company, knowledge of production strategies could be helpful for the case production strategy classification. That, in its turn, could be useful in matching the production strategy with the layout.

Production system is the way company chose to operate. Seven main production systems are distinguished: job shop, batch flow, operator-paced line flow, equipment-paced line flow, continuous flow, Just-In-Time (JIT), and Flexible Manufacturing System (FMS). There are several factors that affect the production system choice:

- Product range (how many different products are made at the factory)
- Production volume (for each product)
- Layout
- Material flow (how much it varies)

(Miltenburg, 2005, p. 51-53)

Conditions defined by these factors are suitable for certain production systems. Correlation between factors and production systems is shown in Table 4.

Production system	Product range	Production volume	Layout	Material Flow
Job shop	very diverse	very low	functional	extremely varied
Batch flow	diverse	low	cellular	varied
Operator-paced line flow	regular to diverse	medium	line	regular
Equipment-paced line flow	regular	high	line	regular
Continuous flow	low	high	line	continuous
JIT	diverse	low to medium	line	regular
FMS	very diverse	low	cellular/line	regular

Table 4. Seven production systems summary (Miltenburg, 2005, p. 52, adapted)

Job shop

Job shop can be described as a factory with functional layout that produces small batches of customized products. Because of that employees are very skilful, as they work with the equipment of certain function on various projects. Such production system could be used by companies that are just starting their business. (Mansueto Ventures, 2020)

Job shops typically produce engineer-to-order products, and each order is treated like a project, requiring its own planning and processing. (Hegyi, 2006) Such way of production leads to long waiting time (related to equipment availability), high WIP and long production lead time. (Miltenburg, 2005, p. 56) Apart from difficult production planning, constant set-up changes are another challenge, incurring extra costs, but, at the same time, leaving room for innovation. (Mahmoud, 2015)

Batch flow

Batch flow can be described as the next step towards mass-production from the job shop, making cost per unit smaller. In job shop each order is treated as individual project, while in batch flow similar orders are grouped together and processed in a batch. Even though, such approach leads to smaller versatility (number of different manufactured products is smaller) and makes the system less flexible, it allows to increase production volume and decrease lead time (comparing to the job shop system). Since similar order (product families) are grouped together for production, usage of cellular layout is suitable, which makes WIP smaller than in job shop system. (Hegyi, 2006)

Batch flow production system has certain features that are consequences of batch production. Since there are no individual orders requiring production anymore, production covers longer period of demand, so forecasting and production planning must be done carefully (to balance between overproduction and lack of availability or cost per unit). When it comes to production, material flow varies greatly between batches, but there are similarities of the material flow in the production of one product family. This makes material handling quite complicated. Set up changes still happen often, but less than in job shop, since they need to be done only between production of different batches. (Mahmoud, 2015)

Operator-paced line flow

When a factory produces various products in changing volume, it is almost impossible to automate the production pace. That’s when Operator-paced line flow production system is in use. In such case production pace is controlled by employees. Operators are located at different production stages and complete similar operations to products (depending on requirements). A good illustrative example of Operator-paced line flow is a fast-food restaurant where volumes of different products fluctuate a lot. (Miltenburg, 2005, p. 58, p. 373-377)

This production system requires very close cooperation between operators. Good teamwork is one of the main factors affecting production speed and output. It also depends on the number of operators in the line and product requirements. The system is very dependant on people (directly on operators, and also supply chain management like production planners and material planners), so it is susceptible to the human factor. (Miltenburg, 2005, p. 58, p. 373-377)

At the same time the system is very flexible and efficient. Efficiency comes from equipment being designed and operators being trained specially for manufacturing a required type of product.

Besides, in comparison to job shop there is some regularity in the production, so it's easier to manage in that sense (there is possibility for improvement). (Miltenburg, 2005, p. 58, p. 373-377)

The operators' main goal is to keep more or less a steady production flow. Bottlenecks can be determined by the high level of WIP in certain production stages. Since people are managing the flow and it is changing from stage to stage, it is possible to ulitize JIT and kanban (discussed in Chapter 4.3) for supply management. (Hegyi, 2006)

Equipment-paced line flow

The idea of Equipment-paced line flow production system is similar to the Operator-paced production strategy with the difference that machinery sets the production pace. In order to make it work, the number of products has to be low. Equipment used in this production system is very specialized and, thus, expensive, so the production volume must be high to overcome equipment investments. (Miltenburg, 2005, p. 56, p. 407-411)

Equipment-paced line flow is considered to be the best production system. Indeed, it has advantageous features such as: high production speed, constant output, high quality, low cost (due to high production volume), employees only do simple repetitive tasks (no need in many special skills). On the other hand, it is not flexible (only several standard products are manufactured) and significant change in the product requires expensive change of equipment) and is profitable only when production volume is high. (Miltenburg, 2005, p. 56, p. 407-411) In case some customization is required, it can only be done at the end of production. (Hegyi, 2006)

Continuous flow

The point of continuous flow production system is similar to equipment-paced line flow but raised to the extreme. A very narrow product range allows high automation rates. However, since specialized equipment is very expensive, it has to be compensated with very high production volumes. Because of that (and due to high automation rate), production usually runs all the time (24 h/day). (Miltenburg, 2005, p. 58, p. 415-419)

Operators only need to monitor the production. However, maintenance is extremely important, as product availability strongly depends on equipment work rate. (Miltenburg, 2005, p. 58, p. 415-419)

The main features of continuous flow are the lowest cost, highest quality and fastest delivery of products. However, the production system is not flexible and requires stable product design. WIP level is low. Production schedule typically has a long frozen zone. High investments are required in the beginning and large facilities are needed as well. (Miltenburg, 2005, p. 58, p. 415-419)

Just-in-time (JIT)

JIT is the most difficult production system. The main difficulty is that continuous improvement takes place at the same time as production goes. Main conditions for JIT production system implementation are the need for various products produced in low to medium volume, lower costs, higher quality and faster delivery in comparison to batch flow production system, and high level of manufacturing capability. (Miltenburg, 2005, p.58, p. 383-387)

JIT is the name for two phenomena: lean manufacturing techniques used in combination with other production systems, and independent production system. Often, only techniques are used for improving another production system. JIT production system implementation is complicated, it requires specific conditions and takes a lot of time. (Miltenburg, 2005, p.58, p. 383-387)

The main point of JIT that makes it stand out from other production systems is the continuous improvement. The main goal is to eliminate waste which is achieved via several steps. Firstly, there should be an inventory storage bin at each production station. Secondly, maximum inventory level must be defined for each storage bin. Next, this maximum level needs to be lowered (the order comes from management). The lower inventory level at the production station may expose problems: production will not continue smoothly if there are any. Each case must be investigated, root cause defined, and solution provided. While the solution is being implemented, maximum inventory level is increased to its initial level. After the implementation, maximum inventory level must be decreased again – and the cycle goes on continuously until all problems are eliminated as well as having the inventory level minimal (just in time for production). (Miltenburg, 2005, p.58, p. 383-387)

Flexible manufacturing system (FMS)

FMS is a combination of machines controlled by computer, automated material handling (with the usage of, for example, AGV (discussed in Chapter 4.7.1) or CNC machines), and a computer system that supervises the production process. This system is used when various products are manufactured in low volumes. Production is done in batches that can be any size (including one piece). In that way it is similar to batch flow and job shop, but automation provides better cost and quality of the final product. The general layout is cellular – certain products are made in a production cell, but material handling goes the same way as in the line layout. Line layout also leads to faster delivery than in the batch flow system. The production strategy is make-to-order which leads to low inventory level (raw material, WIP, and final product). (Miltenburg, 2005, p. 58, p. 359-365)

Initial process planning is difficult as it includes writing programs for each operation and each machine. However, after the start of production FMS can work without human supervision for a while. Operators are having supporting roles. Maintenance is an essential aspect here as well due to high dependability on the equipment. Besides, the equipment is complicated and requires specific knowledge in the new technologies area. (Miltenburg, 2005, p. 58, p. 359-365)

Set-up times are relatively quick, and the system is very flexible, so it is possible to follow very specific product requirements. However, such accuracy cannot be achieved without low quality deviation of raw materials. It is possible to control and set the production schedule in real-time, but bottlenecks might occur due to changing conditions. (Miltenburg, 2005, p. 58, p. 359-365)

4.3 Kanban (Control Cycle)

Kanban is a lean manufacturing tool developed by Ohno Taiichi. Ohno defined the material flow in Toyota by looking at the way supermarkets in America operate. In theory, when a component is used in production, it generates a production order. This system is called a pull system, this means that production orders flow from their finished state to raw material. Another way the pull system works is that control is *pulled* from the assembly line back to basic processes. There is another process called push system, this systems production flow moves from raw materials to finished product. (Santos;Wysk;& Torres, 2006) p. 174

Kanban was created when Ohno discovered that the Pull systems created a problem regarding material handling. The problem was, how does the previous process know what the following process requires? Kanban is translated as ‘card’. What this means is, that the card is located in the handling unit of the part (somewhere visible) and provides information of the part, the number of parts it takes to fill the handling unit, container type, storage locations, etc. Another task that the Kanban system does is, it establishes the number of processes not yet completed. The number of Kanban’s is determined by management. This means that any worker cannot create kanbans more than the amount issued by management. Using Kanbans to manage production flow is possible, but all workers should adhere to the strict rules. Rules below:

1. Do not send defective products to the following process.
2. The trailing or following process removes the product from the current machine and leaves the Kanban.
3. Produce only the quantity removed (the number of pieces written in the Kanban).
4. Production must be level.
5. The Kanban is used to stabilize the production process.

(Santos, Wysk & Torres, 2006, p. 175, adapted)

Kanbans are only possible if the demand is stable. Without a stable demand, the number of kanbans would change constantly. In case of unstable demand, it is necessary to use other types of flow-control. An example of this is the traditional stock management based on safety stocks and EOQ. (Santos, Wysk & Torres, 2006, p. 175)

Kanban operation in a theoretical level

The theory for Kanban in an operational level is quite simple. The example below is a very simplified version, it is taken from automotive production perspective as shown in Figure 7 with 4 different car models. When a car gets sold, the cars’ Kanban moves to the previous workstation to trigger the start of the process, shown in Figure 8. To assemble a car, it needs a chassis (body of the car) painted to the color ordered by the buyer, 4 wheels as well as a roof also colored matched to the chassis. When the chassis gets ‘consumed’ in assembly, the Kanban will go to the chassis section, shown in Figure 9. Once the whole car has been assembled, the car that was sold previously (which started the whole process) is once again in stock and ready to be sold, Figure 10. Figure 11 shows what the process looks like when a new chassis comes from the preceding assembly station. The Kanban cycle is repeated in all assembly stations, whether the parts are finished or still in the warehouse as raw material, this cycle repetition generates production/purchase orders. (Santos;Wysk;& Torres, 2006, p. 175-176)

Figure 7. Starting position for a Kanban cycle (Santos;Wysk;& Torres, 2006, p. 175, adapted)

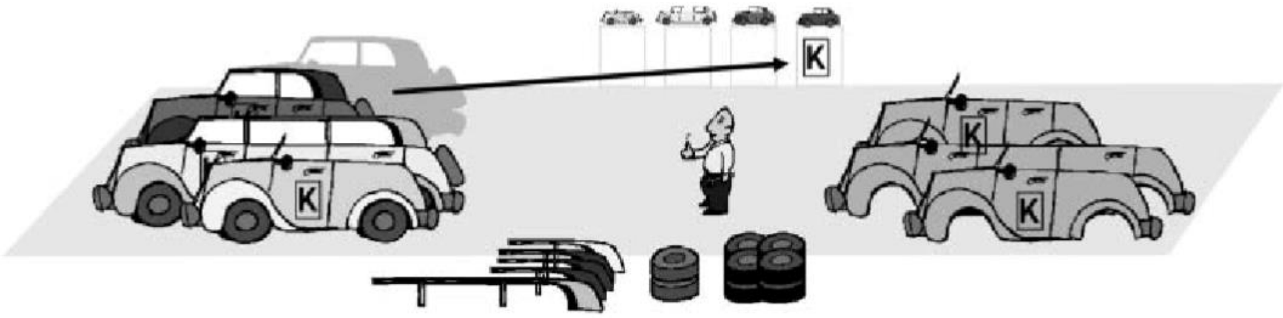

Figure 8. A sale starts the process. (Santos;Wysk;& Torres, 2006), p. 176, adapted)

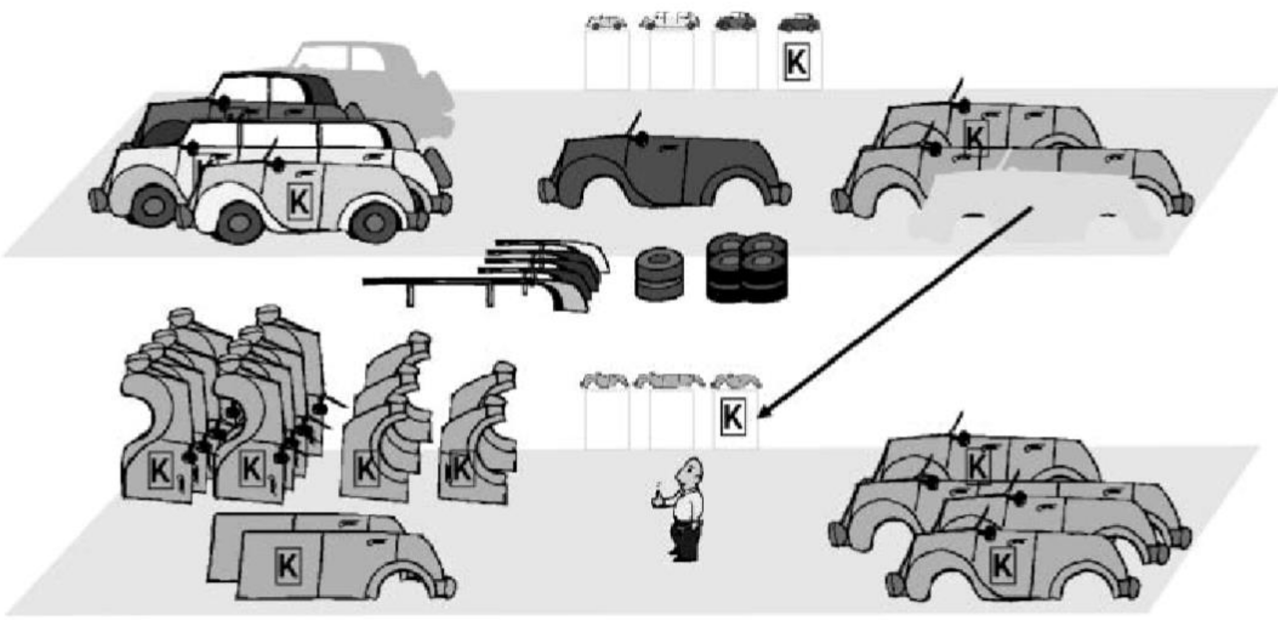

Figure 9. The system moves kanbans through each process. (Santos;Wysk;& Torres, 2006)

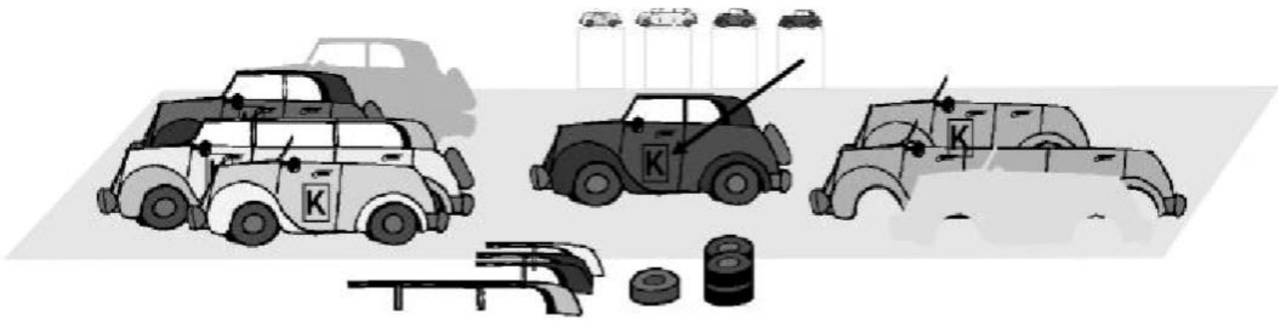

Figure 10. After assembly, a new car is finished (Santos;Wysk;& Torres, 2006)

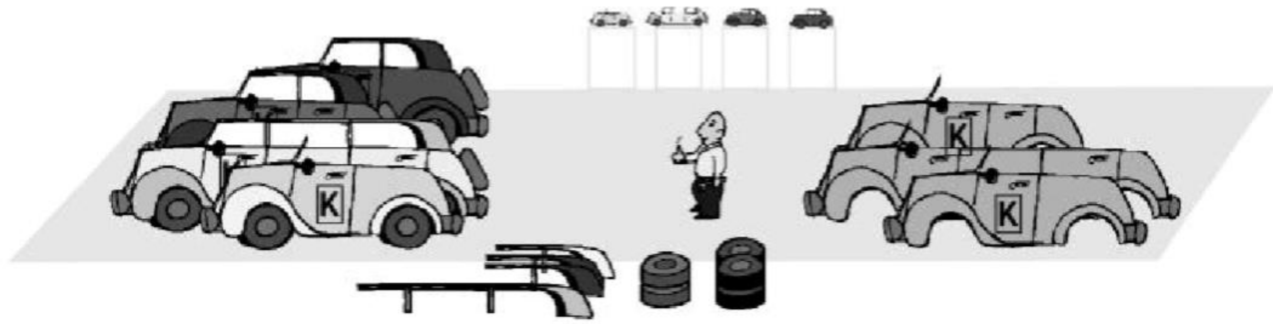

Figure 11. The factory is back to step 1. (Santos;Wysk;& Torres, 2006, p. 178, adapted)

Kanban operation in practice

Kanban is part of JIT and not a main lean manufacturing tool but rather, a part of it. The philosophy of JIT limits companies using a pure Kanban system. Since Kanban systems are used in production cells to be able to independently schedule each cell, in theory each cell could manufacture different components according to the Kanban board (Figure 12) if the worker chooses. The board contains the Kanban's from the previous workstations and are amassed based on their respective consumptions in each column. Each column represents a product reference and is divided into 3 separate areas, in detail below:

- **Below the green line**
  If the Kanbans are below the green line, that means that it is not necessary to produce, especially if there are other priority items.
- **Between the green and red line**
  When Kanbans are between the green and red line, the worker must schedule the production of the products to fill the storage locations marked and replace the stock in the next section.
- **Above the red line**
  When the Kanbans are above the redline, that means that we are starting to use the safety stock in the next production cell. The workers should then stop what they are doing and treat these items as priority one.

(Santos;Wysk;& Torres, 2006, p. 176-177)

The Kanban board method helps transform a scheduling problem into a visual control method. It is not the only method available and does not necessarily need to be a card. Kanbans can be any object, signal, device, that can inform the worker a need for parts. The Kanban board method is similar to a more traditional warehouse management system based on re-order point and safety stocks. (Santos;Wysk;& Torres, 2006, p. 177)

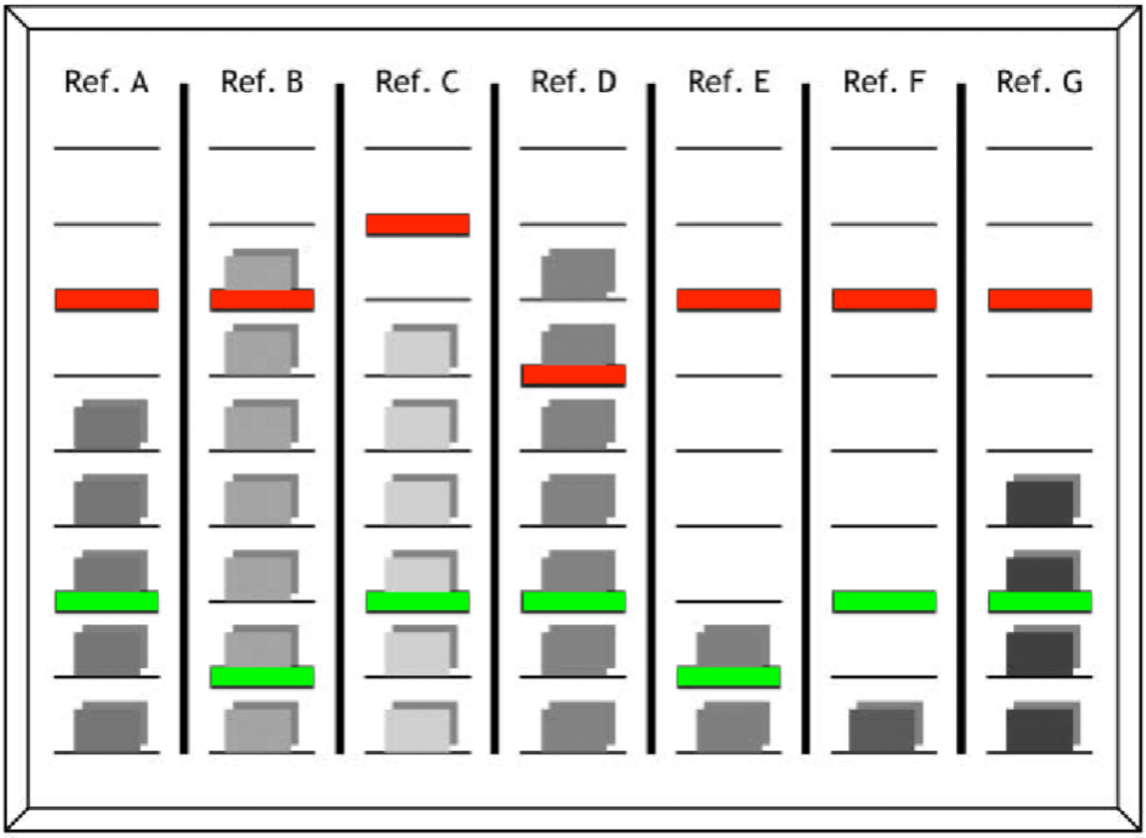

Figure 12. An example of a Kanban board. (Santos;Wysk;& Torres, 2006, p. 179, adapted)

4.4 Intralogistics

Intralogistics is a logistics system inside a factory or a company. It includes mainly warehousing and inventory control, as well as material handling, layout, and material flow. Intralogistics management is aimed at optimizing the processes, making them as efficient as possible (including cost-efficiency).

Since the research questions are directly related to intralogistics, the topic is necessary to discuss. The following subchapters will cover the most essential topics of intralogistics for the research: inventory, intralogistics processes, and equipment.

4.4.1 Inventory

Inventory means materials that are kept in a company's premises. It includes raw material, WIP items and final products that have not been shipped away yet.

Factories manufacture products for the customers. Customers buy the products and factories gain revenue from the sales that is used to cover future functionality of the factory, paying the loans and reinvestment into the business to allow business expansion. On the one hand, inventory can ensure high levels of customer service and short lead times, which boosts company's competitiveness and attracts more customers. On the other hand, keeping inventory is costly, and these costs don't bring value to the final product, so reducing the inventory level can decrease expenditures, and thus, increase profit. Material planners have to keep the inventory level at a good balance, so that inventory costs are minimal, but without risking production and customer service level. The only way to estimate amount of inventory needed is according to demand forecast and production planning. Since forecasts are always wrong, controlling inventory level is very challenging and risky.

There are several main reasons for companies to have a sufficient level of inventory. One reason, that has been mentioned above, is increasing competitiveness. Another reason is that demand for the product is not constant, especially in a case of seasonal product or due to changing conditions in the market. However, rapid changes in the production rate either are not efficient and involve a lot of frequent equipment set-ups or are even impossible to achieve. It's better to have smoother production rates and some extra ready products in stock. Besides, if the production rate needs to be changed, there should be enough raw material available for production. There are also reasons from the side of purchasing. Minimum order quantity (MOQ), Economic order quantity (EOQ) and batch sizes are defined between purchasers and suppliers to ensure the best price of raw material and quality (since the batch size is also related to packaging). Sometimes MOQ/EOQ covers factory demand for relatively long period of time which results in high raw material inventory. Another issue is the lead time. When raw material is ordered, time might be required for supplier production and packaging, afterwards it needs to be transported, and only then it arrives to the factory. To avoid production stoppage while waiting for the material the company should have raw material in inventory. (Kumar S. A., 2007, p. 91-92)

One of the most popular tools for inventory control is ABC-analysis. The analysis can be performed with the following steps:

- Gathering data about items, their annual consumption and value

- Calculation of annual usage cost for each item
- Sorting items according to the annual usage cost from largest to smallest
- Calculating percentage of annual usage cost of each item in relation to total annual usage cost of inventory
- Calculating cumulative percentage of annual usage cost
- Classification: 0%-80% of costs – A class, 80%-95% – B class, and 95%-100% – C class

ABC analysis is based on Pareto’s principle that 80% of total inventory costs are caused by 20% of items. Therefore, only around 20% of items are classified to A class. They require special attention as usually the items are of great value and keeping too many of them in the inventory significantly increases company’s working capital.

4.4.2 Overview of main intralogistics processes

Intralogistics mainly focuses on warehousing and inventory level. The main intralogistics processes include:

- Receiving
- Put away
- Picking
- Packing
- Shipping (Emmett, 2005, p. 88-111)

When the truck with raw material arrives, the material needs to be received. It includes truck unloading, sometimes material unpacking (or repacking for storage), and checking quantity and quality of the items. Packing lists and invoices or purchase orders are used for the items check-up. During receiving, goods are temporarily stacked, and stacker forklifts are typically used. (Emmett, 2005, p. 91-96)

Next process is put away. First, the item’s place must be determined. Two things are needed for that: warehouse location address system and XYZ analysis. Warehouse location address system is the systematic labelling (coding) of the storage places, so that it would be possible to navigate in the warehouse according to the information received about storage place code. XYZ analysis is also based on Pareto's principle and, therefore, the concept is similar to ABC analysis. The difference is that classification is done according to picking times and not annual usage costs. When the optimal location of the items is determined, goods are then moved from the receiving area to the warehouse. (Emmett, 2005, p. 96-97)

At some point, material is moved away from the warehouse, which is a picking process. Again, warehouse location address system is used to locate the goods. There are different methods of picking process: pick-by-paper (with the use of picking lists), pick-by-scanner (with the use of bar code readers), pick-by-light (with the use of light system), and pick-by-voice (with the use of headset).

In the end, finished products need to be packed and labelled. Shipping documents are created, and the goods are shipped, which includes loading the truck and sending products to customers. (Emmett, 2005, p. 110)

4.4.3 Storage methods from space utilization perspective

Inventory storage involves not only working capital costs, but also space utilization costs. Therefore, efficient space usage is essential to reduce costs, that don't result in any additional value, as much as possible. (John J. Bartholdi, 2019, p. 14-18)

There are two main warehousing methods: dedicated warehouse and shared warehouse. The differences are in assigning storage locations to the products. (John J. Bartholdi, 2019, p. 14-18)

The idea behind the dedicated warehouse is that each product has a permanent location in the warehouse and no other product can be stored there. Locations can be defined with XYZ-analysis, they are a constant which makes it easier to manage. However, space utilization is not that efficient as parts of the warehouse are empty sometimes between material reorder points. (John J. Bartholdi, 2019, p. 14-18)

Shared warehouse is a way to improve the problem of dedicated warehouse and minimize space that is left empty. It is done by assigning several locations to each batch of product individually.

When the material is being used and one of the locations frees up, it is reassigned to another product. This way, big spaces are not left empty at any time. The challenge is that such warehouse requires precision and discipline (warehouse workers must strictly follow instructions and process(processes). Furthermore, since the locations of products are changing with each new batch, the put away and picking process must be accompanied with software or instructions from warehouse management all the time. (John J. Bartholdi, 2019, p. 14-18)

As for the efficiency of space utilization, Figure 13 is a graphical representation of it. The vertical axis indicates amount of inventory in a warehouse and the horizontal axis is a timeline (can be indicated in days, weeks, or months). Unit segment of the horizontal segment is equivalent to the time needed for using up all material from one location. Each square is one storage location, and each column shows how many storage locations are assigned to the product at a given period of time. The colored area of the squares represents filled storage locations, and the area without color – empty locations. The more locations there are, the better the space utilization rate is. (John J. Bartholdi, 2019, p. 14-18)

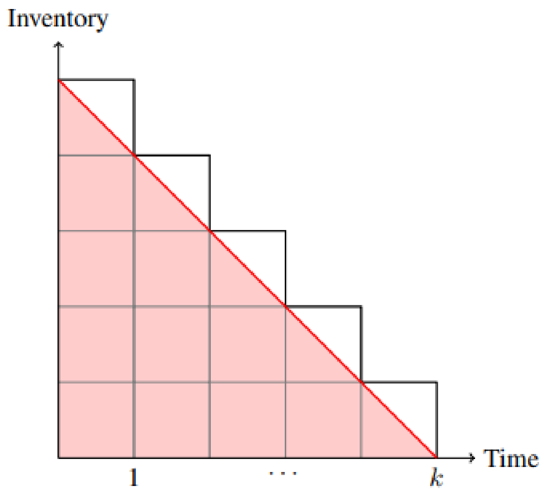

Figure 13. Efficiency of space utilization in shared storage (John J. Bartholdi, 2019, p. 17)

4.4.4 Forklifts

Finding warehousing solution for castings is one of the research questions of the thesis. Warehousing equipment is essential part that must be considered as well. Forklifts are one of the most common equipment types. There are many different kinds of equipment, however, this chapter is focused only on the relevant ones.

Reach truck

A reach truck is a solution for operating within the aisles of warehousing racks. They are most useful for put away and picking processes. Their compact design allows the forklifts to operate in narrow aisles (2,3-2,6 m). Besides, they can operate at relatively big heights (up to 14 m and are electrically powered. Reach trucks can have different operating positions, they can be stand-up (operator is standing; typically used for a smaller warehouses), seated (operator is seated that provides better upwards visibility), and swing (turret is rotating for better access). (Lin, 2023)

Counterbalance forklift

The main idea of a counterbalance forklift is increased mass at the back, which shifts center of mass towards the back. This increases the capacity of the forklift. This additional weight at the rear makes the forklift more stable and, thus, safer. Therefore, they are most suitable for moving heavy loads. Besides, the powerplant can be chosen according to requirements (e.g. electric for indoor application, petrol/diesel for outdoor application). (East Midlands Forklifts, 2023)

Straddle truck

A straddle truck's main feature is its' compact design. The idea behind it is somewhat similar to a pallet jack. However, it is more efficient and convenient, as, for example, the operating height range of the straddle truck is bigger than the pallet jack's range. The system utilizes electronics and hydraulics to lift the pallets and move them around whilst the compact design makes this possible in a confined space. (Douglas Casters and Equipment, 2023)

4.5 Safety Order Time concept

As explained in the *4.4.1 Inventory* chapter of the research, keeping sufficient raw material inventory is necessary for the company. Production plan is based on demand forecast, but it is well-known that forecasts are always wrong, meaning that there is always a probability of deviation from forecast. Typically, to cover the deviation, companies use Safety Stock (SS) – quantity of raw material that is not taken into consideration when ordering material from supplier that can be used in case actual demand is higher than the forecasted one. However, A. Kania et al. (2022) suggests also the concept of Safety Order Time (SOT).

When materials are ordered from a supplier it takes time for it to arrive to the company. This time is called transportation lead time (TLT). In case the company uses only safety stock, the material is ordered when the inventory level consists of safety stock and material needed throughout TLT (order level (OL) = SS + TLT).

Safety stock is fixed while the demand is changing. This means that the time covered by safety stock is changing too. This creates a risk of running out of raw material: if actual demand gets too big, the safety stock set would not have enough material to cover the TLT and if noticed too late, this would lead to a stock-out situation. Dynamic lot sizing, however, would make lot sizing challenging, since lot sizing is estimated with optimization based on the safety stock amount. That is when SOT becomes useful. (Kania, Sipilä, Misitano, Miettinen, & Lehtimäki, 2022)

SOT is set in time units (days, weeks, months) and is an addition to safety stock. For example, if SOT for the material is set for 2 weeks, it means that the order will be done so that apart from SS and TLT there should also be enough inventory to cover 2 weeks of forecasted demand (OL = SS + TLT + SOT). (Kania et al., 2022)

SOT is a dynamic value in terms of stock quantity. If a company uses ERP system, the system generates orders accordingly. This means that a person doesn’t have to revise it as often as safety stock requires. Another issue that SOT eliminates is that safety stock is calculated only based on goal service level and average deviation of demand, which means that the usage rate of materials is not taken into account. This might lead to excessive stock of low-runner materials and vice versa. Usage rate is taken into consideration with SOT. (Kania et al., 2022)

4.6 Outsourcing (3PL)

Outsourcing can be defined by many names; users who are not familiar with the concept may get confused on what the companies who provide the service are doing. To avoid this, it is helpful to get an understanding of some basic terminology for what outsourcing is, in logistics terms. In this case, “third party logistics” or 3PL. Below is a list of the terminologies mentioned as well as a short description.

- **Contract for distribution/ logistics**
  This is a fixed term agreement that grants the company an allocation of resources. (E.g. Vehicles, warehouse, warehouse resources)

- **Haulage companies/ warehouse companies**
  These companies offer either fixed term or ad hoc arrangements for either a dedicated service or consolidated service, the latter being more commonly used. These companies are usually small/medium sized that operate either regionally or nationally. Sometimes, these types of companies have access to the network of other regional companies.

- **Integrators**
  These companies offer fixed term but also offer ad hoc on demand. They use multi-modal transport and are often multinational companies operating worldwide.

- **Express companies**
  These companies offer fixed or ad hoc on demand services that are able to deliver packages within the next day. These companies are either large companies operating worldwide with a vast network or, a smaller company with access to the network of other companies. The latter is usually franchised based.

- **Forwarders**
  Freight forwarders are usually small, local companies. Although there are a few larger companies with owned facilities on a more global basis. Freight forwarders are the ones in charge of selecting the service provider, supervising the transit, providing correct documentation and insurance.

- **Shipping lines and airlines**
  These companies offer fixed or ad hoc arrangements. The services are terminal-to-terminal with the possibility of delivering door-to-door.

- **Postal companies**

  These companies are mainly ad hoc on demand, but fixed term arrangements are also important. Postal companies are either state-owned or formerly state-owned national companies. They have access to other postal networks in other nations.

- **Parcel companies**

  These companies offer ad hoc on demand arrangements for parcels that are not time sensitive. They are mostly compared to express companies in terms of size but without the urgency.

- **Couriers**

  These companies offer fixed term or ad hoc on demand arrangements for packages (usually handheld or small) that require urgent deliveries. They are usually same day or next day delivered, depending on the location. Since the items are small, some courier companies offer on-board services (via commercial flights).

(Emmett, 2005, p. 212-214)

Before using third party logistics, one must first analyze if their company or business needs or will benefit from using such a service. There are a few questions below that help with such an analysis. Table 5 and Table 6 are also shown below to give some ideas on the advantages and disadvantages of using such a service.

- Are your logistic objectives achievable with the use of 3PL?
- Are your suppliers able to meet your current expectations?
  - Shipping on time?
  - Delivery on time?
- Are there any current agreements that prevents you from outsourcing?
- What exactly do you want to outsource?

(Emmett, 2005, p. 214)

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Advantages	
Cost factors	**Service factors**
Less capital on the balance sheet	Flexibility against future legislation changes
Costs now fully on the profit and loss statement	Flexibility for sickness, holidays
Less depreciation risk	Less risk of IR disruptions
More economies of scale	Less employment risk
Less administration and access to fully trained staff and up to date tech.	Improved service levels
Increase business ratios e.g. ROCE	More professionalism and expertise
Cash return for sold off assets	More innovation and new thinking
Tax advantages if leasing	
Planned and more fixed cost levels	

Table 5. Advantages of using 3PL contractors (Emmett, 2005, p. 219, adapted)

Disadvantages	
Cost factors	**Service factors**
Less cost control as costs are 'fixed'	Less direct control on service
More hidden costs for unforeseen 'extras'	Less feedback from drivers on customers
Long-term contracts	Less response to request
Paying a contractor a profit	No innovation

Table 6. Disadvantages of using 3PL contractors (Emmett, 2005, p. 220, adapted)

Once those questions have been answered, it is also good to take note that outsourcing does not apply only to warehousing but also applies as a strategic decision for companies. The following tips have been identified by *Supply Management (29 June 2000).*

- Companies need to focus on what they do well and let the specialist take care of non-core services in other areas
- Keep an open mind to new ideas, what might have worked before, may not work in the future
- Choose a service provider you can grow together with, a strategic partner
- What is the current cost/service level
- Information = power in some areas, for example service level requirements
- Monitor cost/service levels regularly, as well as performance

(Emmett, 2005)

As soon as the analysis has been accomplished and type of 3PL selected, the next step is to provide the correct kind of information to the service provider. Without the correct information, there is a high chance that the service will sub-par and will negatively affect both sides. Naturally, giving the correct information benefits all parties, it can be used for example in benchmarking aspects. Below are a few examples of key information, and the types of questions to ask. This is to help companies get an idea on relevant information for 3PL service providers.

- **Product format**
    - What are the dimensions of the product? Weight?
    - What is the value?
    - The type of packaging?
    - Identification of the product?
    - How to handle the product? Special handling needed?
    - Is the product perishable? Fragile? Hazardous?

- **Throughputs**
    - What is the frequency of shipments going out? (e.g. Daily, Weekly)

  - Are there any peaks or 'seasons' to the shipments? (e.g. over the year, in the month, during the week, during the day)
  - Are there any patterns or requirements in the frequency?
  - Are there any changes to the 'usual' cycle?

- **Collection / Delivery points**
  - Where are the pickup/ delivery locations?
  - What are special features of the locations?
    - Access limited?
    - Limited loading/unloading 'windows'?
    - Loading docks?
    - Side loading only?
    - Maximum height of unloading/loading area?
    - Opening hours?

- **Company policy**
  - What is the service level required?
  - What is the 'return' policy if something goes wrong?
  - Is there any min./max. order size policy?

- **Infrastructure / environment**
  - Are there any traffic bottlenecks?
  - How can these be avoided?
  - Are there any legal restrictions along the route?
  - Are there any specific climatic conditions?

- **Financial issues**
  - Is capital released?
  - Are off-balance sheet finances needed?
  - What is the asset utilization?
  - Are there any economies of scale?
  - What are the planned and the known costs?

- Has a cost comparison, involving 'total acquisition cost' been used?

- **Operational issues**
    - What is the flexibility in 'spreading' peaks/throughs; in delivery times; in future changes?
    - Possibilities to fulfil special requests?
    - What are the management role changes on existing management?
    - How will we keep control? (Management control MUST remain a core activity.)

- **Strategic issues**
    - After the decision, what is the ability to make changes?
    - Are all the assets tied "in one basket"?
    - Any possibilities to bring some of the operations back in-house?
    - What are the possibilities to use another third party?
    - What are the full internal implications?
    - Are the risks spread out?
    - What will be our customers' reactions? (Customer contact MUST remain a core activity.)
    - Has there been a fair and complete comparison?
    - Will the changes assist any internal change/new strategies/ expansion?

(Emmett, 2005)

Now that the analysis has been conducted and all the necessary information has been shared. It is now time to decide on choosing the correct third party. There are usually three points a company aims for when choosing.

1. Cost
2. Speed in transit
3. Reliability

(Emmett, 2005, p. 220)

Those do not represent the order and priority of each company, as they will vary, naturally. In the selection process, companies may want to ask the following questions that help them gain insights on if the third party meets any one or all three points mentioned above. These questions are just examples and may vary depending on each user.

- What type of experience do you have in this industry? Are you successful?
- Have you dealt with our customers before?
- Were there any issues with initial setup of third-party operations for other companies? Why?
- How long will the implementation take?
- What information do you need from our side?
- How will I know that things are going smoothly?
- How can we measure the performance?
- Is there a possibility for strategic partnership?
- Why should you be selected?

(Emmett, 2005, p. 220)

4.7 Automation and robotization

Automation, the word itself originated from the Greek word “Automatos” which means self-acting and gained traction in the United States from the automotive industry in the mid 1940s. They used the word automation to specify the work between two production machines that handle parts. Ever since then, there have been advances in computers and their respected control systems that have broadened the meaning of automation. Before, automation existed on a small scale, using mechanical devices to automate production processes of simple items, nowadays, with the advancements in computer technology, the concept became truly practical as the flexibility provided by the computer allowed it to perform any task. (A. K. Gupta, 2017, p.1)

Automation in its general meaning can be defined as a process following a predetermined set of steps using little or no human force. What automation means in its full sense is that a process is observed and carried out using a variety of devices, techniques, actuators, equipment, and sensors making decisions and controlling all aspects of it. Another way to describe automation is the process of changing various operations from manual to automated. Automation does not only associate itself with robotics (Early adopted by the Automotive industry), but automation can also be applied to all sorts of manufacturing types. Advantages of automation can be found below:

- Increase in productivity
- Reduction of production costs
- Minimization of human fatigue
- Less floor area required
- Reduced maintenance requirements
- Better working conditions for workers
- Reduction in accidents which equals safety for workers
- Better quality of produced components
- Effective control over production process
- Uniform components produced

(A. K. Gupta, 2017, p. 2, 4-5)

Not only are there advantages for automation, but also, there are different automation types. Below is a list of automation types, as well as a short explanation of what they are, what they do as well as possible examples.

- **Low-Cost Automation**
  Is a type of automation that uses, to a degree, existing equipment, tools methods, people, etc. By using existing components, the investment is relatively low hence payback period is short.
  - **Pros:**
    - Reduces manual labor without changing the current setup
    - Low investment
    - Better utilization of material
    - Consistency in production
  - **Cons:**
    - Need for LCA? Some processes do not need automation

        - PMTS tool to check if an existing process will be better timewise and improving it
        - Design, the process may not have been designed with automation in mind
    - **Example:** There are many things that can be made automatic using LCA, some examples of this are loading, feeding, clamping, machining, welding, forming, gauging, assembly and packing.

- **Fixed Automation (Hard Automation)**
  The fixed automation type or "Hard Automation" in other terms uses purpose-built equipment to automate a process and/or assembly operation. This type of automation is used for companies seeking a high production rate while not being very flexible to revisions in product design.
    - **Pros:**
        - Maximum efficiency
        - Low unit cost
        - Automated material handling- fast and efficient movement of parts
        - Very little waste in production
    - **Cons:**
        - Large initial investment
        - Inflexible in accommodating product variety
    - **Example:** Used in productions where the product design does not change that often. For example, light bulb production.

- **Programmable Automation**
  Programmable automation is where the equipment is designed to a certain degree of changes. The equipment can then be changed using a control program designed for the set of changes. This type of automation is used in a batch production style manufacturing.
    - **Pros:**
        - Flexibility to deal with variations and changes in product
        - Low unit cost for large batches
    - **Cons:**
        - New product requires long set up time

        - High unit cost relative to fixed automation
    - **Example:** An example for programmable automation is CNC machining that produces a certain product type according to the input program.

- **Flexible Automation (Soft Automation)**

  For flexible automation, the equipment is designed to manufacture a wide variety of product whilst maintain a short time, changing between different products. This type of automation is useful in producing different variations of a product making it possible to quickly make changes to the product or introduce an entirely new product line.
    - **Pros:**
        - Flexibility to deal with product design variations
        - Customized products
    - **Cons:**
        - Large initial investment
        - High unit cost relative to fixed or programmable automation
    - **Example:** A good example of flexible automation is Honda's motorcycle division during the 1970s. They were successful in introducing a total of 113 changes to its products during this period.

(A. K. Gupta, 2017, p. 6-9)

The positives of automation have been covered, as well as the different types you can expect to see. Taking a look at the negatives must also be discussed, as the entity making the decision on automation must have all the information before deciding on if automation is the right way forward.

When talking about automation, often discussed in the same conversation are the social issues. One of those issues is the impact automation has on employment and unemployment. The fear, once automation is introduced is that human workers would be replaced by computers. This was not the case, as more blue collars were put out of jobs, this freed them up to enter white collar positions which usually paid more. The side effect of this shift from blue to white collar meant that blue collar jobs pay very well in most countries because there is a lack of people able to fill such jobs resulting in supply demand issues. Another social issue raised is better working conditions.

Better working conditions in automation is due to the fact that automated factories need controlled temperature, dust free, humidity environment for the equipment. This gives the workers in the factory good working conditions. (A. K. Gupta, 2017, p. 5-6)

For the reasons on why you should not have automation, the first reason would be labor resistance. While yes, automation increases productivity, making the company more competitive and preserving jobs, there will still be jobs lost due to this reason. Another reason is the cost of upgraded labor. The processes that are repetitious in production are usually the ones that are automated first. This means that the processes that are difficult to automate are the ones that require skilled workers, meaning an increase in manufacturing labor costs to keep the skilled workers. The last reason on why automation would be avoided is the money. Initial investment made could be difficult for the cash flow of the entity even if the ROI is high. Below is a list of issues that the entity may face for automation in factory scale operations:

- Task is too difficult to automate
- Reduced risk of product failure
- Short product lifecycle
- Customized product
- Cheap manual labor
- Fluctuating demand

(A. K. Gupta, 2017, p.10-11)

Robotics, on the other hand, covers many different areas compared to automation. Robots are generally integrated in a system with other manufacturing machines, peripherals, and devices. The reason that they are integrated into a system is that they are rarely useful alone. Robots are considered an integral segment in today's industry. They are able to perform different tasks precisely and do not abide by the same safety and comfort elements that humans need. Even though robots are good, it does however take a lot of resources to ensure a robot functions properly. So what is a robot? It is a computer-controlled machine that is programmed to operate objects and accomplish the work together with the environment the robot is placed in. Another definition for a robot in industrial terms is "a number of rigid links connected by joints of different types that are controlled and monitored by a computer." (A. K. Gupta, 2017, p. 397-399)

As discussed earlier, “robotics is an integral segment in today’s industry as they can perform tasks precisely while not abiding by the same safety and comfort elements that humans need”. With this statement, it is easy to form an opinion on robotics that it is a must and should be adopted. Before this opinion can be made, we need to take a look at the advantages and disadvantages. The table below contains the list of advantages and disadvantages that robotics provides. (A. K. Gupta, 2017, p. 400-402)

Advantages	Disadvantages
Increase in productivity, efficiency, quality, safety, and consistency of the products.	Replacing human workers creates economic problems such as lost salaries and social problems such as dissatisfaction and resentment amongst workers.
Can work in hazardous environments without the need for life support, safety concerns or comfort	Costly due to initial cost of equipment, need for training, need for programming and installation costs.
Does not need environmental comforts such as ventilation, air conditioning, lighting, and noise protection.	Lacks the capability to respond in emergencies, unless the situation is predicted, and the response is included in the system. Safety measures are needed to ensure that they do not injure operators and machines working with them.
Can be much more accurate than humans.	
Can work continuously without experiencing fatigue or boredom, medical insurance, vacation, or hangovers.	
Are very precise at all times, unless something happens to them or unless they wear out.	

Table 7. Advantages and Disadvantages of Robotics (A. K. Gupta, 2017, p. 401-402)

4.7.1 AGVS

AGVS or Automated/Automatic guided vehicle system is a type of material handling system that uses a vehicle capable of independently operating under its own propulsion, guided by a set of pathways in the floor. An example of what an AGV is and how it navigates can be seen below in Figure 14. (Lynch, 2019) They are usually powered by batteries mounted on-board that allow typically 8-16 hours of operation before needing to be recharged. As for the guide or "pathways", they are commonly made using wires embedded in the floor of the area, another alternative would be to use reflective paint to avoid creating a hole in the floor. The vehicle is then guided by the sensors built in. These sensors then follow the wires or paint to their destination. (Kumar S. A., 2007, p. 238)

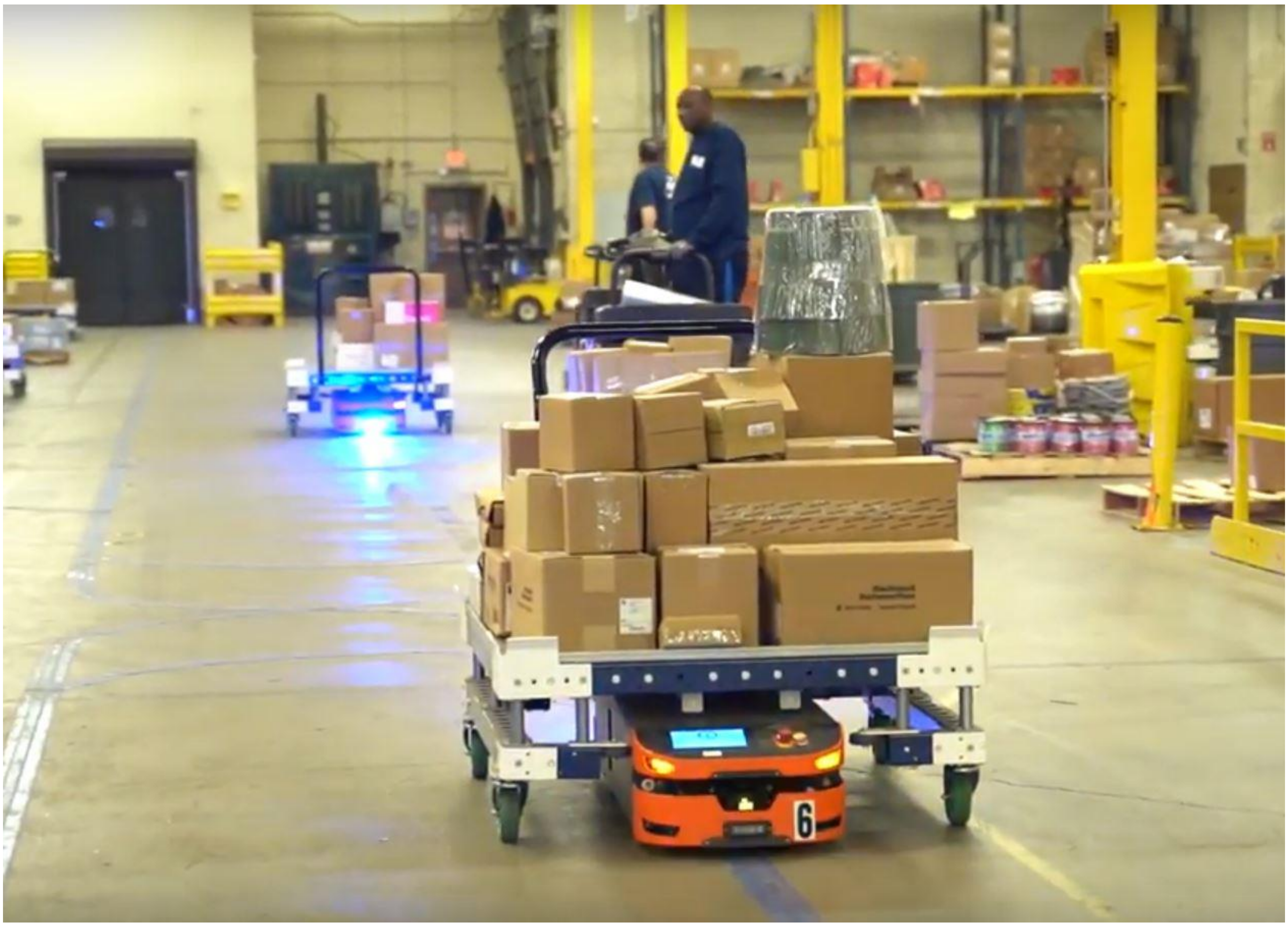

Figure 14. AGV moving a cart full of packages, using blue magnetic tape to navigate. (Lynch, 2019)

Below is a list of AGVS types, the order does not reflect on how good or effective they are. The technology is far from reaching its peak. The industry continues to develop new systems to tackle challenges found in requirements for new applications. An example of said developments is adding a robotic manipulator to an AGVS, granting it the ability to perform complex tasks in and around the factory.

- **Driverless trains:**
  This type of AGVS consists of a towing vehicle that pulls one or more trailers forming a train like convoy. This type is the first type of AGVS introduced and is still popular to this day. Driverless trains are useful where heavy payloads must travel long distances inside the warehouse or factory.

- **AGVS pallet trucks:**
  This type of AGVS, as the name suggests, is used to move palletized items along its specified route. The way this system works is, a worker steers the vehicle backwards into the loaded pallet and elevates it slightly. The worker then drives the vehicle to its initial starting point, at which point, the worker programs its destination and the vehicle then proceeds automatically to its destination. Once it reaches the end, it is then unloaded.

- **AGVS unit load carriers:**
  This type of AGVS is used to move unit loads from one workstation to the next. They are built with automatic loading and unloading with the help of powered rollers, moving belts, mechanized lift platforms, or other devices.
  Light load AGV is a small vehicle with the capacity to carry a light load. This AGV does not need the same space as a conventional AGV and is designed to move small loads through the factories that have the need for light manufacturing.
  Assembly line AGVS are designed to carry partially completed subassemblies through various workstations according to its designated build process.

(Kumar S. A., 2007, p. 239)

Applications for AGVS are varied at this point. But discussing the different use cases for AGVS is needed to be able to understand or get an example of possible uses that the reader may have not thought possible. Below is a list of applications.

- **Driverless train operations**
  This application type usually involves large quantities of materials that move over large distances. An example of this type of movements would be movement between buildings, within a large warehouse to the factory. And the movements are done by driverless trains consisting of 5-10 trailers to be efficient.

- **Storage/Distribution systems**
  Pallet trucks are usually used in these types of applications. This type of application involves the movement of materials in unit loads from or to different locations. The application usually combines AGVS with other automated interfaces like automated handling or storage systems.

- **Assembly line operations**
  AGV systems are becoming more and more common in assembly-line applications. In these types of applications, the production rate is quite low as there are different model varieties being produced. The AGVs carry the products and move with the product from workstation to workstation. In between the workstations items are preassembled, for example electric harnesses needed down the line are mounted and tucked in the product, ready to be installed at the next workstation. Because of this, workstations are generally arranged parallel to each other, this makes them quite flexible. AGVS used in these types of applications are the light load vehicles.

- **Flexible manufacturing systems**
  AGVS that are used in this application are used as the material handling system of the FMS. The vehicles deliver the goods from the staging area to individual workstations in the FMS. After the workstation is done processing the item, they are then transferred to the AGVS that then bring it to the next step of the process. AGVs provide a versatile material handling system that works in unison with the flexibility of the FMS.

- **Miscellaneous applications**

  Other applications for AGVS that does not include manufacturing or warehousing applications are, for example, mail delivery in office buildings and material handling operations for hospitals. The AGVs that are being used in hospitals are used to transport meal trays, linen, medical and laboratory supplies, as well as other materials between various departments in the building.

(Kumar S. A., 2007, p. 239-240)

4.7.2 Robotic arms (Industrial robot)

Industrial robots are essentially advanced automated systems that are controlled by a computer. Computers in today's day and age are so advanced that they are able to manage production lines as well as control manufacturing systems. New generations of robots can execute various tasks in the industrial system and play a role in the fully automating factories. In Japan, (considered to be the leading frontrunner in the world in the field of robotics) (Japan: the Land of Rising Robotics, 2023) they have defined industrial robots in four different levels:

1. Manual manipulators: perform fixed or preset task sequences.
2. Playbacks: repeat pre-programmed fixed instructions.
3. NC Robot: carry out tasks through numerically loaded information.
4. Intelligent robots: perform through their own recognition capabilities.

(A. K. Gupta, 2017, p. 399)

To understand better, the differences between what a robot can do compared to its non-robotic counterpart, let us take a crane as an example. In some ways, a crane and a robotic arm is similar. They both contain links attached together in serial with joints. Some of these links contain an actuator which controls each joint. Both the crane and robot have "hands" that can move objects in a certain space defined by limits of workspace and can carry a certain amount of load. And for both, all the movements made are controlled by a central controller. Here lies the difference, one central controller is operated by a human (the crane) and the other one (the robot) is controlled by a computer. This means that if the program that the computer uses to run the robot is changed, the actions change accordingly. (A. K. Gupta, 2017, p. 399-400)

An industrial robot is made up of 4 main components. A picture representing those components can be seen below in Figure 15 in addition to detailed descriptions of each part.

- **Drive:**

  This component is important as it supplies the power to the robot which makes it move. The drive system can be powered by different sources. For example, hydraulic, pneumatic, or electric. Hydraulic powered drives are used in heavy lift scenarios. Pneumatic drives are used in high speed, non-servo robots. Electric drive systems are used to provide precision lift depending on the type of motor chosen as well as servo system selection and design.

- **Control system:**

  The control system is essentially the brains of the operation. The control system processes information and communication that translates into everything the robot does. Most industrial robots are equipped with computer or microprocessor controllers that performs and interacts with sensos, grippers, tooling and other equipment.

  Programming this control system does not have to be on-site, it can also be done off-site. (On-site meaning in the factory premises where the robot is located, Off-site meaning if the robot is connected to the Wi-Fi system or GSM network, it can be programmed or updated without the need for the technician to visit the factory.

- **Mechanical unit:**

  The mechanical unit as a term, refers to the robot's arm and its base. The unit consists of a structural frame attached with supporting mechanical linkage joints, guides, actuators, control valves, limiting devices, and sensors. The design and dimensions of the mechanical unit varies depending on the use case as well as the requirements needed. An example of a mechanical unit can be seen in Figure 15 below.

- **Tooling:**

  Tooling is used by the robot to perform tasks required. Depending on the use case, a robot has only one function. This function may be integrated to the robot's mechanical unit or then the tool is attached to the robot's wrist-end effector interface ("hand"). Alternatively, the robot may be programmed to use different tools that may be changed manually or then automatically during the work cycle. Tooling equipment are usually attached to the wrist-tooling interface that are in the end of the robot, these are also called end effectors, tool changers, and grippers.

- **Sensors:**
  Sensors are used to collect information about the various internal state of the robot or to help the robot communicate to the outside world. Similar to humans, the control system needs to know where each part of robot is situated to be able to accurately know the configuration of the robot. The robot's sensors are integrated into the various parts and sends information about each part. Examples of sensors that are external mounted to aid the robot communicate to the outside environment: vision system, touch and tactile sensors, speech synthesizers.

(A. K. Gupta, 2017, p. 403-405)

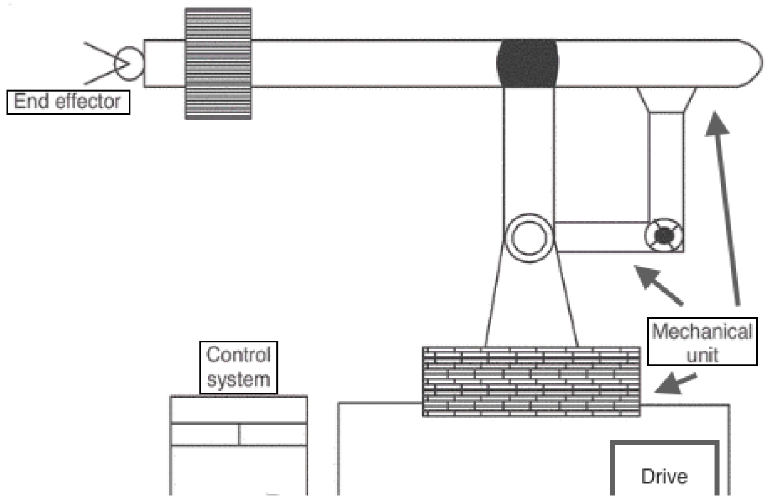

Figure 15. 4 main components that make an Industrial robot (A. K. Gupta, 2017, adapted)

4.7.3 Conveyors

Conveyors are a type of material handling equipment primarily used in handling bulk items and also for conveying items that fit in the conveyor system, in big batches continuously. The items using the conveyor travels uni-directionally from point A to B over a fixed route. The primary function of conveying is that the material is moving, the equipment as a whole does not move. (Ray, 2008, p. 30)

There are several common types of conveyors, the list below contains a short explanation of the types of conveyors as well as different characteristics or any special features. The authors acknowledge that there are a multitude of different conveyor types but choose to focus only on types relevant for the study case covered by the research.

Belt conveyors

Belt conveyors, as the name says, is made of a flat, flexible, piece of belt. That piece of belt can be made from different types of materials, for example fabric, plastic, rubber, leather, or metal. It must also be made of sufficient strength to be able to transport different materials for each use case. (Ray, 2008, p. 57)

- **Characteristics**
  - Belt conveyors operate on a vertical plane, horizontally or with a tilt upwards or downwards. The tilt based on the frictional properties of the conveyed load.
  - For changes in direction, more than one belt conveyor is required.
  - The capacity of the conveyor can be controlled by adjusting the speed of the belt.
  - Belt conveyors are generally used for the continuous flow of materials with some special belt conveyors that can carry hot, abrasive, and reactive materials.

(Ray, 2008, p. 57)

- **Types**
  - **Flat Belt Conveyor**
    For this conveyor type the "active side"(the side of the belt that carries the load) is flat and is supported by rollers or a flat slider. This type of conveyor is typically short (distance) and is suitable for conveying unit loads like crates, packages, boxes etc.
  - **Troughed Belt Conveyor**

This conveyor type has the carrying rollers setup in a way that makes the active side of the belt, shaped into a trough (V shaped to give a better understanding). This type of conveyor is good for carrying bulk material, due to the shape, that otherwise would fall in a flat belt configuration.

- **Closed Belt Conveyor**

  Closed belt conveyor type is for a special type of material that needs some sort of cover/tube around the load. Examples of this use are for fine bulk materials that need protection from air to avoid being swept away, moving reactive or corrosive material and preventing them from contaminating the work area.

- **Metallic Belt Conveyor**

  This type of conveyor is essentially a flat belt conveyor. Instead of using a flexible belt, the conveyor system uses cold rolled carbon or stainless-steel belt. The belts are lap joint riveted and run on rollers, same as the conventional flat belt conveyor. These types of conveyors can also be made from wire-mesh or rolled strip steel-belts. Metallic strip belts are used in the food industry as well as the chemical industry, while wire mesh belts are used to handle items like bread through an oven.

- **Portable Conveyor**

  These conveyors are short in length and on a wheeled structure. These features make it portable and are useful for loading and unloading transports.

- **Chain or Rope Driven Belt Conveyor**

  This conveyor uses a specially designed belt that is powered by a chain or rope. The belt is only a load carrier and the movements made by the chain or rope.

- **Submerged Belt Conveyor**

  This type of conveyor comprises of a belt that moves through a casing which is filled with powdered material at the input. The belt consists of holes which moves the material to the output end of the casing. Example can be seen in Figure 16.

(Ray, 2008, p. 57-60)

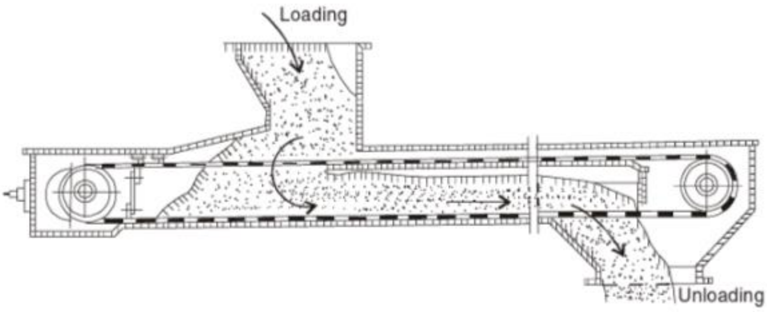

Figure 16. Submerged belt conveyor for powdered material (Ray, 2008, p. 60, adapted)

Roller conveyors

A roller conveyor type means, that the load gets moved from point A to B on top of a series of rollers. The rollers are mounted together with bearings and sit at fixed spacings on two sides, the stands being equally spaced out at certain intervals. The spacing between the rollers are determined by the load they are carrying. Whether it is ingots, pipes, logs, plates, boxes, pallets etc. (Ray, 2008, p. 101)

- **Characteristics**
    - Used for conveying unit loads with a rigid surface that moves across two or more rollers at a time.
    - Typically used in between buildings, machines. Assembly and packaging industry, and for warehousing solutions like storage racks.
    - Limited for use only with rigid flat surfaces, movements over short distances, need to have side guards so that the items on the rollers do not fall off.

(Ray, 2008, p. 101)

- **Types**
    - **Unpowered Roller Conveyor**

      As the name states, this type of roller is not powered. The rollers are simplistic in design and are competitively priced while being trouble free to operate. Unpowered roller conveyors usually work with a slight slope to help the items move. Due to the slight slope, the goods are usually moving in one direction only.
    - **Powered Roller Conveyor**

In this type of roller conveyor, either one or all rollers are connected to one or multiple motors. The loads are moved using the frictional force caused by the load and the rollers powered by the motors. These types of rollers are used mostly in heavy process plants like rolling mills that feed hot metal to various other processes in the plant. The powered rollers can be unidirectional or one way, depending on the application.

- **Portable Roller Conveyor**

  This type of conveyor is a short section of roller conveyor that is mounted with wheels or without. This makes it portable and used for the unloading or loading of trucks.

(Ray, 2008, p. 102-107)

The other conveyor types available but not covered here are mentioned below, each conveyor type consists of a sub-category that is based on the application:

- Chain conveyors
- Haulage conveyors
- Cable conveyors
- Bucket conveyors
- Screw conveyors
- Pneumatic conveyors
- Hydraulic conveyors

These types of conveyors are good for their specific use. However, the authors feel they are not applicable in this case.

5 Research Implementation

This chapter of the research focuses on primary data collection and analysis. By this point all secondary data needed for the theoretical background has been gathered.

5.1 Data collection methods used

The research is done according to the mixed research method. This means that both quantitative and qualitative data is in use. The authors used different data collection methods and sources from the commissioning company. Summary of the ways of obtaining needed information from the commissioning company is presented in Table 8.

Data	Data type	Data source
Castings parts list	Qualitative	Excel from Manager Material Flow Planning
Castings parts type (heavy/light)	Qualitative	Excel from Manager Material Flow Planning
Material planning data (DOH, packing qty, safety stock, safety time, etc)	Quantitative	Current ERP system
Production plan per transmission type	Quantitative	Excel from Manager Material Flow Planning
Transmission plant storage capacity	Quantitative	Interview with Tooling / Programming Specialist and Project Manager Machining
External warehousing costs	Quantitative	Contract with 3PL service provider (warehousing) Logistikas provided by Project Manager Supply Chain EME
		Interview with CEO Logistikas
Transportation costs	Quantitative	Contract with transportation company Järvikylä and transportation company Schenker price list provided by Project Manager Supply Chain EME
Data about castings external storing pr	Quantitative, qualitative	Interview with external warehouse supervisor
Pallet racks sizing data	Quantitative	Excel from Manager Material Flow Planning
Building cost	Quantitative	Interview with Manager Material Flow Planning
Pallet racks cost	Quantitative	Contract with 3PL service provider (warehousing) Logistikas provided by Project Manager Supply Chain EME
Labour (internal)	Quantitative	Interview with Manager Material Flow Planning
Forklifts (internal)	Quantitative	Interview with Manager Material Flow Planning
VTA+VTT Layout	Quantitative	Vistable file from Manager Material Flow Planning
Export data template for Vistable	Quantitative	Excel from Manager Material Flow Planning
CVT transmission master data	Quantitative	Interview with Tooling / Programming Specialist and Project Manager Machining
Packing Qty. Calculator	Quantitative	Excel from Warehouse Planner

Table 8. Data Collection

5.2 Casting storage solution

Castings are the base part for tractor transmissions. As discussed in Chapter 4.1, the castings production process is rather complex, and the lead time is long. Therefore, the commissioning company must keep sufficient inventory of castings. The risk of a run-out situation is reduced with the utilization of safety stock and safety order time, the concept of which has been described in Chapter 4.5. That's why castings take up so much space and are the parts to focus on when planning the layout and storage solution.

Currently, castings are stored in commissioning company's external warehouse, which is outsourced. There is a smaller storage at the factory premises, where castings are brought just before start of production. Castings are machined with production systems that have their own storage space, but castings cannot be brought directly there. Since the metal is rather sensitive to temperature changes, castings must spend some time inside the factory to warm up to room temperature before they are machined. The problem with production system internal storage is that the system picks pallets from its' own storage at a random order, so there is no guarantee that a casting will spend enough time in the storage area.

The problem with the current situation is that castings are high-runner parts – the daily demand is rather big. Therefore, transport between external warehouse and factory must be utilized a lot. This creates a lot of traffic at the factory premises and might not be the most efficient and sustainable way of storing castings. Besides, the production plan for transmissions in 2028 is bigger than the current one. Thus, the demand for castings will be bigger and the increased quantity needs to be considered in planning their warehousing.

This Chapter is focused on the options for castings storage and costs related to them. The options in question are keeping castings storage completely outsourced, investing in a new castings warehouse at factory premises, or a mixed solution (keeping castings partially outsourced).

5.2.1 Castings in stock

Quantity	**Type**	**Line**	***2028***
xxx	xxx	xxx	##
xxx	xxx	xxx	##
xxx	xxx	xxx	##
xxx	xxx	xxx	##
xxx	xxx	xxx	##
xxx	xxx	xxx	##
xxx	xxx	xxx	##
xxx	xxx	xxx	##
xxx	xxx	xxx	##

Table 9. Transmissions production plan for 2028

Table 9 shows the production plan of different types of transmissions for 2028. Different colours stand for the different kinds of transmissions. In practice, this means that these different kinds of transmissions use different number of parts. There is one more transmission type in the original production plan file, however, it is not included here, since it falls to the research limitations area.

The authors have got the list of castings used in transmissions and also information about which type of transmissions each part is used in from Manager Material Flow Planning. Besides, the authors have used the current ERP system used in commissioning company to gather information about the quantity of each part needed for a transmission, packing instructions for each part (packing type and packing quantity), minimum order quantity (MOQ), safety stock and safety time. MOQ, safety stock and safety time are used to calculate Days on hand (DOH) for each part. The data from ERP system is the current one and based on the current demand for parts, taken from the average demand for May 2023. Safety time, as discussed in Chapter 4.5, is flexible and changes with variations in demand. However, safety stock doesn't, and with the increase of demand, current safety stocks will be too low. Since appropriate DOH estimation and safety stock calculation are not part of the research, the authors calculated the new safety stock for 2028 simply proportionally to the demand changes. DOH quantity and packing quantity are then used to estimate average number of pallets that are kept in stock (further referred to as "Average no. of pallets on hand" or "APH" for shortness). Daily demand and packing quantity are used to calculate number of pallets used (processed) daily (further referred to as "Average no. of pallets processed" or "APP" for shortness). The calculations have been done in the following way:

$$Average\ daily\ demand = Transmissions\ production\ qty * No.of\ parts\ per\ transmission$$

$$Average\ no.of\ pallets\ on\ hand\ (APH) = \frac{Average\ daily\ demand * DOH}{Packing\ qty}$$

$$Average\ no.of\ pallets\ processed\ (APP) = \frac{Average\ daily\ demand}{Packing\ qty}$$

There are several places inside the factory where castings can be stored. Heavy castings are machined in production systems that have their own storage space. Besides, there are pallet racks in the production area and small warehouse next to production area, as shown in Table 10. The total storage capacity of these places is far from enough to keep all the needed quantity of castings; however, it has sufficient space to keep the needed quantity of castings that could cover couple days of demand. These places must also be considered in calculations: the quantity that could be stored inside the factory is subtracted from the average quantity of total number of pallets on hand (APH), in order to calculate quantity of pallets that requires warehousing solution.

$$No. of\ pallets\ to\ be\ stored\ \ externally/internally = APH - Factory\ storage\ capacity$$

XXX	##	Heavy
XXX	##	Heavy
XXX	##	Heavy
XXX	##	Heavy
XXX	##	Light
Other		

Table 10. Factory storage capacity (from left to right: storage; capacity (pallets); casting type)

5.2.2 Option 1: Outsourcing

The commissioning company is currently using three external warehouses, all operated by the same 3PL provider (referred to as *Warehouse provider*). The prices are regulated within the contract between the companies. Prices associated with outsourcing are covering inbound and outbound logistics processes, storaging itself, labour and equipment costs. However, according to the agreement for the particular warehouse used for castings, transaction costs (for inbound and outbound processes) are not charged. Warehousing has several options: inside heated storage, unheated but covered storage, and outside storage – but as castings are sensitive to temperature and susceptible to rust, the only appropriate way is storing the parts inside in the heated storage. Besides, there is extra cost for work on Saturdays and Sundays or national holidays. Equipment costs are related to the monthly costs for information system and devices and rent. Besides, forklifts leasing and maintenance implies own costs, but forklifts are provided not by the Logistikas in the case of the warehouse in question.

Another area of costs that occurs while utilizing external warehouse is transportation. Castings need to be brought to the factory regularly to fulfil the demand, but the quantity shouldn't be too big in order to not overwhelm the internal storage area. Since castings are a rather high-running material, they are brought in often (several times per day), following the Kanban cycle that is set up in ERP system. Thus, the commissioning company made a contract for a shuttle service with one transportation company (referred to as *Transportation company 1*) between the external warehouse where castings are stored and the factory. The shuttle service has a day-based fee (with a fuel surcharge) and is expected to make up to 5 trips per day. Besides, there is another transportation company (referred to as *Transportation company 2*) with trucks of bigger capacity that conducts transfers between all the external warehouses and the factory. Even though there is a shuttle service for castings, there is also one larger shipment conducted by Transportation company 2 on a daily basis. Transportation company 2 price is based on the total weight of a shipment. This can be summarized in the following way:

$$\begin{aligned} Warehousing\ costs\ (external) \\ &= Inside\ storage + Labour + Weekend\ extra(if\ needed) + Rent \\ &+ Equipment + Transportation \end{aligned}$$

$$Transportation\ costs = Shuttle\ (+fuel\ surcharge) + Daily\ shipment$$

$$External\ warehousing\ costs = Warehousing\ costs + Transportation\ costs$$

There are two major problems in completely outsourcing the storage of castings to the external warehouse. One is already present, and it is related to the high traffic at the factory's goods receiving area due to high daily demand of castings. Since the demand is expected to grow significantly, the traffic could become a real challenge. Another problem is the capacity of external warehouse. The authors have communicated with the external warehouse Supervisor and they informed the authors that the warehouse is already full and increased quantity will not fit. Therefore, in case of complete outsourcing of castings storage, additional solution needs to be found either from 3PL provider (Warehouse provider), transport companies or material planning side.

5.2.3 Option 2: New warehouse at own premises

Another option for storing castings would be to keep them internally. However, it should be determined whether additional storage space is available. Thus, investment needs to be made for building a brand-new warehouse at the company premises owned by the commissioning company. This solution is more expensive in a short-term perspective; however, it is cost-efficient in the long-term perspective. The reason is that annual costs for warehousing at company's own premises are lower, but a rather high investment is required in the beginning.

For estimating the total costs of this option two things need to be calculated: initial investment and annual costs. Annual costs are the ones related to labour, equipment and other costs like cleaning, heating, etc. However, after discussion with the Manager Material Flow Planning, it was decided that these other costs related to premises servicing may vary a lot depending on the overall situation and should not be considered in general calculations.

The required investment is directly related to the size of warehouse needed. It depends on the average number of casting pallet's on hand (this is estimated as discussed in Chapter 0). Besides, the pallet racks can be either bought or rented and both options are mentioned in the contract with 3PL provider (Warehouse provider) that operates the company's external warehouses. In case of purchasing pallet racks, this cost is added in order to calculate the total investment required, while costs of renting pallet racks add up to annual costs. To summarize:

$$Investment = Warehouse\ building + Pallet\ racks(if\ bought)$$

$$Annual\ costs\ (internal) = Labour + Equipment + Pallet\ racks(if\ rented)$$

$$Internal\ warehousing\ expenditures = Investment(one\ time) + Annual\ costs$$

This option is less expensive in a long-term perspective and can eliminate the problem with high traffic at the factory goods receiving area. However, it requires major investment and would have limitations for demand fluctuations in the further future (after 2028), as much higher demand can result in the average quantity of pallets stored exceeding warehouse capacity significantly.

5.2.4 Option 3: Mixed

A compromising option that could moderate the challenges of Options 1 (Chapter 5.2.2) and 2 (Chapter 5.2.3) would be a mixed solution meaning partial outsourcing of the castings parts warehousing. The quantity stored in the external warehouse could be in the range of the warehouse capacity. Commissioning company's own warehouse could still be built, but in smaller scale, reducing the required investment and improving traffic situation at the goods receiving area. Besides, in case of a demand increase, that is bigger than expected, extra pallets could be stored in the external warehouse.

The calculations for this solution would be combining calculations for Options 1 and 2. First, the desired pallet quantity stored in external warehouse must be decided. Then the calculations like in Option 1 are conducted for the quantity that is planned for external warehousing. The quantity is subtracted from the average number of pallets on hand and then the calculations similar to Option 2 are conducted. In the end, the costs are summed up to define total costs of such solution. The following formulas are a summary of the paragraph:

$$\begin{aligned} No.\,of\ pallets\ stored\ internally\ (mixed) \\ &= APH - factory\ storage\ capacity \\ &- no.\,of\ pallets\ desired\ for\ external\ warehousing \end{aligned}$$

$$\begin{aligned} Mixed\ option\ costs \\ &= External\ warehousing\ costs(partial) \\ &+ Internal\ warehousing\ costs(partial) \end{aligned}$$

The goal for this part of research implementation is to make a tool for calculating expenditures scenario (in terms of money spent) for all three warehousing options. This allows decision-makers to compare the options considering the available budget. According to the targets set by the commissioning company the research covers only the actual money flow and not the overall capital, therefore, things like depreciation are not taken into consideration in the calculations.

5.2.5 Calculations and Excel tool

There are three main options for warehousing solution for castings. Each one of them has benefits and challenges and implies certain costs of different amount and type. This makes the decision complicated, and all the features should be considered by the responsible people in the commissioning company's side. Besides, the results of the calculations are based on many variables that might change. If, for example, production plan changes, results of current calculations would not be valid anymore. Moreover, the mixed version is very flexible and is best analyzed when changing the input variables and comparing the results. Therefore, the authors decided that the best way to proceed is to make a calculation tool that provides the results of calculations with different parameters given. For the tool the authors have chosen MS Excel. Such tool would not only allow adjustments for variables, but also to check different options for mixed solution in terms of quantities stored externally and internally.

The tool consists of several sheets. The first one is "Introduction" which contains the basic information about other sheets' and marked cells' roles. Next sheet is "Input-Output". The authors have decided that it would be better to have input and output data in the same sheet as it would be clearer than how output changes with the change of input data. Input information consists of production plan for transmissions (Table 9), factory storage capacity (Table 10), and data for the three Options (see Table 11). The highlighted cells are the ones that need to be filled in by the user. The authors have gathered the data and inserted it as an example for calculations, however, it can be adjusted by the user. Further explanation of the calculations and data gathering is provided in the following sections of the chapter.

External warehousing and transportation			
	No. of work Saturdays planned	0	days
	No. of work Sundays/national holidays planned	0	days
	Castings share from total volume	##	(%)
	Current fuel price (average in previous three months)	1,89	€/l
	Average casting pallet weight (for Transportation company 2 shipments)	##	kg/pallet
Mixed solution			
	Desired no. of pallets for external storaging	##	pallets
	Are pallet racks bought or rented?	Rented	
Internal warehousing solution			
	Storage utilization rate	##	(%)
	Building cost	##	€/m^2
	Warehouse worker salary	##	€/year
	Forklift leasing and maintenance cost (average)	##	€/year
	Are pallet racks bought or rented?	Bought	

Table 11. Options data input area

Output consists of calculation results for all three options (Table 12). They include annual costs implied by the Options 1 and 3 and the investment (including also space requirements) for Options 2 and 3.

OUTPUT					
	Only external warehousing				
	External warehousing costs (including transportation)	**Warehousing + transportation costs**	**##**	**/year**	
	Only internal warehousing				
	Extra space building	**Space requirements**	**##**	**m^2**	
		Investment	**##**		
		Annual costs	**##**	**/year**	not including service costs (heating, cleaning, etc.)
	Mixed warehousing				
	External warehousing costs (including transportation)	**Warehousing + transportation costs**	**##**	**/year**	
	Extra space building	**Space requirements**	**##**	**m^2**	
		Investment	**##**		
		Annual costs	**##**	**/year**	not including service costs (heating, cleaning, etc.)

Table 12. Output area

The following sheets are “External” and “Investment + internal”. They contain all the calculations related to outsourcing the castings warehousing and building the company’s own storage correspondingly. Besides, they contain calculations for both parts of the mixed solution.

Finally, there are sheets with titles marked in brackets. They have supporting role for the calculations and contain information from 3PL contracts, information about the parts that was gathered from ERP system and preliminary calculations, e.g. the ones described in Chapter 0. Besides, there is sheet “(Order of outsourcing)”, the main idea of which is that it establishes the correlation between the number of pallets outsourced in mixed option and the number of pallets processed daily, which is then used for calculating transportation costs in the mixed option. It contains data about parts, including individual information about average number of pallets processed and average number of pallets on hand. The list is sorted by the average number of pallets processed daily from smallest to largest to define parts with lower daily demand in pallet-quantity. Outsourcing of the parts should go from the top to the bottom of the list to reduce transportation of pallets between the external warehouse and the factory. Cumulative numbers of pallets processed daily and pallets on hand are calculated, so that the correlation between the values can be observed.

First, the transmission production plan is inserted in the corresponding field in the Input area. For the example of calculations, the authors have used data for the year 2028, since currently these numbers are at the peak of the known demand. The field is shown in

Table 9. Next, the data is summarized in the sheet “(Castings parts info)” by the type of the transmissions. The data is represented as the number of transmissions of each type produced annually and daily (Table 13). In order to calculate the daily production quantity, annual production quantity is divided by the number of workdays in the year in question (there are 252 workdays in 2028), which is one of the multipliers inserted in the Input area. Additional row is added to the daily quantities calculations. The reason is that there are two similar types of transmissions. They use the same parts, but one of the transmissions uses additional parts. The parts are then used either

in both types or in one of them only. Additional row in the daily transmissions quantity calculation is a sum of daily quantity of these two transmission types transmission types.

Line/a	2028
XX	##
XX	##
XX	##
XX	##
XX	##

Line/d	2028
XX	##
XX	##
XX	##
XX	##
XX	##
XX	##

Table 13. Annual production quantity per transmission type

In the same sheet there is a list of castings parts used and the data gathered from ERP system is there as well. In order to calculate daily demand for each part, number of parts per transmission is multiplied by the number of daily production quantity for the corresponding transmission type. Current DOH values have been estimated based on data from ERP system and the authors assumed that DOH stays the same. The average number of pallets on hand is calculated by multiplying average daily demand by DOH value to get the quantity in pieces, and to get pallet quantity the value is divided by packing quantity. The number of pallets processed daily (APP) is average daily demand expressed in number of pallets. The values for each part are summed up and this makes total average number of pallets on hand (production plan results in ## pallets in 2028) and total average number of pallets processed daily (## pallets in 2028). This is the basic data used in further calculations. The following formulas is a summary of the paragraph:

$$Average\ daily\ demand = Transmissions\ production\ qty * No.of\ parts\ per\ transmission$$

$$Average\ no.of\ pallets\ on\ hand\ (APH) = \frac{Average\ daily\ demand * DOH}{Packing\ qty}$$

$$Average\ no.of\ pallets\ processed\ (APP) = \frac{Average\ daily\ demand}{Packing\ qty}$$

Costs calculations for complete outsourcing of castings warehousing

Next, the costs for the option of storing castings completely externally are estimated. The prices are based on the contract with the Warehouse provider. A summary of parts in the contract relevant for calculations can be found in sheet "(Warehouse provider contract)", also shown in Table 14.

(secret)

Table 14. Relevant parts of contract with Warehouse provider

Warehousing price is given per pallet place per week. Therefore, in order to calculate annual warehousing cost, the average number of pallets on hand is needed. The factory storage capacity is subtracted from it and the number is multiplied by the cost and number of weeks in a year – 52. With the given data, the average number of pallets on hand is ## pallets, factory storage capacity is ## pallet places, and warehousing cost for inside storage is ## €/pallet rack/week, making the total warehousing costs for a year ## €. To sum up, the calculations are:

$$Warehousing\ costs(€/year) = (APH(pallets) - factory\ storage\ capacity(pallets)) * Warehousing\ cost(€/pallet/week) * Weeks(week)$$

Next, labour costs are calculated. The authors decided to estimate number of workers needed proportionally to the current situation (in terms of demand and number of workers). According to the external warehouse Supervisor, there is capacity for ## pallets of castings and the warehouse is full. Thus, the quantity of castings pallets in 2028 will be double in comparison to the current quantity. Currently, there is ## shift(s) of ## workers and ## foreman/foremen working ## hours per day dedicated to the external warehouse. Since the quantity of pallets is double, two teams of ## workers are needed. Labour costs include monthly cost for the daily shift(s) of ## workers (## €/month), which is doubled as two teams are needed, and the foreman/foremen's hourly salary (## €/h). Monthly cost is multiplied by 12 months and the foreman/foremen's salary is multiplied by ## h/day and by the number of workdays in a given year (252 days for 2028). Since the castings make up only ##% of the warehouse, the authors assumed that ##% of labour is dedicated to castings, so ##% of the labour cost is related to castings. The result of the calculation for the year 2028 is then ## €/year and the calculations are as follows:

$$Labour\ cost(€/year) = Share\ of\ castings * (2 * Costs\ for\ \#\#\ shift(s)(€/month) * 12(month/year) + foreman/foremen\ \ salary(€/h) * \#\#(h/day) * No.of\ workdays(day/year))$$

Normally, the work is completed only on weekdays. However, due to disruptions in supply chain sometimes work over the weekend is needed. In order to consider this in the calculations, the authors have added related areas to the Excel tool. There is a place in the input area where the number of working Saturdays, Sundays or national holidays can be entered (for example, statistical data from previous years). According to external warehouse Supervisor only ## worker(s) is/are dedicated for the parts used in transmission during the weekend. Since the volume of 2028 is double, ## worker(s) will be needed. According to the contract with Warehouse provider, the additional charge for weekend work is ##% for Saturdays and ##% for Sundays and national holidays. Therefore, additional costs for weekend work is calculated by multiplying worker's/workers' hourly salary (## €/h) by ## h (one workday) and by ##% for each Saturday and ##% for each Sunday or national holiday. However, since the authors are assuming the situation in a perfect world scenario, the authors decided to use 0 days of work over a weekend or national holiday in the example calculations.

$$Weekend\ extra\ (€/year) = 2 * Worker(s)salary\ (€/h) * \#\#\ h/day * (\#\#\% * No.of\ Saturdays + \#\#\% * No.of\ \ Sundays/holidays)$$

Another matter relating to costs from the external warehouse is rent and equipment costs. The commissioning company is obliged to pay rent of ## €/month. There is also a fixed cost for information systems and devices which accounts for ## €/month. These monthly costs are multiplied by 12 months to calculate annual costs. Overall annual costs for the rent and equipment provided by Warehouse provider is then ## €.

Forklifts are another cost source (costs come from maintenance and leasing). According to Supply Chain Management annual costs for forklifts that are used in the external warehouse are ## €. Since the number of pallets is doubled in 2028, forklifts usage is estimated to double as well. Similarly to labour, only ##% of forklifts utilization is devoted to castings, which is also considered in calculations. Therefore, calculations are as follows:

$$Forklift\ costs\ (2028) = \#\#\% * 2 * \#\#\ €/year = \#\#\ €/year$$

When castings are stored externally, they need to be transported to the factory premises. This is one more area of costs that must be considered in the calculations. There are two types of transport between the external warehouse and the factory: Transportation company 1 shuttle and Transportation company 2 shipment. According to the information provided by the supervisor of external warehouse, on average ## pallets fit to the shuttle shipment and ## pallets fit to the Transportation company 2 shipment. One daily Transportation company 2 shipment is considered as basic transportation mode and shuttle shipments are considered to have more of a supporting role. According to the contract, there can be only up to ## shuttle shipments, so this is checked in the following way (using Excel function ROUNDUP, which rounds the number up leaving given number of decimal digits). In this case the roundup function in Excel rounds the result of the calculation up leaving 0 decimal digits, since the shipments can be counted only in integers.

$$No. of\ shuttle\ shipments = Roundup(\frac{APP - \#\#\ pallets/shipment * No. of\ Transportation\ company\ 2\ shipment}{\#\#\ pallets/shipment}; 0)$$

As calculated earlier, there are ## pallets processed daily (daily demand for castings is ## pallets), which means that ## pallets with castings need to be transported from the external warehouse to the factory every day on average. If there is only one Transportation company 2 shipment then number of shuttle shipments needed is:

$$No.of\ shuttle\ shipments = \frac{\#\#\ pallets - \#\#\ pallets/Transportation\ company\ 2\ shipment * 1\ shipment}{\#\#\ \ pallets/shuttle\ shipments} = \#\#$$

Therefore, there are ## shuttle shipment needed daily. However, according to the contract with Transportation company 1, shuttle can make only up to ## shipments. Therefore, when the number of shuttle shipments is greater than ##, warning message appears in Excel next to the calculations (as shown in **Error! Reference source not found.**) and similar one in the output area. This is achieved with the use of IF function. The number of Transportation company 2 shipments needs to be increased manually in the highlighted cell (which is also mentioned in the warning message in the output area) and the transportation costs are adjusted automatically.

(secret)

Table 15. Warning message for transportation in Excel

Transportation company 1 shuttle service has a fixed daily fee with the fuel surcharge. Fuel surcharge is based on the difference of the fuel price compared to the one valid at the time of signing the agreement. The base fuel price is ## €/L, the current fuel price (calculated as average fuel price for the previous three months) is entered in the Input area. The difference is then calculated and the change in price is expressed as a percentage from the base fuel price. Fuel takes up ##% from the tariff price, so the fuel price change percentage is multiplied by ##% to get the change in tariff price. The Table 16 shows calculations of the tariff change when the current fuel price is 1,890 €/L (in this case the tariff is increased by ##%). Columns from left to right: title, value, unit, formulas behind values (not included to the original Excel table, only used in the report for calculations explanation).

Fuel surcharge	base fuel price	##	€/l	K14
	new fuel price	1,89	€/l	K15
	fuel price difference	##	€/l	=K15-K14
	fuel price change	##	(%)	=K16/K14
	share from tariff (excl. taxes)	##	(%)	K18
	tariff change	##	(%)	=K17*K18

Table 16. Transportation company 1 fuel surcharge calculation (cell with value 1,89 is K15)

$$Shuttle\ price(€/day) = Base\ tariff(€/day) * (1 + fuel\ surcharge(\%))$$

Transportation company 2 prices are based on the weight of the shipment. The price list (for the route *external warehouse – factory*) consists of weight ranges and corresponding prices and is in the sheet “(Transportation company 2 prices)”. The authors have received information from external warehouse supervisor that the average pallet weight in Transportation company 2 shipment is ## kg. However, this value is inserted in the Input area and can be changed if needed. The total average shipment weight is calculated by multiplying the average pallet weight by the number of pallets (## pallets per Transportation company 2 shipment). For automatic calculation, the total shipment weight is rounded up to the higher limit of the range using CEILING function. Next, the price corresponding to the higher weight limit of the weight range is looked up from the price list with the use of Excel function VLOOKUP. When the average pallet weight is ## kg, total shipment weight is ## kg and the price is ## €.

Shuttle price and price of Transportation company 2 shipment are summed up to get total daily transportation cost. It is then multiplied by the number of workdays in a given year (252 days for 2028) to calculate the annual transportation cost. With the given data, daily price of the shuttle is ## €, Transportation company 2 shipment price is ## €, which equals to a total annual transportation cost of ## €. This is expressed in the following formula:

$$Transportation\ costs(€/year) = \left(Shuttle\ costs(€/day) + Shipment\ price(€/day)\right) * Workdays(day/year)$$

Each type of costs is calculated and summed up to calculate the total annual costs for the option of complete outsourcing of the castings warehousing. With the given data the total cost is ##

€/year. Table 17 shows the summary of the costs. However, in reality cost will probably be somewhat smaller, as the real situation will not be as smooth as the theoretical one. Disruptions in supply chain may lead to a smaller number of castings in stock (resulting in smaller inbound, outbound and warehousing costs), express delivery of castings straight to the factory (resulting in smaller need for transportation between external warehouse and the factory), and so on.

Inbound costs	##	€/year
Warehousing costs	##	€/year
Outbound costs	##	€/year
Labour costs (increased volume)	##	€/year
Weekend/holiday extra	##	€/year
Equipment costs (incl. rent)	##	€/year
Transportation costs	##	€/year
Total	**##**	**€/year**

Table 17. Total annual costs for completely outsourced warehousing of castings

Costs calculations for complete internal warehousing of castings

The second option is building a new warehouse and using it for storing castings. This means that the costs come from investment in the beginning and from warehouse usage (labour, equipment, etc).

Warehouse building cost is in direct ratio to storage capacity (the more pallet places are needed, the more space it takes, the bigger building costs are). Therefore, an average number of pallets on hand (APH) is useful data for the calculations, it is calculated for each type of castings (heavy or light) separately, using function SUMIF. As mentioned earlier, there are pallet racks inside the factory and production systems have their own storage space, so part of the castings pallets can be stored there. The space available is calculated for each casting type and subtracted from average number of pallets on hand also considering casting type. The casting type must be considered because heavy castings must be stored at the lower levels due to safety reasons. Even though the total space and cash requirement is summed up in the end, the separate calculation provides a better overview of warehouse contents. According to Manager Material Flow Planning, pallet racks in internal storage consist of shelf units, which fit ## pallets in a row and have ## levels, thus, each shelf unit fits ## pallets. Number of shelf units is calculated by dividing number of pallet places needed by ## pallets/shelf unit. Warehouse utilization rate is also considered at this step (according to Manager Material Flow Planning, it is ##%, but it can also be adjusted in the input area). Manager Material Flow Planning provided the data from their previous calculations that each shelf unit requires ## m^2 (shelf unit itself and aisles), so the total space requirement is calculated by multiplying the number of shelf units needed by ## m^2. Manager Material Flow Planning also informed the authors that building cost is ## €/m^2, so this value is multiplied by space requirement for estimation of the investment needed to build the warehouse. With the given data the total building price is ## €. **Error! Reference source not found.** shows the information from Manager Material Flow Planning's prior calculations that was utilized for the research. The calculations are shown in the

Casting type	Pallets	Available space	Overflow	Overflow Shelf units	**Additional space needed (m^2)**	**Investment**
Heavy	##	##	##	##	##	##
Light	##	##	##	##	##	##
Total	##	##	##	##	**##**	**##**

Table 19 and summarized in the formulas below:

$$Pallet\ spaces\ needed\ (pallets) = APH(pallets) - Space\ available(pallets)$$

$$Shelf\ units\ needed(shelf\ units) = Palet\ spaces\ needed(pallets)/\#\#(pallets/shelf\ units)$$

$$Space\ requirement(m^2) = \frac{Shelf\ units\ needed\ (shelf\ units)}{Utilization\ rate} * \#\#(m^2/shelf\ unit)$$

$$Investment\ for\ building\ (€) = Space\ requirement\ (m^2) * Building\ cost\ (€/m^2)$$

Pallets/shelf unit	##	
Utilization rate	##	(%)
Area	##	m^2/shelf unit
Cost	###	€/m^2

Table 18. Data provided by Manager Material Flow Planning

Casting type	Pallets	Available space	Overflow	Overflow Shelf units	**Additional space needed (m^2)**	**Investment**
Heavy	##	##	##	##	##	##
Light	##	##	##	##	##	##
Total	##	##	##	##	**##**	**##**

Table 19. Building investment

Another decision to be made is whether to buy pallet racks or rent them. In case the pallet racks are bought, the price is added to the building price to calculate total investment for a new warehouse. Renting pallet racks implies additional annual costs. This choice for calculation purposes is available in the Input area. A possibility to buy or rent pallet racks for the company's own facility is included to the contract with Warehouse provider, so their prices are used for calculations. Price for pallet racks that fit ## pallets is ## € (when bought) or ## €/month (when rented). However, a different number of pallet places might be needed, so the price is calculated proportionally. Depending on the value of the corresponding cell in the Input area ("Bought"/"Rented"), the proportional price is either added to the total investment or proportional rent is added to the annual costs. With the given data, buying pallet racks implies additional price of ## € to the investment, while renting them costs ## € annually.

Next, annual costs are calculated. Majority of the costs come from labour. According to Manager Material Flow Planning number of workers needed is based on the number of pallet-movements: 1 person per ## pallet-movements/day. In terms of warehousing, when a pallet is received it needs to be put away, which is one pallet movement, and then picked and brought to the production area, which is another pallet-movement. Therefore, number of pallet-movements is same as number of pallets that go through inbound or outbound in the external warehouse. With the given data, ## pallets are processed daily on average (for each inbound and outbound), so in total there are on average ## pallet-movements daily. This means that ## warehouse workers are needed. According to Manager Material Flow Planning, the average salary of warehouse worker is ## €/year. Therefore, annual labour costs are ## € in this case. Manager Material Flow Planning also provided information that ## shift(s) is/are needed, so number of forklifts is ## less than number of workers needed and on average, the leasing and maintenance costs are ## €/year/forklift. This makes annual costs related to forklifts ## €. Table 20 shows annual costs when pallet racks are bought and Table 21 shows annual costs when pallet racks are rented.

Staff	##	people
Salary	##	€/year
no. of forklifts	##	
Leasing and maintenance cost	##	€/year/forklift
Shelf unit cost	##	€/month
Labour costs	##	€/year
Equipment costs	##1	€/year
Total	**##**	**€/year**

Table 20. Internal warehousing annual costs if pallet racks are bought

Staff	##	people
Salary	##	€/year
no. of forklifts	##	
Leasing and maintenance cost	##	€/year/forklift
Shelf unit cost	##	€/month
Labour costs	##	€/year
Equipment costs	##2	€/year
Total	**##**	**€/year**

Table 21. Internal warehousing annual costs if pallet racks are rented

Costs calculations for mixed option

Mixed option is a combination of the other two options. In practice, this means that castings warehousing is partially outsourced. The excel calculation tool is made in such a way that number of castings pallets storage (of which the decision maker would like to outsource) is entered in the input area. Calculations of warehousing costs are the same as for the option of complete outsourcing, but for the different number of pallets (entered in the Input area). The castings share of following costs is calculated proportionally to the current situation. Currently, there are ## pallet places planned for storing castings, castings account for ##% of total warehouse capacity, and there is/are ## shift(s) oh ## worker(s) and foreman/foremen devoted to the external warehouse.

Number of workers is estimated to be the same as currently when number of castings pallets does not exceed current volume (## pallets) and calculated proportionally if the volume exceeds current one. Then the number is divided by ## to calculate number of teams of ## workers required (due to the billing conditions: there is a separate price for ## shift(s) of ## workers in the contract with Warehouse provider). The number of extra workers needed is calculated by subtracting the number of people in team(s) from the total number of workers needed. Labour costs are then calculated by summing up costs for the number of teams needed (monthly costs), number of extra workers needed (hourly salary) and foreman/foremen (hourly salary). The share of the labour devoted to castings is estimated proportionally to the current situation when the number of casting pallets stored externally is not bigger than the current one and is expected to stay the same (##%) when number of castings pallets is bigger than the current volume stored externally. Extra charge for work during weekends/holidays is calculated in the same way as for the complete outsourcing option, assuming that when the number of pallets stored externally is within the current quantity, ## worker(s) is/are needed to cover transmission plant demand, and when the value is bigger than the current one, ## worker(s) is/are required. Information system and devices and rent costs stay the same, and forklift costs are calculated proportionally to the current situation. Transportation costs are calculated in a way similar to calculations for complete outsourcing option with the difference that volume can be so small that it doesn't fill the Transportation company 2 shipment fully. Number of pallets processed daily is roughly estimated according to the "(Order of outsourcing)" sheet where correlation between number of pallets outsourced and number of pallets processed daily is established. Number of pallets transported in Transportation company 2 shipment is calculated by subtracting the number of pallets transported by the shuttle from the average number of pallets processed daily. Otherwise, transportation costs are calculated in the same way as for the first option. Costs are then summed up for the total annual costs calculation.

The entered number of pallets is then subtracted from the total average number of pallets on hand and calculations same as for complete internal warehousing are conducted (the same calculations as for the complete internal warehousing option are conducted). One adjustment is that in the calculation of investment for internal warehousing the number of pallets stored externally is expressed in the table as additional available space. Another adjustment is that for calculation of the daily pallet movements the value for mixed option is subtracted from the total number of pallet movements, which is included to the staff calculation.

5.3 Material flow analysis

Hidden in public version.

6 Results and discussion

There is always room for improvement in logistics. However, the research is limited in time and resources. Therefore, it has covered the given problem in the overall outlook, but smaller parts of the issue can still be researched in more details.

The first research question covers the warehousing issue for castings. Currently castings are stored in the external warehouse and that creates problems related to transportation and warehouse capacity (in case of demand increase). At the same time building a new warehouse requires a very big investment, which implies significant responsibility in making the decision creating the need for the research. The result of the research for the first research question is the calculation tool created in Excel which makes costs calculations using inserted variables for all three warehousing options: complete external warehousing, complete internal warehousing, and a mixed option (partial outsourcing of castings warehousing). The tool allows the comparison of costs for all three options in the same production scenario and to compare the costs of each options in different production scenarios (by adjusting the inserted variables).

The calculation tool for the warehousing options is made using some rounding, which increases threshold for errors. This is done to allow a better coverage of costs, as exact calculations would require more time and resources than what was available for the research. Besides, as mentioned previously, the calculations are done for the perfect world scenario (the way it should be), however, there are many disruptions in supply chain that leads to changes in costs. To take this into account, statistics could be included for comparison and calculations with the use of weighted values. Another area that has research potential are factors affecting costs, including the input and calculations related to them. Moreover, material planning of castings could be researched more thoroughly considering areas like DOH estimation and safety stock quantity adjustment. Another thing that could be researched is the costs from the capital perspective, and not only the cash flow. This would include consideration of capital costs, e.g. depreciation.

The second research questions results are hidden in the public version.

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Appendices

Appendix 1. Costs calculation tool

Sheet: Introduction

Insert data

Insert data

Go to *Input-Output* sheet
Insert data to cells marked with light orange colour or
Correct data which is in *italic* for the correct outlook
Cells with (title) are supporting the calculations and should be modified only when necessary

Sheets with details of calculations:
External - calculation of costs related to 3PL providers (for complete outsourcing option and mixed option).
Investment + internal sheet - calculation of extra space needed with given input and cost of building it (for complete internal warehousing option and mixed option)

Sheet: Input-Output

(secret)

Sheet: External

(secret)

Sheet: Investment+Internal

(secret)

Sheet: (Transportation company 2 prices)

(secret)

Sheet: (Warehouse provider contract)

(secret)

Sheet: (Castings parts info)

(secret)

Sheet: (Order of outsourcing)

(secret)

Appendix 2. Title of the Appendix

Index