Linking warehouse with production

Determining where and how to design a pull system at Tetra Pak

Authors:
Alexander Hantelis
Gustav Östlund

LUNDS UNIVERSITET

Supervisor at Tetra Pak: Toni Eklund

Supervisor at LTH: Joakim Kembro

Examiner at LTH: Jan Olhager

Master Thesis in Mechanical Engineering

Division of Engineering Logistics, Department of Industrial Management and Logistics
Faculty of Engineering, LTH, Lund University, PO Box 118, SE-221 00 LUND, Sweden
Lund 2022

ACKNOWLEDGEMENTS

This thesis was conducted by two authors during the spring of 2022 as a last project of the master program within Logistics and Supply Chain Management at the Faculty of Engineering at Lund University. The thesis was conducted as a design science study of linking the material flow between a warehouse and a production site at Tetra Pak in Lund.

We would like to acknowledge our supervisor Joakim Kembro from the Division of Engineering Logistics. Throughout our thesis you have been providing us with continuous helpful guidance and feedback on our work. Further, we are very thankful towards Jennifer Andersson that have been acting as our opponent during the entire thesis process.

We also want to express our thanks to Johan Karlström at Tetra Pak, who initiated this project and made it possible. Further, we want to express our gratitude to our supervisor at Tetra Pak, Toni Eklund. Thank you for helping us with providing lots of information and data to help us throughout the entire process. Our weekly meetings have been much appreciated. Finally, we would like to thank all the employees at Tetra Pak that have helped us out by providing data and useful insights.

Alexander Hantelis

Gustav Östlund

Lund, May 2022

ABSTRACT

Title Linking warehouse with production – Determining where and how to design a pull system at Tetra Pak

Authors Alexander Hantelis, Gustav Östlund

Supervisor Joakim Kembro, Department of Industrial Management and Logistics, Faculty of Engineering, Lund University

Problem description Tetra Pak is currently using a push system for most movements of material between their component warehouse, the yard and the PPCL production site and are interested in how a potential implementation of a pull system could affect the efficiency of the material flow.

Purpose The purpose of this master thesis is *to create decision– and design propositions for determining when it is appropriate to utilize a pull system and how a pull system can be designed at Tetra Pak PPCL.*

Research objectives
RO1: *Describe the current state of the material flow between warehouse 111, the yard, and the PPCL production.*
RO2: *Identify how the current material flow between warehouse 111, the yard, and the PPCL production is performing.*
RO3: *Determine which parts of the material flow between warehouse 111, the yard, and the PPCL production that are suitable for a pull system.*
RO4: *Define, at determined suitable parts, how the material flow between warehouse 111, the yard, and the PPCL production can be set-up as a pull system.*

Methodology The methodology to accomplish the purpose have been a design research process in six steps. The six steps have been (1) identifying the problem, (2) framing it, (3) creating an analytical framework to solve it, (4) theorizing the findings from the second and the third step, (5) apply the analytical framework, and (6) communicate the solution. Steps 2, 3, 4, and 5 was done as an iterative process.

Conclusion/Findings The thesis resulted in decision propositions for determining when it is appropriate to utilize a pull system and design propositions for how to design a pull system. These propositions were used to develop recommendations for Tetra Pak PPCL. To develop the propositions an analytical framework was created. This framework was a useful tool for accomplishing the purpose and can be used in other similar situations.

Keywords Material flow, Information flow, Warehousing, Production, Lean, Design science research

DEFINITIONS

Contextual factor	Contextual factors are things that cannot be changed, but instead factors to adjust according to when fulfilling the purpose of the thesis.
Design proposition	A design proposition is a conclusion that has been drawn regarding design guidelines for a specific circumstance and situation.
Decision proposition	A decision proposition is a conclusion that has been drawn regarding decision-making for a specific circumstance and situation.

ABBREVIATIONS

BPU	Branded Processing Units
CAMO	Context Agent Mechanism Outcome
CONWIP	CONstant Work In Process
ERP	Enterprise Resource Planning
HP	Homogenizers/High pressure Pumps
HT	Tubular Heat Exchangers
MAPE	Absolute Mean Percentage Deviation Error
MES	Manufacturing Execution system
MPE	Mean Percentage Deviation Error
MRP	Material Requirement Planning
PPCL	Processing Production Centre Lund
RFID	Radio Frequency Identification
RTLS	Real Time Location System
WMS	Warehouse Management System

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1. INTRODUCTION

1.1 Background

The performance of a business is greatly influenced by the allocation of its resources in relation to its operations (Poon et al., 2011). Commonly, in a manufacturing company, two of these operations are warehousing and production, and these are linked with each other through incoming and outgoing goods (Davarzani & Norrman, 2015). Thus, having an effective interconnection between these functions is of importance (Poon et al., 2011). One thing to focus upon within the linkage between warehouses and production is the material flow from both sides (Davarzani & Norrman, 2015; Pach et al., 2006).

A material flow can be described as the movement of material, including the materials chemical transformation, manufacturing, consumption, recycling, and disposal (Bringezu & Moriguchi, 2003; Graedel, 2019; Hinz, 2006). By analyzing the material flow, it can provide a system-analytical perspective of the linkages between different processes to help with strategic design (Bringezu & Moriguchi, 2003).

Warehousing is the process of storing and retrieving goods, including the gathering and usage of required information for performing these operations (Gunasekaran, Marri & Menci, 1999; Manzini, 2012). The production process can be described as the transformation of either raw materials or components into finished products or new components (Costin, 1991). The material flow between these processes consists of retrieving goods from the warehouse to the production site and the gathering of unwanted goods from the production site to put back in the warehouse (Zhang et al., 2017).

There are generally two different fundamental principles when it comes to handling movement of material from a warehouse to a production site. These are pull systems and push systems (Hopp & Spearman, 2004). The push system is the older one of the two and is characterized by forecasting and the use of manufacturing production schedules to push materials into production. A pull system emerged from Toyota in the 80s (Spearman & Zasanis, 1992). The set-up of a pull system consists of a trigger mechanism, usually located in production. When the mechanism is triggered, it signals that material should be moved from one location to the next (e.g., from the warehouse to a production unit) (Spearman & Zasanis, 1992). This means that a pull system is a system that has an explicit limit to the work in progress due to its usage of a trigger, while a push system does not have any such constraints.

Both systems are dependent on the usage of some sort of information system for them to function (Hopp & Spearman, 2004). However, the direction of the information flow is different for the two material flow systems. The direction of the information flow for a push system goes in the same direction as the material flow and the information flow for a pull system goes in the opposite direction of the material flow (Hopp & Spearman, 2004).

It is not always obvious which principle that is the most suitable option for a material flow. Different material flow principles are appropriate in different situations (Hopp & Spearman, 2004; Krishnamurthy, Suri & Vernon, 2004). A useful tool for determining what principle for handling movement of material to use in a certain situation is principles from lean. Lean principles, such as identifying, analyzing, and removing wastes in the supply chain is an example of something that could be of use (Bhamu & Singh Sangwan, 2014; Jasti & Kodali, 2015). The identification and analysis of wastes could help with making decisions on appropriate material flow principle. Further, it is of importance to first understand the current situation before developing pull system guidelines when designing a pull system. Otherwise, the pull system guidelines might not be suitable for the specific situation (Lu, Yang & Wang, 2011).

As of today, challenges regarding warehousing and production have been solved without a holistic view (Davarzani & Norrman, 2015; Jolayemi & Olorunniwo, 2004; Manzini, 2012). Thus, most of the developed solutions have been oriented towards specific challenging areas. Meaning that there is a gap in research regarding creating solutions linking warehousing and production with a holistic view. Further, studies that are comparing when a push system or a pull system is appropriate are limited in numbers (Krishnamurthy, Suri & Vernon, 2004). Resulting in another gap within the research field that could be filled.

1.2 Case Company

Tetra Pak is a company that develops complete solutions for the operations of processing, packaging, and distributing food products (Tetra Pak, 2021a). Their vision as a company is to make food safe and accessible everywhere and they are constantly striving towards accomplishing appropriate solutions and groundbreaking innovations (Tetra Pak, 2021b). Today the company has net sales of more than 10.8 billion euros and are selling their products in more than 160 countries (Tetra Pak, 2021c). A part of the company that have links between their warehouse and production, and a material flow available for analyzing is their Processing Production Centre Lund (PPCL).

Tetra Pak PPCL is a part of the company that handles and produces three types of products. These are Homogenizers/High pressure Pumps (HP), Heat exchangers (HT) and Branded Processing Units (BPU). On the 1st of October 2020, a central planning and logistics function was established and one of its responsibilities is Tetra Pak PPCL. One of the things this function is responsible for is the flow of material between an outside storing area referred to as the yard, warehouse 111 and the PPCL production site consisting of the four connected buildings 105, 106, 107 and 108. The warehouse building and the yard are separated from the production buildings by a small road where the materials are passing through when entering the production site. Further, the production site consists of multiple unloading points to where the material from the yard and the warehouse is delivered to. A general layout of the yard, warehouse 111 and the PPCL production site can be seen in figure 1.

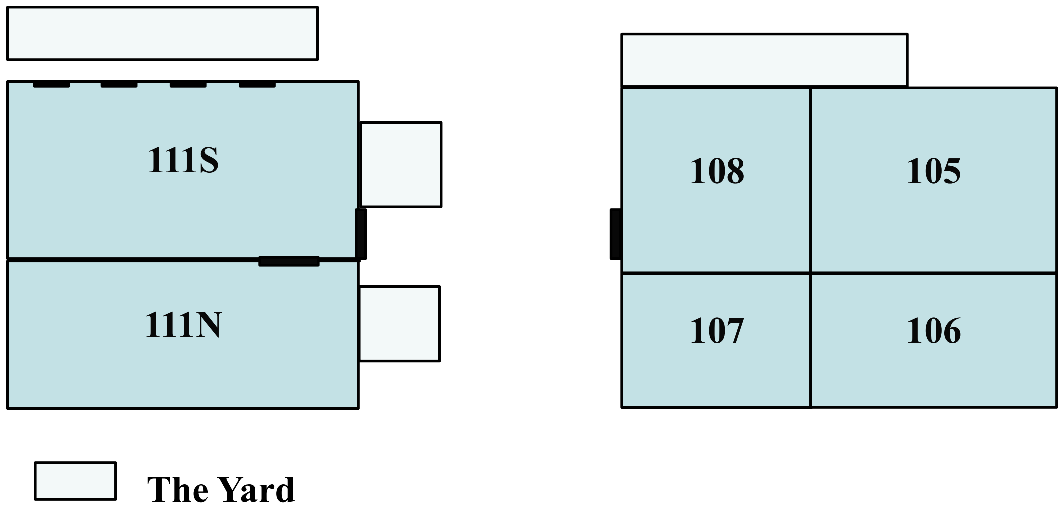


Figure 1: How the warehouse, the yard and the PPCL production are positioned to each other.

Tetra Pak PPCL's production site in Lund is currently using a push system for most movement of material from warehouse 111 and the yard. These movements of material are pushed from the warehouse and the yard to the production site according to a master production schedule that is cyclically updated. This results in that all goods in one specific cycle will be moved to the production site within that cycle, without any constraints. The other movements of materials are moved from warehouse 111 to the production site with a pull system. They are being moved with a Kanban strategy, which is a pull method (Gaury, Pierreval & Kleijnen, 2000). Kanban is a strategy where the amount of work at a process is regulated by the usage of a certain number of cards in a system that travels between processes limiting the allowed work at a process (Gaury, Pierreval & Kleijnen, 2000). Recently, Tetra Pak PPCL have investigated if they should implement tracking technologies for their material flow. Further, the newly established central planning and logistics function in Lund is currently focused on making lean improvements.

1.3 Problem formulation

Tetra Pak's site in Lund have established a central planning and logistics function. This function wishes to make certain that enough service can be provided to the PPCL production site in Lund. They want to be sure that material is picked and delivered to the production site at the time when it is needed.

Tetra Pak's PPCL organization is currently using a push system for most movements of material between warehouse 111, the yard and the PPCL production site. This is to guarantee that they can provide a satisfying service level for all their production units. However, this has resulted in inefficiencies for some production units due to excess materials in production. Thus, the case company is interested in investigating if a pull system would be able to remove some of the wastes along the material flow that the current push system is causing. They want to investigate whether some movements of material to the production units included in the material flow would be more suitable to be done with a pull strategy.

When designing a pull system between a warehouse and a production site it is of importance to understand the interaction between the functions. As of today, this interaction between warehouses and production is one of the least researched areas in literature (Davarzani & Norrman, 2015). Therefore, when analyzing the movements of material between warehouse 111, the yard and the PPCL production site it is important to take this interaction into consideration. An investigation of this interaction, when different material movement strategies are appropriate and how a pull system can be designed could be made to better understand when and how to use a pull flow. This would further assist with helping to determine when it is appropriate to utilize a pull system, and thereby help with contributing to the second research gap (Krishnamurthy, Suri & Vernon, 2004).

1.4 Purpose and research objectives

The purpose of this master thesis is *to create decision– and design propositions for determining when it is appropriate to utilize a pull system and how a pull system can be designed at Tetra Pak PPCL.*

To be able to achieve this purpose and provide Tetra Pak with recommendations based upon propositions for when to use a pull system and how it can be designed four research objectives (RO1, RO2, RO3 and RO4) have been produced. The four research objectives are as follows:

RO1: *Describe the current state of the material flow between warehouse 111, the yard, and the PPCL production.*

This objective is done to gain an understanding of how the material flow is configured. To achieve the objective data will be gathered through observations, interviews, and secondary data. Combining these three data collecting methods will help with showing how much, how often, where and when material is moved, creating a layout of the production site and the warehouse, and with describing how the processes are done. Further, it will help with understanding what contextual factors that needs to be acknowledged when creating decision- and design propositions. The objective will upon its fulfillment indicate the demand for different production lines at the production site, help with understanding the current interaction between the functions, identify what the contextual factors are, and help with understanding how the processes are configured.

RO2: *Identify how the current material flow between warehouse 111, the yard, and the PPCL production is performing.*

This objective will provide an indication of how different flows of material within the material flow between warehouse 111, the yard and the PPCL production site in Lund is currently functioning. The judgement of the performance is for this case depending on the number and severity of wastes identified in the material flow. This objective will help with understanding the requirements a potential pull flow must fulfill as well as what flows of material within the material flow that could be of interest to analyze further. Also, it will give an indication of what the current issues within the material flow are. To accomplish this objective the data gathering methods of interviews, observations and secondary data will be of use as well as literature.

RO3: *Determine which parts of the material flow between warehouse 111, the yard, and the PPCL production that are suitable for a pull system.*

The objective will be used to develop specific decision propositions for when to use a pull system and is also required for fulfilling the fourth objective. Literature have been used to complement the results from the first and second objective to identify appropriate flows of material for utilizing a pull system. To complement the observative, it will be investigated if there are any potential changes at Tetra Pak PPCL that could affect the decision for if it is appropriate to utilize a pull system or not.

RO4: *Define, at determined suitable parts, how the material flow between warehouse 111, the yard, and the PPCL production can be set-up as a pull system.*

All the previous research objectives will be used as the basis for the fourth research objective. Further, literature will also be used to help with accomplishing this objective. The research objective will be accomplished by the creation of design propositions, and thereafter guidelines for Tetra Pak PPCL will be created based on the design propositions.

To achieve the purpose an analytical framework has been constructed with its basis in the four research objectives and the literature. The foundation of the analytical framework is presented in figure 2.

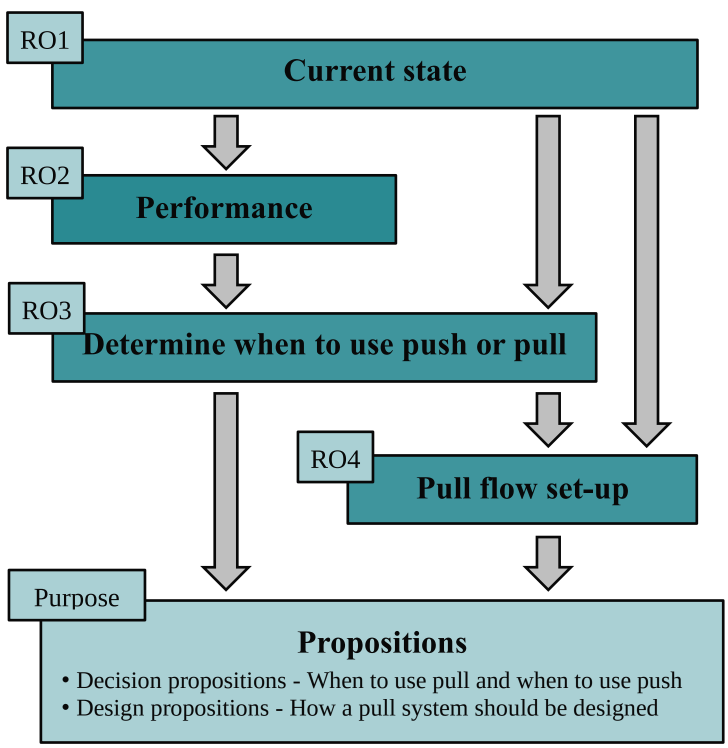


Figure 2: The foundation of the analytical framework.

1.5 Focus and delimitations

The main target of this master thesis is within material flows, especially regarding the concept of pull flow and when to use it and how to design it. This covers literature regarding design methodology, push flows, pull flows, information flows and to some extent warehousing and production. Specific warehousing or production operations are of secondary focus. This includes for example picking methods, picking routes and quality controls. The concept of lean will also be of relevance within the thesis. This is because of how its practices are of use for identifying issues within material flows, and thereby helping with analyzing the flow. Further, it is the entirety of the material flow and not any specific material that will be analyzed. Therefore, the material that is currently being moved with a Kanban strategy will not been investigated by itself.

The data gathering from both literature and Tetra Pak PPCL will be focused upon the configuration of the current material flow solution, how it performs, how to determine when to use a push system or a pull system, and on how to design a pull system. The current material flow solution will be investigated through the usage of multiple data collection methods and analyzing tools.

The scope of this study will be the material flow between warehouse 111, the yard and the PPCL production site at Tetra Pak in Lund. Further, the order handlers will be part of the scope due to them being responsible for assuring that an order is fulfilled. Continuing, the information flow between the three functions will be considered when developing the decision- and design propositions for Tetra Pak PPCL. The operations featured within the material flow will be included and analyzed in the study. However, operations within warehouse 111 and the PPCL production site that is not featured in the material flow will not be included in the study. The scope of the study is displayed in figure 3.

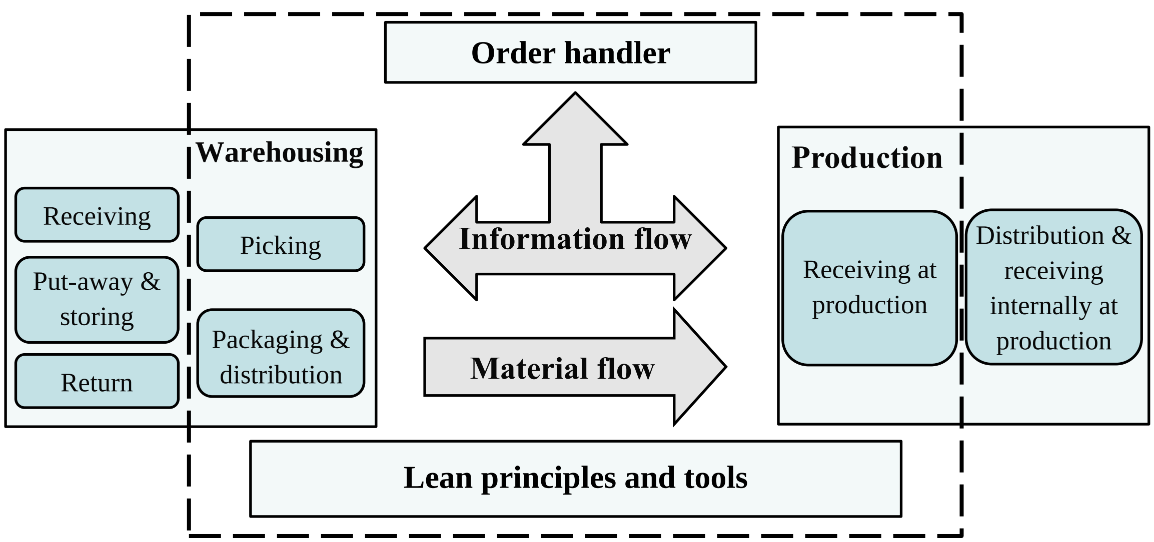


Figure 3: Display of the scope of the thesis. The dotted line tells what operations within warehousing and production that are included and what parts that are not.

The depth of the proposed decision- and design propositions is delimited. This is because of the master thesis time-limit restricting the studies to 20 weeks. Parts like ensuring that the propositions will be applicable in other environments than that of Tetra Pak PPCL will not be included. Further, factors outside of the material- and information flow that could be considered for change to improve the appropriateness of a pull system will be of second prioritization.

The propositions will be evaluated for the specific environment at Tetra Pak PPCL. This will be done by having a workshop with employees at Tetra Pak PPCL discussing the different decision- and design propositions.

1.6 Disposition

The following list presents the continued outline of the thesis.

2. Methodology	The chapter covers the research strategy and process. Further, the strategy behind the literature review and the empirical data gathering is explained. Finally, the processes of data analysis and research quality is discussed.
3. Frame of reference	The chapter includes five different areas that are being investigated. Namely material flow, information flow, warehouse operations, production, and lean. Further, with the help of these parts an analytical framework is created and presented. The analytical framework describes the entire process for accomplishing the purpose of the thesis.
4. Empirical findings	The chapter is divided into four different areas in which data have been gathered. The areas are warehouse and production configuration, material flow processes, the characteristics of the material flow, and the information flow characteristics.
5. Analysis	The chapter contains two different parts. The first part of the analysis is determining when it is appropriate to implement a pull system, and the second part is creating a pull system design for the parts where it is deemed appropriate.
6. Applicability of propositions	The chapter focuses on the applicability of the created propositions and their implications for Tetra Pak PPCL. The applicability is evaluated through a workshop focusing on discussing the propositions in general and if they are applicable for Tetra Pak PPCL.
7. Conclusion	The chapter concludes the thesis in three different parts. The first part consists of discussing how the purpose and the research objectives have been fulfilled. The second part discusses the contribution of the thesis, and the third part explains limitation for the thesis and suggests future research that could be of interest.

2. METHODOLOGY

The purpose of this chapter is to present and discuss the methodology that has been used to fulfill the purpose of the research. The first part of the chapter discusses the research design. That is, choosing a research strategy and presenting the research process. Continuing the data collection methods are presented. These are divided into literature review and empirical data gathering. Further, how the data has been analyzed is presented and discussed. Finally, the research quality is discussed. The outline of chapter two is presented in figure 4.

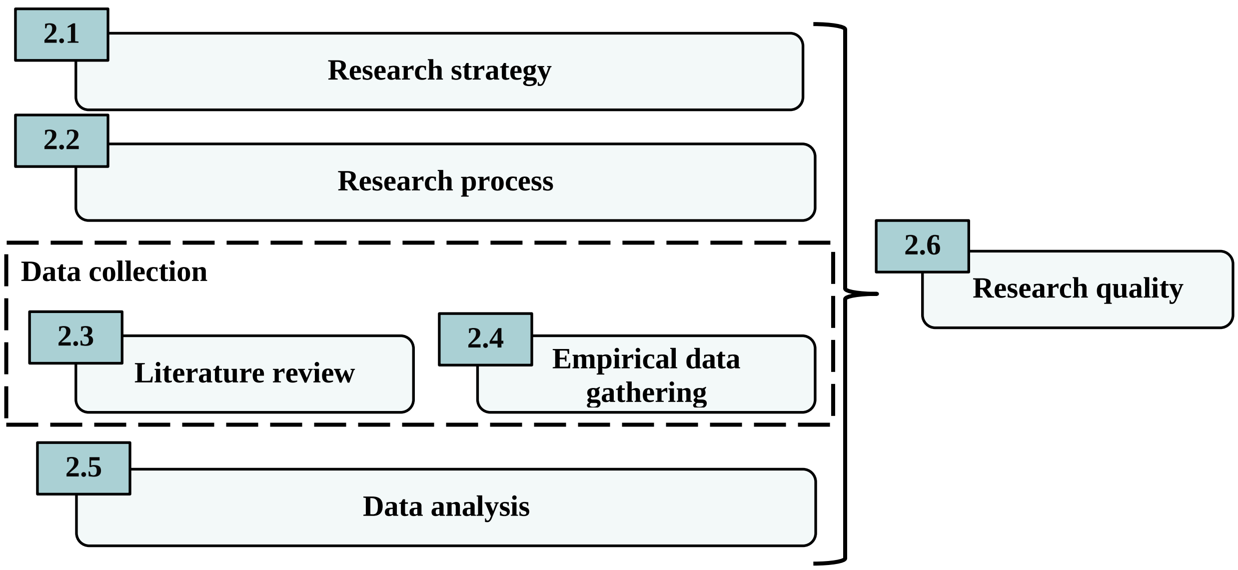


Figure 4: Outline of the methodology chapter.

2.1 Research strategy

There are different research strategies for approaching a defined purpose and research objectives of a master thesis. Lukka (2003) presents a matrix that can help with deciding the most suitable research strategy. The objectives and the purpose of this master thesis can be defined as empirical due to the requirement of own observations and data gathering. Determining whether the master thesis is descriptive or normative is more difficult. The first and second objective is to evaluate the current state and that can be regarded as being more descriptive. However, the third and fourth objective is to design a new solution and can instead be regarded as a normative one. These conclusions have led to a placement within Lukka's (2003) matrix as presented in figure 5.

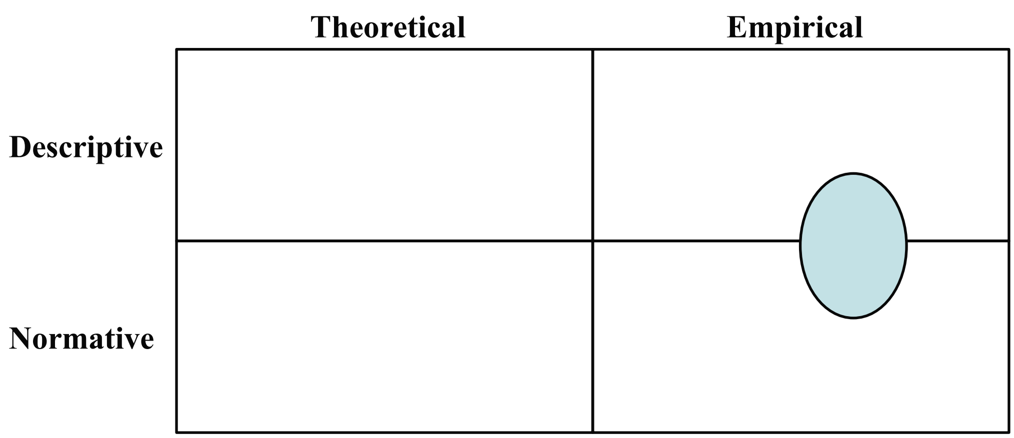


Figure 5: The figure shows the placement (blue ellipsis) of this thesis objectives and purpose with the use of Lukka's (2003) matrix.

Based upon the placement of the thesis purpose and objectives within Lukka's (2003) matrix there are two research strategies that could be suitable to have as a foundation. These are case research and design research. The difference between the two strategies is that a design research strategy has its starting point in the problem and a case study has its starting point in the phenomenon (Romme & Dimov, 2021; Yin, 2009). Therefore, due to the nature of the thesis purpose, a design research strategy is seen as more appropriate. This is because it is a practical problem that should be solved. However, it is advantageous to remember that the important thing is not what the strategy is called, but rather how it is used to fulfill the purpose (Saunders, Lewis, & Thornhill, 2007). Meaning that the strategy should not be seen as a set of rules that need to be followed unquestionably. It should rather be seen as a guidance towards being able to fulfill the purpose.

The design research strategy includes analyzing the present state, analyzing the desired state, and designing a road map to move from the present state to the desired state (Romme & Dimov, 2021). Holmström, Ketokiivi and Hameri (2009) describes the main advantage of a design science research strategy to be what the primary focus of the strategy is. A design science research strategy focuses on exploring, while many other methods instead are focused on being explanatory (Holmström, Ketokiivi & Hameri, 2009). This results in that the knowledge gained from using design science research strategy is more likely to be useful in practice. However, using the problem as the starting point increases the risk of not developing theoretical knowledge (Holmström, Ketokiivi & Hameri, 2009). Furthermore, in this thesis only one company is evaluated and worked with. This means that similar advantages and disadvantages as with a single case study can be seen. The main advantage is that by using one company a great depth of knowledge can be developed (Voss, Tsikriktsis, & Frohlich, 2002; Yin, 2009). On the contrary, the disadvantage is that the knowledge could be hard to generalize and might be biased toward the evaluated company (Yin, 2009).

2.2 Research process

The presentation of the research process will follow a three-step sequence. First, an appropriate design research process will be constructed with the help of previous literature about design research. Thereafter, the application of the constructed research process will be presented. Finally, the process of demonstrating the analytical framework will be presented in more depth.

2.2.1 Construction of design research process

The research process is inspired by the design science process presented by Romme and Dimov (2021). They divided the design process into four steps: (1) framing, (2) creating, (3) validating, and (4) theorizing, see figure 6. The four steps are divided into two phases. According to Romme and Dimov (2021) the phases are design and science. They describe that framing and creating is the design phase and the science phase consists of theorizing and validating, see figure 6.

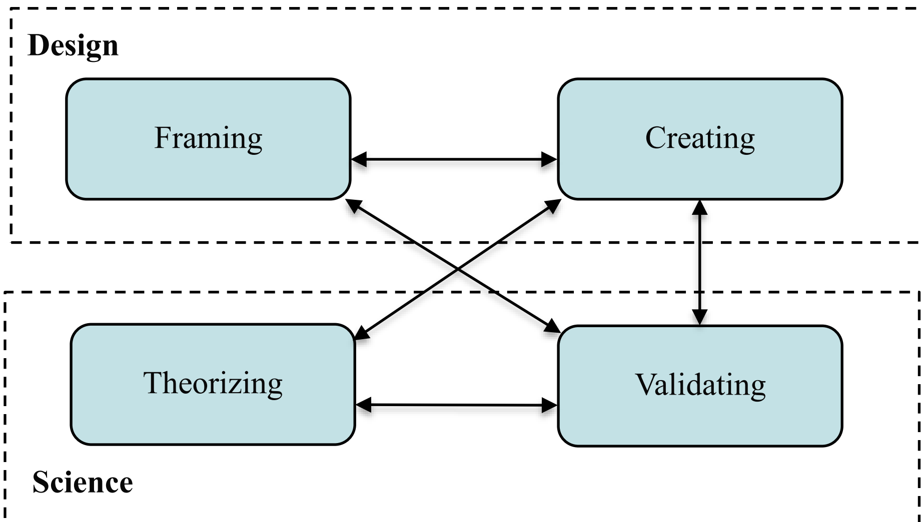


Figure 6: This is a modified version of the Romme and Dimov (2021) design research process that has been used in this thesis. In the original model there is a back-and-forth arrow between framing and theorizing. However, with the delimitation in this report, it was not suitable.

Firstly, framing is described as the step where the problem is explored and understood. Secondly, creating is described as the step where the so-called artifact is created. An artifact in design science is a broader term for a solution. It is something that does not exist, but something that upon creation helps with solving a problem or solves a problem. Thirdly, validating is about checking if the framing of the problem, the created artifact and the created theory are valid. There are many ways that an artifact can be tested. Hevner et al. (2004) describes case study, simulations, experimental, analytical, and field studies as all suitable ways of testing an artifact. However, depending on the artifact some tests are less or more suitable. Further, Van Aken, Chandrasekaran, and Halman (2016) emphasizes that some sort of real scenario testing, such as case study or field study, is the most suitable in operational management. Fourthly, theorizing is the process when the knowledge gained from the validation process is used to create more generalized theory (Romme and Dimov, 2021). Even though all the steps in the process are presented in a sequence Romme and Dimov

(2021) encourage that the steps are performed iteratively and there is no fixed step that the research should start with.

The process model presented by Romme and Dimov (2021) defines the basic processes and shows the interactive processes in a satisfying way. However, it is somewhat simple and non-concrete. Therefore, it is complemented with an older design process developed by Peffers et al. (2007). They present an expanded model, compared to Romme and Dimov (2021), with six steps. The steps are: (1) identify problem and motivate, (2) define objectives of a solution, (3) design and develop, (4) demonstrate, (5) evaluate, and (6) communicate. Step one is to find a problem and argue why it is relevant. This is a step that Romme and Dimov (2021) do not explicitly present. Step two in Peffers et al.'s (2007) model is similar to the *framing* step in Romme and Dimov's (2021) model. According to Peffers et al. (2007) their second step includes defining the objectives of what should be achieved by the artifact. Step three includes designing the artifact, which is similar to the *creating* step in the model presented by Romme and Dimov (2021). Step four is about applying the artifact to solve the problem defined in step one and try to fulfill the objectives defined in step two. The fourth step is one of the parts of the *validating* step in the model developed by Romme and Dimov (2021). The fifth step is about considering how the artifact performed and if it fulfilled its purpose. The sixth and final step is to communicate the results and the artifact's contribution to research. All six steps included Peffers et al.'s (2007) model can be seen in figure 7.

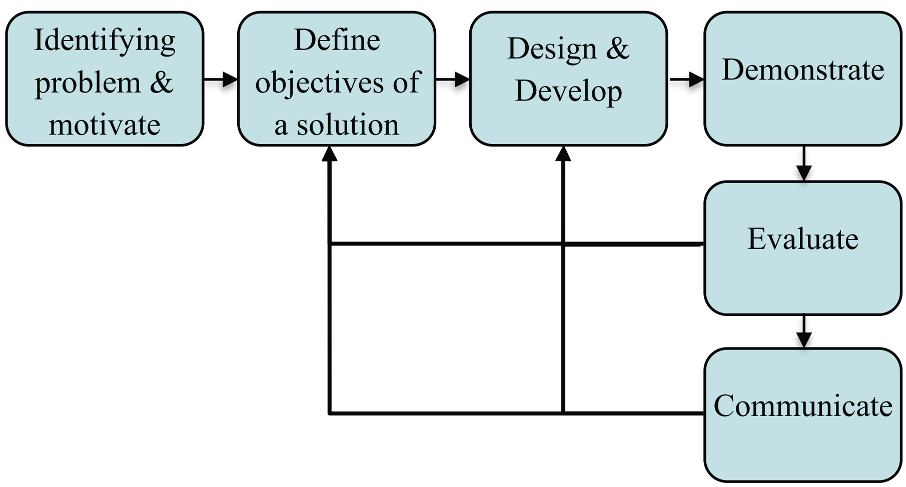


Figure 7: The process model presented by Peffers et al. (2007).

The process model developed by Peffers et al. (2007) is more concrete and includes a broader view of the research process. Thus, complementing the model presented by Romme and Dimov (2021). The process model by Peffers et al. (2007) was originally developed in an informational system research environment, which is within a different area than this thesis. Comparatively, Romme and Dimov (2021) have a more operational management approach to the design science research process. Thus, including both is believed to result in a better overall process and increase the validity.

By combining the two models, the process presented in figure 8 is created. This is the process that will be used in this thesis. A more comprehensive description of how the process has been used is presented in the next section (*2.2.2 Application of design research process)*.

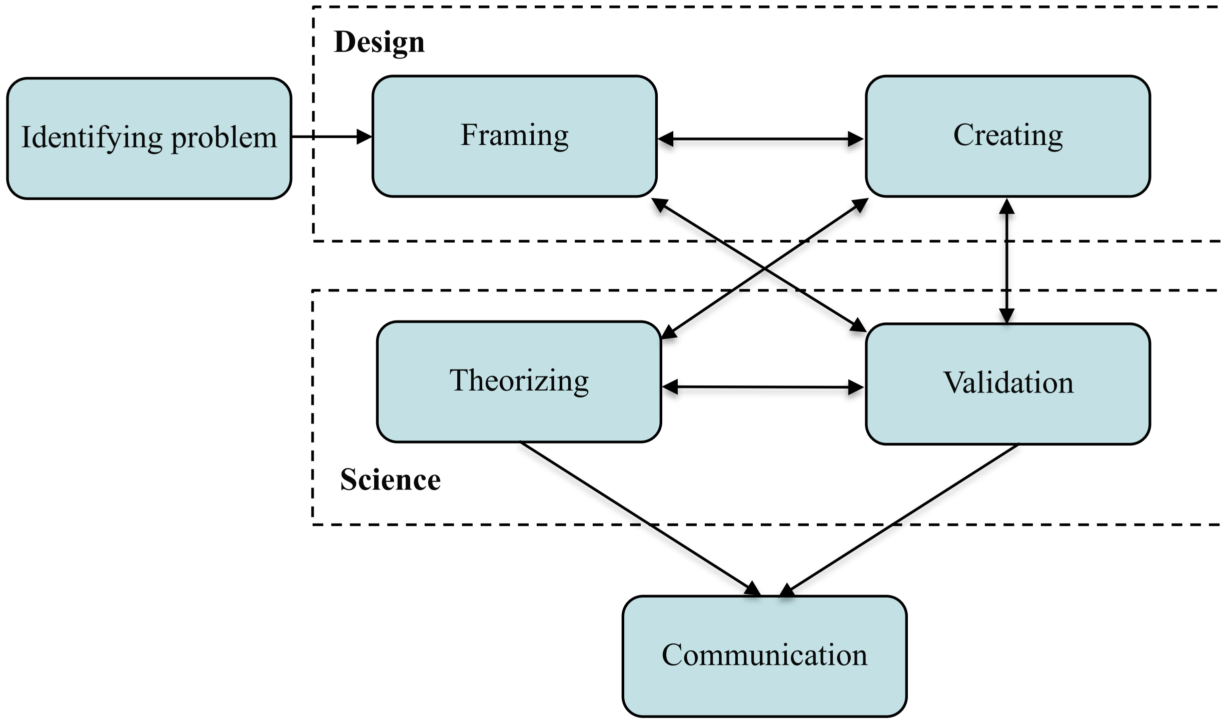


Figure 8: The figure shows the overarching process that has been used in this thesis (Peffers et al., 2007; Romme & Dimov, 2021).

2.2.2 Application of design research process

The artifact in this thesis is an analytical framework that will be used as guidance when developing decision and design propositions. It includes the processes for determining when to use pull or push, and for how to design a pull system. The strategy of developing and using the analytical framework is what will be presented in the rest of this section.

Identifying a problem is the first step in the process model presented in figure 8. The objective of this step was to find a suitable problem. A suitable problem in this thesis is defined as foremost a practical problem for a company. However, ideally there should also be a gap in research about the problem. This step is what has been presented in the section *1.3 Problem formulation*. The practical problem is the material flow between Tetra Pak PPCL's warehouse and their production. Further, the research gaps are within linking the two functions of warehouse and production and deciding on when it is appropriate to use a pull or push system.

After the problem was identified the design parts, described by Romme and Dimov (2021), can start. This part consists of framing and creating the analytical framework. Framing refers to understanding the previous research about material flow to be able to create a useful analytical framework. More precisely, the objective of the framing step was to understand the areas of (1) material flow, (2) information flow, (3) warehouse operations, (4) production, and (5) lean principles and tools. By fulfilling the objective, it was possible to move on to the creating step.

In the creating step the analytical framework was created. This was facilitated by using the knowledge from the framing step. More concretely, this step includes developing an analytical framework that can be used as guidance when gathering and analyzing data to decide when to use push or pull systems and how pull systems should be designed. The research objectives were used as guidance when creating the analytical framework. Thus, applying the analytical framework should fulfill the objectives. This implies that the output of applying the analytical framework is decision and design propositions. Further, when constructing these propositions, the so-called CAMO structure in design science was used (Romme & Dimov, 2021).

CAMO is an abbreviation for Context, Agent, Mechanism and Outcome. The generic structure of CAMO is described by Romme and Dimov (2021, p. 9) as “If in context C agency A activates mechanism M, this is likely to generate outcome pattern O.”. Further, the generic structure of CAMO can be rewritten in different contexts. The authors define the following structure of CAMO to be suitable when developing design propositions: “To generate outcome pattern O in context C, do something like A to activate mechanism M.” (Romme & Dimov, 2021, p. 9).

Romme and Dimov (2021) explain the different parts of CAMO. Context is the conditions of the situation that can lead to constrains in the design, examples of this in a material flow setting is layouts, demand, and type of information system. Agents includes the actor or actors and their action or actions. It is regarding who is doing something and how they should do it, examples are that the operator should inform the information system when they are done with a process. Mechanism is the link between the action of the agent and the outcome. It is what should be achieved by the action of the agent, and it is the driver of the outcome. Outcome is the outcome of the agents’ action that activates the mechanism, examples could be less stock or shorter lead times, but it can also be broader things such as a pull system.

By concluding the creating step the science part of the process model presented in figure 8 can begin. This part consists of validating and theorizing. Validating is carried out in two ways. Firstly, the function of the analytical framework is shown by applying the analytical framework in a real case scenario at Tetra Pak. Further, the performance of the analytical framework is tested by evaluating the applicability of the decision- and design propositions with the use of a workshop at Tetra Pak. There are interactions between the steps of framing, creating, and validating. More precisely, it was understood that parts were missing from the analytical framework when applying it, resulting in a need to enhance the framing step, and updating the analytical framework accordingly.

When the analytical framework is validated the next step in the science part can start. This is theorizing. Theorizing is in this case referring to the generalization of the propositions created when applying the analytical framework.

The final step was to communicate the knowledge gained from the theorizing step to the research field, together with communicating how the created decision and design propositions affect Tetra Pak. A summary of the concrete strategy that has been used in this thesis is shown in figure 9.

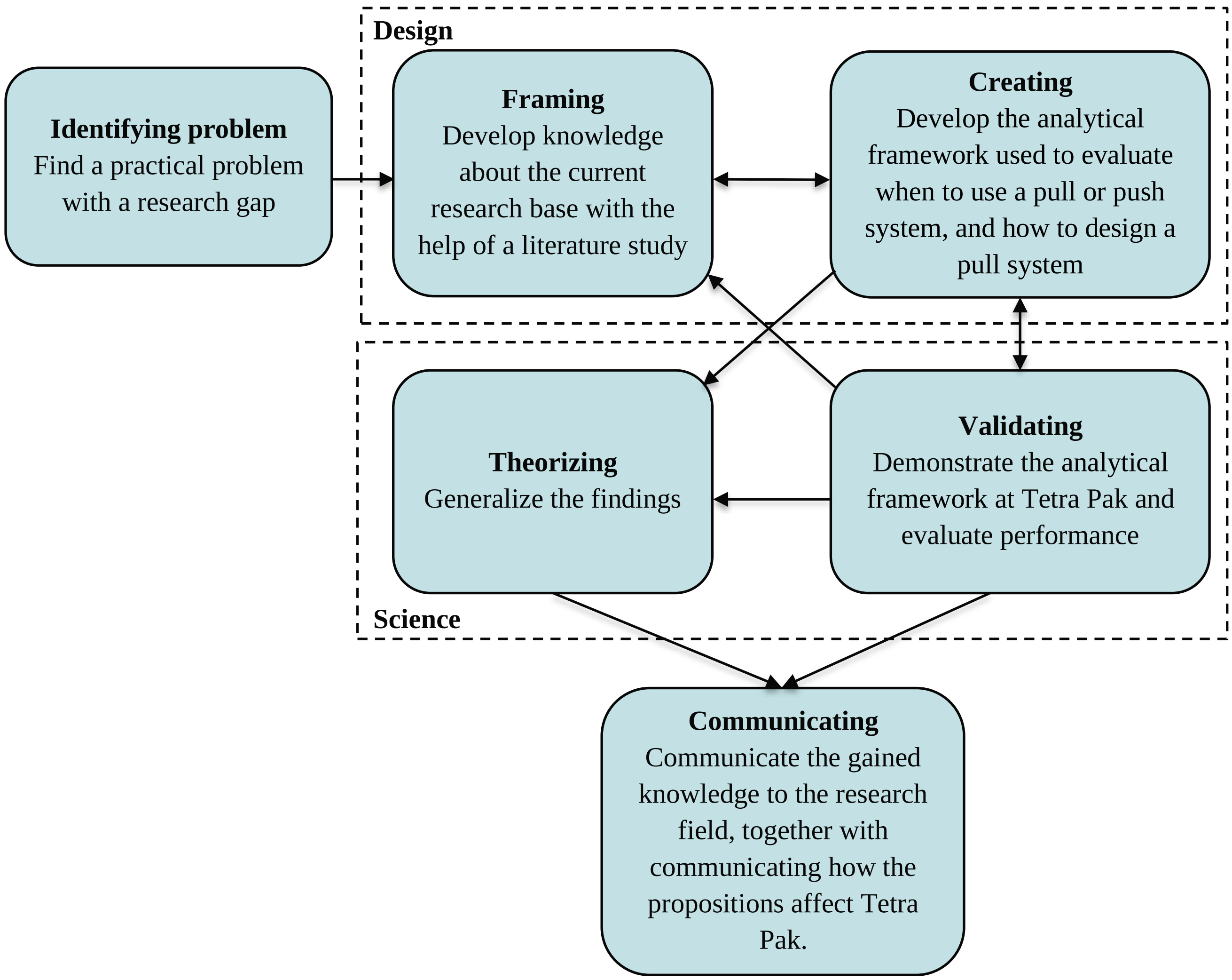


Figure 9: The figure outlines the research process in this thesis, it uses the overarching process in figure 7 as a skeleton framework.

2.2.3 Process of demonstrating the analytical framework

Hevner et al. (2004) describes many ways of testing and evaluating an artifact. Since the artifact is an analytical framework that will facilitate when evaluating and designing material flows it is deemed most suitable to use a case study process for validating it.

Voss, Tsikriktsis, and Frohlich (2002) presents three strengths of a case study, which originally was described by Benbasat, Goldstein, and Mead (1987). The three strengths are (1) relevance, (2) understanding, and (3) exploratory. Firstly, relevant refers to that it is possible to study the phenomena in its natural setting. Secondly, understanding regards how answering the question of why results in a deeper understanding of the phenomena. Thirdly, exploratory refers to that a case approach is easy to use when the phenomena or the result is unknown. How the three strengths are related to this study is presented in table 1.

Table 1: Presents how the three strengths of a case study are related to this study.

Strength	Relation
Relevance	It is possible to use the analytical framework in a real setting. This is achieved by using the analytical framework to evaluate when it is appropriate to use a push system or a pull system and how a pull system can be designed in a real setting. Through this the performance of the analytical framework is understood.
Understanding	By applying the analytical framework to a case, it is possible to understand its functionality.
Exploratory	The developed analytical framework's performance is unknown and the exact result of applying it is unknown as well. Thus, a case study is suitable.

There are also disadvantages with a case study. Meredith (1998) mentions (1) access to time, (2) triangulation requirements, (3) lack of control, and (4) unfamiliar procedure as the dominate disadvantages. However, other research processes are deemed to have more effectful disadvantage when validating the analytical framework.

The research process that has been used in this report is presented in figure 10. It consists of the overarching design steps (1) identifying problem, (2) framing and creating, (3) validation, (4) theorizing, and (5) communicating. The validation step has been modified from the case research processes presented by Yin (2009) and Kembro and Norrman (2020). The modification is that the steps of identifying problem, framing, theorizing, and communicating are not included in the modified validation step.

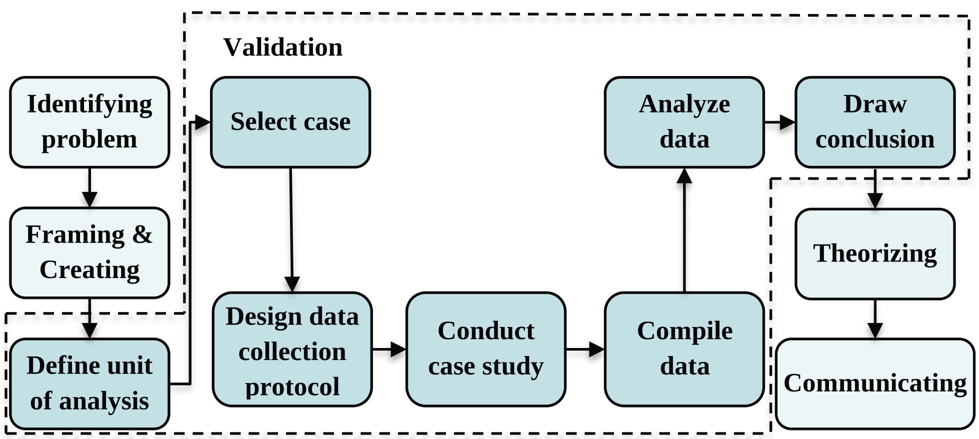


Figure 10: The figure presents an adapted and inspired research process from Yin (2009), Kembro and Norrman (2020), Romme and Dimov, 2021, and Peffers et al., (2007). The steps within the dotted line represent the steps of the validation process that follow a process inspired by common case research processes. Further, the steps outside the dotted line represents the steps in the design research process.

The first step of the validation process is to define the unit of analysis. Unit of analysis is what should be studied, and it should reflect the research purpose and objectives (Yin, 2009). Further, a clearly defined unit of analysis is something that is commonly forgotten even though it is one of the most crucial parts of a research case process (Barratt, Choi, & Li, 2011; Dubé & Guy, 2003; Yin, 2009). The unit of analysis can be interpretated as the phenomenon that, with the help of the case study, conclusions can be drawn about. The case study applies the analytical framework, which has the output of decision and design propositions. Thus, the result of applying the analytical framework is that conclusion can be drawn about material flow design. This implies that the unit of analysis is material flow design. It is emphasized that with design both deciding what material flow strategy and how the material flow strategy is designed is included.

After the unit of analysis has been defined, the case type was selected. Voss, Tsikriktsis, and Frohlich (2002) presents four different type of cases that can be chosen, they are (1) single case, (2) multiple cases (3) retrospective cases, and (4) longitudinal cases. Both, retrospective and longitudinal cases require collection of historical data either by using retrospective data or by conducting the cases over a long time. Conducting a retrospective or longitudinal case are deemed not suitable, due to not fitting with the purpose of the validation process. Further, since the research strategy is design science, which has its starting point in a practical problem at Tetra Pak it is essential to at least apply the analytical framework at Tetra Pak. The researchers realize that it would be beneficial to apply the analytical framework at more companies. However, due to the time required it is impossible with the time limitation. Therefore, the chosen type is a single case, and the case company is Tetra Pak. According to Voss, Tsikriktsis, and Frohlich (2002) the advantage of a single case is great depth. On the contrary, they describe limitation of generalizability and biases towards the single case company as disadvantages

The next step, after selecting Tetra Pak to be the single case company to study, is to design data collection protocols. The developed analytical framework is used as guidance when deciding what data is needed. This is then used as an indicator of how data collection protocols need to be designed. When the data collection process is defined, the case process is started by applying the analytical framework. When the analytical framework is applied design- and decision propositions are created. During the conducting of the case these propositions are tested with the help of a workshop, see table 2 for more information about the workshop.

Table 2: Displays some general information about the workshop that was held. It displays the positions of the Tetra Pak representatives, the topic and purpose, the date it was held, and the duration of the workshop.

Positions	Topic/Purpose	Date	Duration
Supply chain specialist; Supply chain specialist	Presentation of developed decision and design propositions. Discussion of the possibility and feasibility of the propositions	2022-05-02	2h

During the entirety of the validation process data has been compiled. The data gathered during the application of the analytical framework is thereafter analyzed. The results of this are used to draw conclusions about the unit of analysis and this is the final step of the validation part. The conclusion about the unit of analysis is then used as input to the design research process step of theorizing.

2.3 Literature review

Rowley and Slack (2004) describes the purpose of conducting a literature review as summarizing and gaining an understanding of the subject. They further emphasize that a literature review can be useful when (1) identifying research purpose and objectives, (2) gaining knowledge about the current theoretical concepts, and (3) gaining knowledge to be able to analyze the empirical findings. Furthermore, Hevner et al. (2004) describe that when creating the analytical framework literature should be used as a foundation. Continuing, Romme and Dimov (2021) present that when developing propositions in a design science context it is of importance to have a good theoretical foundation.

The literature review in this thesis has three purposes, which are linked to three steps. The first step was to develop a knowledge base for the problem of interest. The underlying reason of the first step was to be able to create a purpose and research objectives that would contribute to the research field. The second step was to gain theoretical knowledge to be able to create the analytical framework. The third step can be seen as an extension of the second step. In step three the ambition was to fill in the gaps from the second step. This was done so that the analytical framework could be fully used for the analysis of the material flow. There was iteration between the different steps even though they are described to have happened in sequence.

The conducted literature review involved finding academic articles and books that are well-reviewed, relevant, well-cited, and favorably primary sources. Two databases were primarily used for this. They were Lund University library's database *LubSearch* and *Google Scholar*. The strategy of the literature review was to find a few key terms that were searched in the databases. Some of the key terms used were *material flow, pull flow, push flow, information flow, and design science research.* When a key term was identified, it was used together with the term *literature review*. Meaning, that literature studies on the key term were identified. Then with cross-referencing from the literature studies additional journals and books were identified. When selecting which articles should be prioritized two rules were used. Rule one was that literature with the most citations was premiered and rule two was that newer articles were premiered.

No key literature has been used in the literature review. Rather, the goal has throughout the literature review been to use a wide range of sources to support the used facts. This strategy was chosen to increase the research quality.

2.4 Empirical data gathering

Empirical data gathering can be done in many ways (Forza, 2002). In operational management interviews, surveys, observations, and content analysis of documents are common data gathering methods (Forza, 2002; Voss, Tsikriktsis, & Frohlich, 2002). When deciding which method should be used it is important to consider (1) accessibility, (2) limitations in time and money, (3) if historical or current events should be evaluated, and (4) if a deeper or a broad result is sought after (Olhager, 2022). Depending on these considerations the type of method may vary. Furthermore, it is common to use multiple data gathering methods to evaluate the same problem, so called triangulation (Voss, Tsikriktsis, & Frohlich, 2002). Triangulation is usually used in the hopes of increasing the reliability (Voss, Tsikriktsis, & Frohlich, 2002).

The type of data that is collected is commonly divided into quantitative and qualitative data. The distinction between these is important to make since the analysis differs between the two (Saunders, Lewis, & Thornhill, 2007). According to Saunders, Lewis, & Thornhill (2007) qualitative data is the softer form of data and is commonly used to explain things. They describe interviews and observations as common methods to gather qualitative data. On the contrary, they describe quantitative data as harder and consisting of hard values, such as key performance indicators (KPI). It is not uncommon to use both types of data in operation management research (Saunders, Lewis, & Thornhill, 2007; Yin, 2009).

In this thesis, similar to what has been discussed as common, both quantitative and qualitative data will be used. The data will be gathered with multiple gathering methods. Further, there needs to be a distinction between data gathering with regards to the first and second objectives, and the third and fourth objectives. This is because there is a difference between what type of data that is needed and how it is possible to gather that data. To get necessary data to fulfill the first and second objectives interviews, secondary data from the ERP system, and observations has been used. Data collection related to the third and fourth objectives is mostly related to testing the solution. This data has primarily been gathered by discussing the solution with relevant members of Tetra Pak's PPCL organization. A summary of the different methods used is presented in table 3.

Table 3: A summary of the different data gathering methods that have been used.

Collection method	**Purpose**
Interview	Interviews has been used to get more specific knowledge that was not possible to gather from observations or secondary data.
Observation	Observation of the current solution has been used to better understand the environment. More precisely it is used to understand- where it is suitable to introduce a pull system design and how a potential pull system can be designed.
Secondary data	Raw data and internal documents have been gathered to map and understand the current situation.

2.4.1 Interviews

Doody and Noonan (2013) describe interviews as one of the most common tools that is used to gather quantitative and qualitative data. They further describe that there are three types of interviews that are used. These are: (1) structured interview, (2) unstructured interview, and (3) semi-structured interview. Because a semi-structured interview gets the best of both a structured and an unstructured interview, it is the most common type (Doody & Noonan, 2013).

This report has used a combination of structured, semi-structured and unstructured interviews to gather information about the current solution. Unstructured interviews were used in the beginning since they were suitable to gather overarching knowledge about the current situation at Tetra Pak. When the authors had the overarching knowledge, the interviews became semi-structured to be able to gather more specific knowledge that was needed. At the end, the interviews were structured and only a few specific questions were asked at these interviews. To create a comfortable interview environment no recordings have been conducted and all interviews were held face-to-face with at least one of the authors being present.

In total 13 interviews have been conducted with various people in different positions and the interview guides are presented in Appendix I. Most of the interviews (12 out of 13) have been conducted face-to-face, the other has been conducted with the help of Microsoft Teams. During all interviews one of the authors was responsible for leading the interview and the other was responsible for taking notes. A summary of all the conducted interviews is presented in table 4.

Table 4: The table summarizes all the conducted interviews, it presents which position the person interviewed held at Tetra Pak at the time of interview, the topic that was discussed, which date it was held, and the duration.

Position	Topic/Purpose	Date	Duration
Warehouse operator	Distribution between warehouse and production	2022-03-15	45 min
Picker	Picking process	2022-03-15	45 min
Supply chain specialist	Material flow and information flow overview	2022-03-21	1 hour
Team leader BPU multiline	Understanding the work process and how material are received at BPU multiline	2022-03-28	45 min
Team leader BPU special	Understanding the production process and how material are received at BPU special	2022-03-28	45 min
Order handler HT	Understanding the order-handling process for HT products	2022-03-29	60 min
Team leader HT MTS and Assembly	Understanding the work process and how material are received at HT production	2022-03-31	45 min
Order handler HP	Understanding the order-handling process for HP products	2022-04-06	60 min
Team leader BPU test for assembly	Understanding the work process and how material are received at BPU test	2022-04-11	30 min
Order project leader BPU	Understanding the order-handling process for HT products	2022-04-11	60 min
Team leader HP; Production leader HP and HT	Understanding the work process and how material are received at HP production	2022-04-12	30 min
Vice team leader BPU manufacturing	Understanding the work process and how material are received at HT production	2022-04-12	30 min
Supply chain specialist	Weekly meetings about scope, progress, and general information regarding the current situation.	2022-02-11 to 2022-05-25	0.5-1.5h/week

2.4.2 Observations

Denscombe (2010) describes observations to be a common approach to collecting data. He describes two types of observation methods: (1) structured observation, and (2) participant observation. Structured observations are when you observe from the sideline and participant observations are when you observe by participating. The main advantage of observations, as described by Denscombe (2010), is that you are getting first-hand knowledge instead of relying on what people say and think in an interview. However, the disadvantages with both types of observation methods are the issue of perception. The issue of perception is that two people might perceive something differently even though they observe the same thing (Denscombe, 2010). The problem of perception has been tackled by having a clear purpose for each observation and by having both researchers present at all observations.

Structured observations were deemed most suitable, due to the relationship between Tetra Pak and researchers, and the time frame. The purpose of the observations is primarily to gather an understanding of the current situation. To do this the observations in table 5 has been conducted. Furthermore, even though the name is structured observation, there was a difference in how structured the observations were. In the beginning a more unstructured approach was used to get an understanding about the big picture, and in the end more target-oriented observations were conducted to get deeper knowledge.

Table 5: The table summarizes all the conducted observations at Tetra Pak. It presents where the observation was conducted, what the purpose of that observation was, when it was conducted, and if there were any additional attendees.

Purpose	Date	Additional attendees
Tour of PPCL's production and warehouses.	2022-02-11	Warehouse and forklift leader; Supply chain specialist PPCL
Mapping and confirmation of PPCL's production and warehouse layout.	2022-03-01	--
Mapping and confirmation of unloading points in PPCL's production and warehouses.	2022-03-02	--
Tour of Packaging Equipment's production. The purpose was to better understand material flows in general and Tetra Pak	2022-03-04	Supply chain specialist packaging equipment
Mapping and confirmation of current Kanban stations in PPCL's production.	2022-03-09	--
Tour of train route	2022-03-15	Train driver
Tour of components and parts' production and warehouse. The purpose was to better understand material flows in general and Tetra Pak	2022-03-30	Manufacturing and supply chain integration component and parts; Supply chain specialist PPCL

2.4.3 Secondary data

Secondary data is data that has already been collected and where the main purpose was to be used for other reasons (Saunders, Lewis, & Thornhill, 2007). Even though primary data is usually seen as better, there are situations when secondary data are useful, due to time limitation of collecting data or the possibility of it. Saunders, Lewis, and Thornhill (2007) describe that internal company data are one common type of secondary data. This is the type of secondary data that has been gathered in this thesis.

The internal data that have been used can be divided into two subcategories. The first type is documents and illustrations, and the second type is raw data. Documents and illustrations have been provided by Tetra Pak and consists of maps and Standard Operating Procedures (SOP). They have been used to save time in mapping out layouts and processes. Raw data has predominantly been gathered from Tetra Pak's ERP system where the data has been exported to excel files. From the raw data things such as throughput, demand and lead-time have been evaluated. The raw data that has been gathered is from the period 2019-03-01 to 2022-02-28. Further, to compile the raw data Power BI and Excel has been used. It should be noted that 3-4% of the raw data was incomplete, thus, being excluded. A summary of all the gathered documents is presented in table 6.

Table 6: The table summarizes all the gathered documents and their purpose divided by type.

	Document description
Document & Illustration	Layout of unloading points in the PPCL production (building 105-108)
	Layout of unloading points in warehouse 111
	SOP Distribution between warehouse 111 and the PPCL production
	SOP Picking warehouse 111
	SOP Picking and distribution from the Yard
	Routing of BPU product 1
	Routing of BPU product 2
	Routing of BPU product 3
Raw data	Transfer order (items in order, quantity of items, delivery points, confirmation of picking dates)
	SKUs data (ID, Description, Weight, Primary storage bin in warehouse, maximum number of units in primary storage bin)
	Storage bin type data (abbreviation, description, size)
	Storage locations data (type of product dedicated to different locations)

2.5 Data analysis

Data analysis is an important part of any operational management research and is used to describe, explain and/or interpret the situation that is being studied (Denscombe, 2010). Denscombe (2010) describes how there is a difference between analyzing quantitative data and qualitative data. However, he presents a generic five step strategy that can be used for analyzing both types of data, and this strategy has been used in this thesis. The five steps are: (1) data preparation, (2) initial exploration of data, (3) analysis of data, (4) presentation and display of data, and (5) validation of data. The difference between analyzing quantitative data and qualitative data is within how the steps are performed and which of the steps that are the most important ones (Denscombe, 2010). How the steps are performed can be seen in table 7.

Table 7: Describes the different steps when analyzing quantitative and qualitative data (Denscombe, 2010).

	Quantitative data	**Qualitative data**
Data preparation	Coding of data and categorizing the data.	Cataloguing the interviews or observations.
Initial exploration	Evaluate if there are any obvious trends.	Look if there are any reoccurring trends in the notes.
Analysis of data	Further analyze the data.	Categorize the notes and use frameworks.
Presentation and display of data	Present the results, usually with the help of figures, tables, or charts.	Present in written words.
Validation of data	Check the results internally.	Triangulate and follow-up observations and interviews.

The differences are further discussed by Voss, Tsikriktsis, and Frohlich (2002). They describe that when analyzing quantitative data, it is more crucial to prepare and code the data to be able to get a useful analysis. They further describe that the common output of an analysis of qualitative data is useful quotes from interviews. Comparatively, when analyzing quantitative data different data handling tools are usually used such as Power BI and Excel. This results in that when analyzing quantitative data, the output is usually graphs, charts, or tables.

The framework in figure 11 outlines how the data has been used to achieve the purpose of this study. This framework has been further developed into an analytical framework, in section *3.6 Analytical framework*, which goes deeper into what the analysis of the data should result in. However, a brief description will follow to get an initial understanding of how the data has been analyzed. The backbone of the data analysis is the four types of data that has been gathered. They are observations, interview notes, secondary data, and literature. All these types of data except literature have been used primarily to understand the current situation at Tetra Pak, which concerns RO1 and RO2.

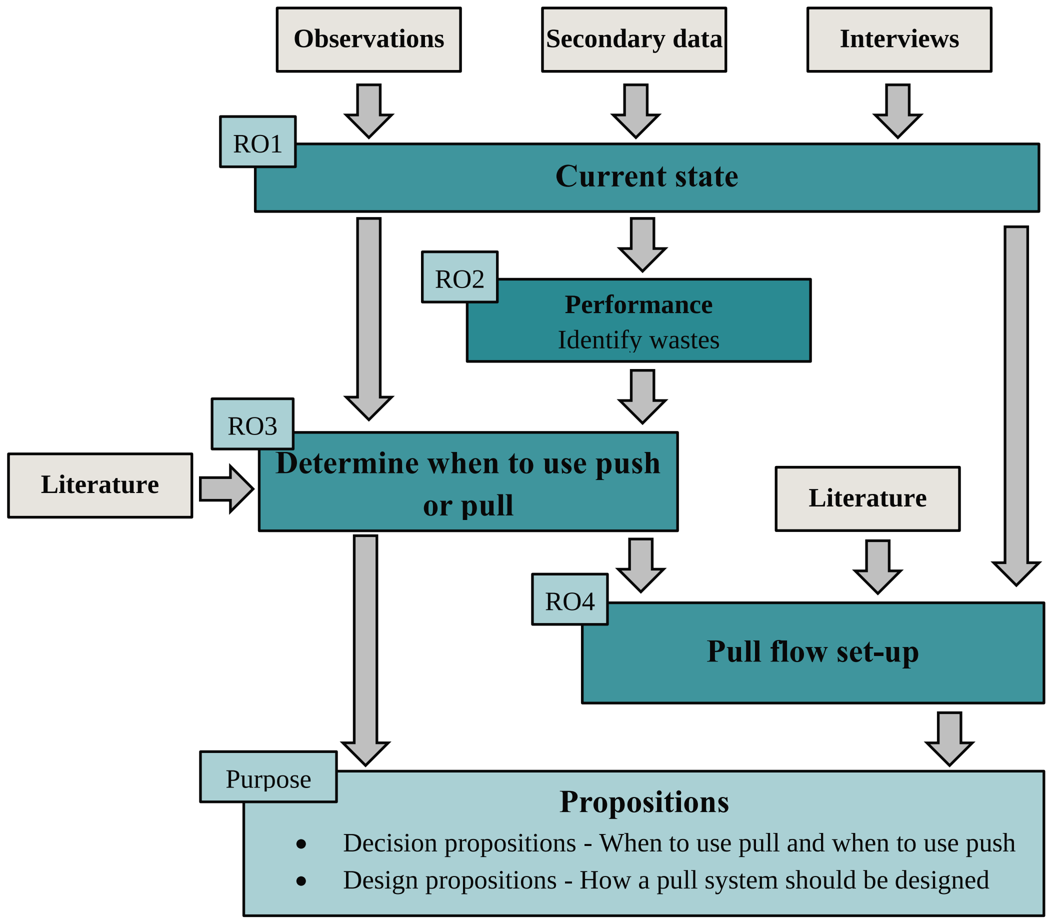


Figure 11: Skeleton framework of how the data has been analyzed and used to in the end create design- and decision propositions. The skeleton framework has been further developed to create an analytical framework in section *3.6 Analytical framework*.

The results from the identified and analyzed current state is then further used as input when moving on to RO3. The data analysis is carried out by finding patterns between the current state at Tetra Pak and the literature of when push or pull systems are suitable. Further, the result of this is used to create decision propositions and is at the same time used as input to RO4. Also, it is investigated whether there are any potential changes that could affect whether a pull system is deemed suitable or not. This is analyzed with the help of comparing literature with the current state and results in outputs in the form of one more decision proposition. The output of RO3, literature and the contextual factors are used as the basis for RO4.

Regarding RO4 the analysis was conducted by finding patterns between the literature and the current situation at Tetra Pak PPCL. The output of this analysis is design propositions that are used to create a pull system design at Tetra Pak PPCL.

When conducting the analysis, the four principles of data analysis presented by Yin (2009) was used to increase validity. They are: (1) include all important information even though it could be contradictorily and not what you thought it would be, (2) present alternative solutions in the final recommendation, (3) only spend time analyzing data that is relevant to the main purpose of the research, and (4) it should be clear to the reader that the authors are familiar with the subject.

2.6 Research quality

A study's research quality is always of importance (Bryman & Bell, 2017). Research quality includes validity and reliability (Näslund, Kale, & Paulraj, 2010). Näslund, Kale, and Paulraj (2010) describe validity as that the results are showing the right thing, and the reliability is good if the same result is achieved if the study is repeated. It is important to notice that one concept does not cancel out the other. Meaning that both concepts need to be fulfilled to achieve a satisfactory research quality, this could be likened with shooting at a target, see figure 12.

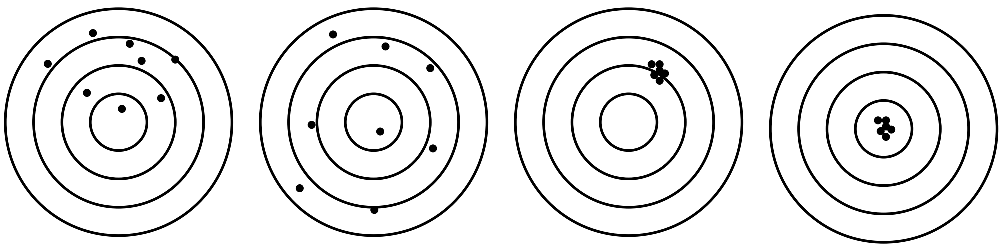


Figure 12: The interaction of reliability and validity.

The research design for testing and evaluating the analytical framework with the purpose of creating decision- and design propositions have been conducted on a single case company. This results in that the core of the research quality is within the validating step of the research process. Outside the core, the research quality is dependent on the other steps. Much discussion has been had about the research quality in case studies (see e.g., Voss, Tsikriktsis, & Frohlich, 2002; Yin, 2009), and less has been had about research quality in problem-solving research such as design research. Näslund, Kale, and Paulraj (2010) discuss research quality in a problem-solving research process. They concluded that even though there are differences in the processes of problem-solving research and case study research, the research quality discussion should be similar. Thus, inspiration from case research quality could be used when evaluating the research quality of problem-solving research such as this one.

Gibbert, Ruigrok, and Wicki (2008) describe four criteria that are commonly used when evaluating the research quality in field studies. They are (1) construct validity, (2) internal validity, (3) external validity, and (4) reliability. The same criteria are adapted and presented by Yin (2009) for a case study. See table 8 for definitions of the four criteria.

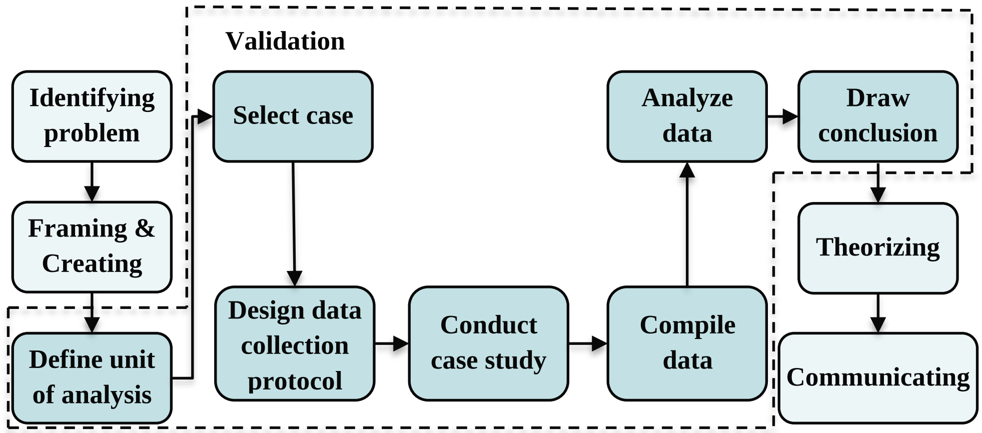
Table 8: Presents the four quality criteria commonly discussed in research quality in operational research (Bryman & Bell, 2017; Gibbert, Ruigrok, & Wicki, 2008; Saunders, Lewis, & Thornhill 2007; Voss, Tsikriktsis, & Frohlich, 2002; Yin, 2009).

Quality parameter	Definition
Construction validity	If chosen measurements are appropriate and able to measure the phenomena that is being studied, it exists construction validity.
Internal validity	It concerns if the conditions found lead to the conclusion of it was a coincidental result. This means that internal validity primarily boils down to if the empirical finding and analysis are rigid.
External validity	Commonly interchanged with generalizability. Meaning the ability to draw more general conclusions and not only about the studied situation.
Reliability	It concerns the replicability of the research. Meaning, that a study is reliable if the same result would be achieved if the study would be replicated.

Research quality is not something that is automatically received in a study, therefore, there needs to be a strategy to achieve research quality. Even with a strategy the researchers conducting the study need to be critical about its quality (Kembro & Norrman, 2020; Näslund, Kale, & Paulraj, 2010; Voss, Tsikriktsis, & Frohlich, 2002). The strategy used in this study is primarily inspired from Kembro and Norrman (2020), Näslund, Kale, and Paulraj (2010), and Voss, Tsikriktsis, and Frohlich (2002). Further, the strategies that are used and when they are relevant is summarized in figure 13.

To increase the construction validity four principles has been used, see figure 13. Firstly, results were presented to fellow students and case company representatives with seminars and a workshop. It is worth noting that only one workshop was conducted, and it was not possible to include all relevant people at Tetra Pak PPCL due to time limitations. Nevertheless, it is believed that the workshop enhanced the research quality. Secondly, the terminology used is clearly described, either in the relevant chapters, in the abbreviation list or in both. Thirdly, multiple sources, mostly primary sources, and sources with different perspectives were used. This principle was applied when conducting the literature review and the empirical data gathering. The authors made it a priority to talk to people from different parts of the organization. More precisely, the goal was to talk to people from a broad variety of positions e.g., warehouse employees, warehouse managers, production employees, production leaders, order handlers, and supply chain specialists. Finally, the empirical findings gathered from observations and interviews has been fact-checked by case company representatives.

Three different principles were used to increase the internal validity, see figure 13. The first principle consisted of using multiple sources when understanding the phenomena. The second principle was that two interviewers/observers where always present at all interviews/observations. This was done to reduce the probability of misinterpreting the interviewees answers. The final principle to increase internal validity was that summarized tables and figures were used. The goal of this was to make it easier to understand the reasoning behind conclusions and open-up for comparison with other companies.



Construction validity	• Multiple sources when identifying a problem • Multiple sources when framing and creating the analytical framework • Clearly described terminology	• Clearly described terminology • Empirical findings fact-checked by case company representative	• Workshop and seminars
Internal validity	• Figures and tables to summarize literature findings	• Multiple sources about the same phenomenon • Two interviews/observers present at all interviews/observations • Figures and tables were used to summarize empirical findings	• Figures and tables were used to summarize conclusions and show argument for conclusions
External validity	• Rigid theoretical foundation	• Clearly described case company's situation	• Combination of theory and empirical findings when drawing conclusions
Reliability	• Clearly described process which is summarized in figures. • Standard interview guides presented in Appendix I	• Well documented interviews and observations	

Figure 13: Summarizes the strategies used to achieve research quality. The layout of the figure is inspired by Kembro and Norrman (2020). The strategies are inspired Kembro and Norrman (2020), Voss, Tsikriktsis, and Frohlich (2002), and Näslund, Kale, and Paulraj (2010).

External validity or generalizability was achieved with two principles, see figure 13. The first principle was that the situation at the case company was described in detail to simplify for comparison with other companies. The second principle was that conclusions were drawn by combing theory with the empirical findings. This required a well-established frame of reference.

Reliability has been increased with three principles, see figure 13. The first principle is that the research process has been presented in detail to enable for recreations of it. Particularly what interviews and observations that was conducted, when they were conducted, and with whom they were conducted with. The second principle is that standardized interview guides was used for the people at similar positions and these interview guides are presented in Appendix I. The third principle was that when conducting empirical data gathering, the knowledge was documented in a structured way to facilitate back tracking.

3. FRAME OF REFERENCE

The frame of reference chapter presents the required theoretical knowledge to be able to understand material flows and create decision- and design propositions for when to use a pull system and how to design a pull system at Tetra Pak PPCL. The chapter is divided into six sections.

In the first and second sections theories about warehouse operations and production operations are described. This is done with the purpose of gaining an understanding of some of the contextual factors included in the scope. The third section is discussing material flows in general and different types of material flows are presented. The purpose of the third section is to get an understanding about the concept of material flow strategies and when different strategies are preferable. Further, the section discusses how to design a pull system and different types of pull flow methods are presented to provide the reader with an understanding of how a pull system can be designed. The fourth section presents theory about information flow. This section describes what information flows are and presents some of the more common information systems and tracking technologies. Then the section presents how information can be moved between functions and what kind of information that is of relevance to flow between functions. The fifth section presents the idea of lean thinking and shines a light on some lean practices that are of relevance for the purpose of the thesis. In the final section everything is tied together in an analytical framework showing how the literature review connects with the different research objectives and how the empirical- and analysis sections will be conducted to fulfill the purpose of the thesis. The structure of the frame of reference chapter is presented in figure 14.

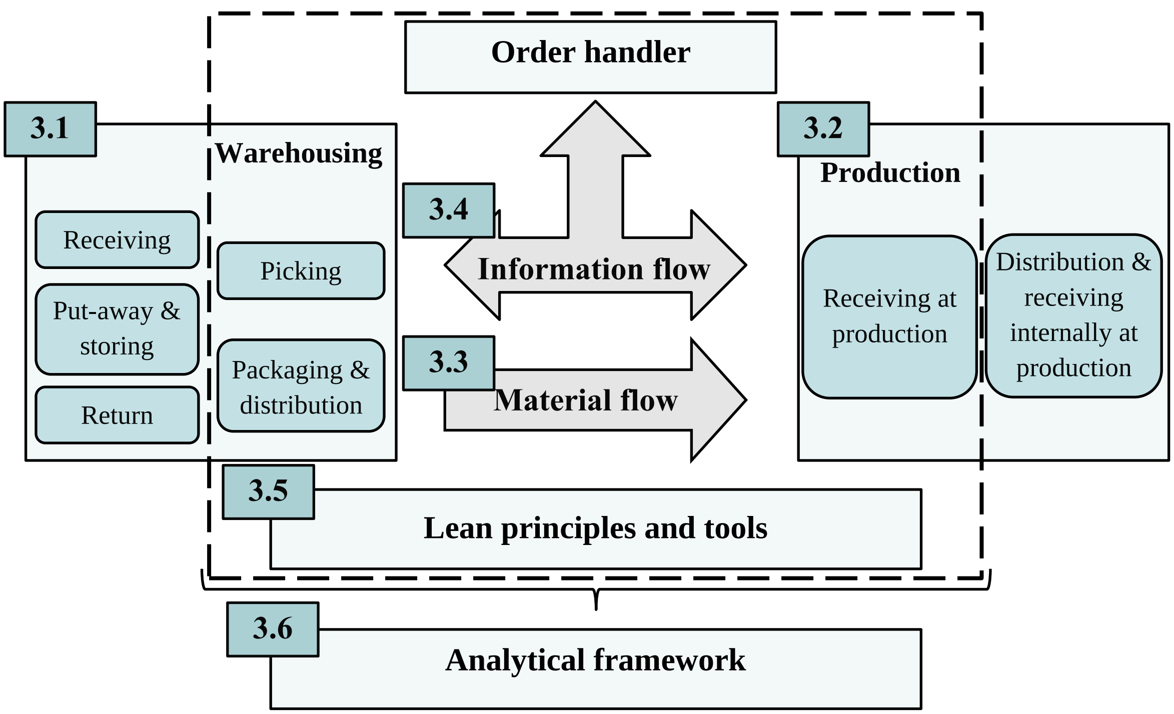


Figure 14: The figure presents the outline of the frame of reference chapter.

3.1 Warehouse operations

Warehouse operations include (1) receiving, (2) put-away and storage, (3) picking, and (4) packing and distribution (Bartholdi III, & Hackman, 2019; de Koster, Le-Duc, & Roodbergen, 2007; Rouwenhorst et al., 2000). Further, Kembro, Norrman and Eriksson (2018) has used a more extended warehouse operations definition, they included the operation of returns as well. The different warehouse operations and their interrelationship is depicted in figure 15.

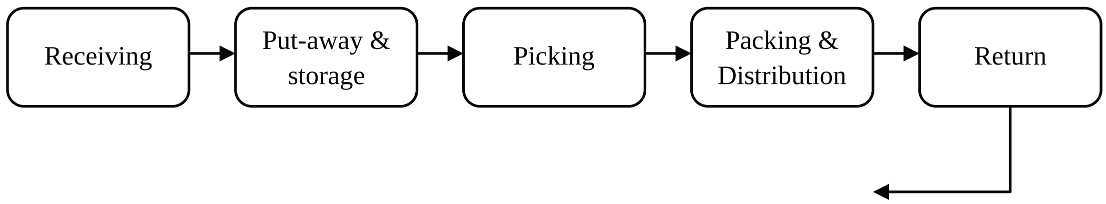


Figure 15: The different warehouse operations and their interrelationships, adapted from Kembro, Norrman and Eriksson (2018).

Within the delimitation of this thesis the warehouse operations of picking, and packaging and distribution are of relevance. Furthermore, since it is a component warehouse and the production lines are wall-in-wall with the warehouse in the case company, the packaging and distribution operation is of less importance and will, thus, only be briefly described in the frame of reference.

3.1.1 Picking

Picking is seen as the most labor-intensive part of the warehouse operations and the biggest cost-driver (Bartholdi III, & Hackman, 2019). There are three different picking methods, and they are: (1) single-order picking, (2) batch-picking, and (3) zone-picking (Gu, Goetschalckx, & McGinnis, 2007). Firstly, single-order picking is when one order is picked at a time by one person. Secondly, batch-picking is when multiple orders are put together and picked at the same time. Finally, zone-picking is when the warehouse is divided into zones, and orders are split and picked by different people divided by the zones. Furthermore, batching, routing, sequencing, and sorting is parts that need to be considered within the picking methods (Gu, Goetschalckx, & McGinnis, 2007).

3.1.2 Distribution

The distribution operation generally consists of checking the orders (quality and quantity), packing the order, and sending the order to the customer (Rouwenhorst et al., 2000). In the component warehouse, the customer is the production line and since the production line usually is located next door, the distribution process becomes small. However, things such as distribution schedule and fill rate of transport method needs to be considered (Bartholdi III, & Hackman, 2019).

3.2 Production

Production is the process in which raw materials are refined to create the product for the customer (Poon, et al., 2011). Production can refer to many different processes and a production line can typically consist of multiple of those processes that are being performed at workstations along the production line (Bartholdi III & Eisenstein, 1996). Examples of such processes can be welding, testing, and assembling. Welding refers to the process of joining two pieces of metal together (Lancaster, 1986). Testing is the part in production when the material is tested to certify that it can fulfill its requirements and assemble is when different components are assembled to create a new component or a product (Colledani et al., 2014).

Depending on how finished the product is when an order is placed, the so-called customer order decoupling point (CODP), the requirements on manufacturing are different (Olhager, 2010). Related to the CODP there are different production strategies, and they are: (1) make-to-stock, (2) assembly-to-order, (3) make-to-order, and (4) engineer-to-order (Olhager, 2010). The extremes are make-to-stock and engineer-to-order. Make-to-stock means that all products are made before they are ordered. On the contrary, engineer-to-order is when the design of the product is not created before the order is placed. Assembly-to-order is closely related to make-to-stock. However, instead of having a finished product in stock, components are kept in stock. These are assembled to a finished product when the order arrives. The final strategy is make-to-order, this is when raw materials are kept in stock and the production of the finished product starts when an order arrives.

3.3 Material flow

If a supply chain is to be as effective as possible it is required that its material flow is integrated (Childerhouse & Towill, 2003). Simply explained, this means that all processes within the material flow need to be unified. If the material flow were to be simplified, wastes throughout the supply chain could be removed (Bartholdi III & Hackman, 2019; Åhlström, 1998). In a simplified material flow the required material is received at the time that it is needed at the place where it is needed (Bellgran & Säfsten, 2009). According to Towill, Childerhouse and Disney (2000) there are twelve rules that one can follow to simplify the material flow, see table 9.

Table 9: Twelve rules to simplify the material flow, copied from Towill, Childerhouse & Disney (2000).

Rule	Description
Rule 1	Make production that can be quickly dispatched and invoiced to customers.
Rule 2	Only make component in one time bucket that are needed for assembly in the next period.
Rule 3	Streamline material flow and minimize throughput time, i.e., compress all lead times.
Rule 4	Use the shortest planning period, i.e., the smallest run quantity which can be managed efficiently.
Rule 5	Only take deliveries from supplier in small batches as and when needed for processing or assembly.
Rule 6	Synchronize “time buckets” throughout the supply chain.
Rule 7	Form natural clusters of products and design processes appropriate to each value stream.
Rule 8	Eliminate all uncertainties in all processes.
Rule 9	Understand, document, simplify, and only then optimize the supply chain.
Rule 10	Streamline and make all information flows highly visible throughout the supply chain.
Rule 11	Use only proved, simple, and robust decision support systems.
Rule 12	The operational target is to enable the seamless supply chain, i.e., all players should act as one unit

If disruptions to the material flow are to occur it can cause a stream of additional disruptions downstream the supply chain from the disruptions point of origin (Bartholdi III & Hackman, 2019). Disruptions within the material flow are less likely to occur within a simplified material flow (Childerhouse & Towill, 2003). Therefore, a simplified material flow can be considered to also prevent inefficiencies between the processes of warehousing and production (Childerhouse & Towill, 2003).

3.3.1 Material flow strategies

There are different strategies to utilize for handling the movement of material. Generally, it is said to exist a total of three different strategies and all movements of material can be done utilizing one of those. These are push flow, pull flow and hybrid push/pull flow (Hopp & Spearman, 2004).

3.3.1.1 Push flow

A push system does not have any information flow downstream (Spearman & Zasanis, 1992). Instead, Spearman and Zasanis (1992) state that the material flow starts from a specific start date. The date is determined through calculations based upon estimated lead-times and dates when the material is required at certain processes. Simply explained, a push system produces products in accordance with an estimated product demand (Teeravaraprug & Stapholdecha, 2004). A push system is a system that does not have any limits regarding the quantity of work that can be in the system (Hopp & Spearman, 2004). An example of a push system is material requirement planning

(MRP) (Deleernyder et al., 1992). The material- and information flow within a push system is depicted within figure 16.

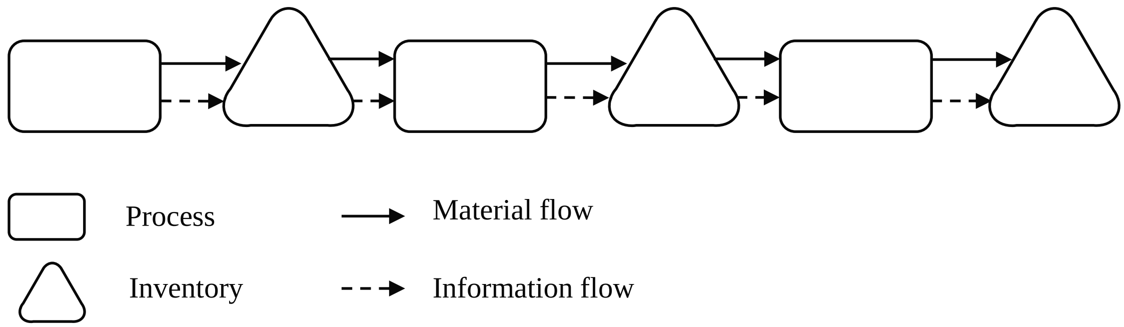


Figure 16: An illustration of the material- and information flow in a push system. It is developed based on descriptions of a push system from (Spearman & Zasanis 1992; Teeravaraprug & Stapholdecha, 2004; Hopp & Spearman, 2004).

Because of the predetermined production schedule, the lead times within a push system are typically relatively short and the work-in-process relatively low (Puchkova, Le Romancer & McFarlane, 2016; Teeravaraprug & Stapholdecha, 2004). However, with the lack of internal control a push system risks causing bottlenecks within the material flow due to its inability to make potential required adjustments if anything were to happen (Krishnamurthy, Suri & Vernon, 2004; Teeravaraprug & Stapholdecha, 2004). Thus, it could risk creating piles of material at processes that are experiencing issues or whose lead-times have been wrongfully calculated. Further, a push system commonly results in high inventory costs, reduced service levels, and a bigger risk of material becoming obsolete (Ghrayeb, Phojanamongkolkij & Tan 2009; Puchkova, Le Romancer & McFarlane, 2016).

A push system is preferable in situations with high fluctuations in demand and when unexpected issues arise (Ghrayeb, Phojanamongkolkij & Tan 2009; Puchkova, Le Romancer & McFarlane, 2016). This is because its high inventory levels can counteract such happenings. Furter, it is suitable at production sites that are producing a big variety of products and that have very distinctive demand or requirements on the production processes (Krishnamurthy, Suri & Vernon, 2004). Krishnamurthy, Suri, and Vernon (2004) also state that a push system is suitable in environments where complex products are engineered-to-order and produced in small lot sizes.

3.3.1.2 Pull flow

Hopp and Spearman (2004) describe a pull system as a system that does have limits regarding the work in process that can be within the system. A pull system can be described as a system in which products are produced upon either customer orders or to replace components taken for use (Spearman & Zasanis, 1992; Teeravaraprug & Stapholdecha, 2004). Teeravaraprug and Stapholdecha (2004) explain that there is an information flow in the system between a customer order and the finished product inventory or the final production process. If the order cannot be fulfilled within that process it will make an order from the preceding process and so on

(Teeravaraprug & Stapholdecha, 2004). The material- and information flow within a generic pull system can be seen illustrated in figure 17.

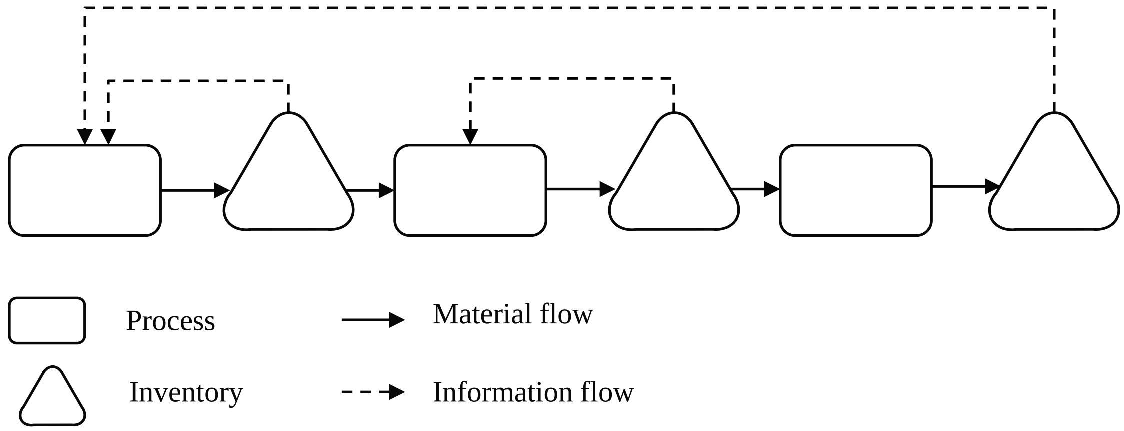


Figure 17: An illustration of the material flow and information flow within a generic pull system. Developed based on descriptions of a pull system from (Hopp & Spearman, 2004; Spearman & Zasanis, 1992; Teeravaraprug & Stapholdecha, 2004).

A pull flow is driven by customer orders and can, therefore, maintain low inventory levels (Zheng & Lu, 2009). However, Zheng and Lu (2009) state that it causes the pull system to require longer response times than a push system and it is more difficult to attain economies of scale. With a pull system it is easier to control the material compared to a push system, while also resulting in less congestion (Hopp & Spearman, 2004; Spearman & Zasanis, 1992). Ohno (1988) describes two requirements for a functional pull system. These are that the production needs to be level and that the work methods are standardized (Ohno, 1988). With a functional pull system, the work in process is lower and the lead-times are shorter than with a push system (Ghrayeb, Phojanamongkolkij & Tan, 2009; Teeravaraprug & Stapholdecha, 2004; Zheng & Lu, 2009).

A pull system is the most useful within an environment with a high percentage of throughput material (the percentage of material that successfully passes the processes within the system) and with downstream operations (Cheng & Podolsky, 1996; Hopp & Spearman, 2004; Teeravaraprug & Stapholdecha, 2004; Zheng & Lu, 2009). This is because the system can stop processes downstream when problems occur in earlier processes through its internal control. By stopping processes downstream, the system is preventing the material from piling up at certain processes (Cheng & Podolsky, 1996). Further, it can be argued that a pull system improves quality and reduces cost in comparison to a push system (Hopp & Spearman, 2004). This is due to the requirements of the system, in which it does not accept high levels of material loss and how it is more problem-solving oriented than a push system (Hopp & Spearman, 2004).

3.3.1.3 Hybrid push/pull flow

Not all systems are either applying a pull system or a push system (Bonney et al., 1999). Bonney et al. (1999) state that many material’s flows instead consist of systems that are combining the different systems. For instance, the flow between the component warehouse and production can be utilizing a pull system, while the flow between production and the finished goods warehouse are instead utilizing a push system. Typically, a hybrid system consists of push and pull subsystems with integration points between them (Puchkova, Le Romancer & McFarlane, 2016). The hybrid systems can be divided to either a vertically integrated system or a horizontally integrated system (Geraghty & Heavey, 2004). Geraghty and Heavey (2004) explain that the vertically integrated system consists of two levels where one utilizes a pull system and the other utilizes a push system, and the horizontally integrated system consists of only one level where different stages are controlled with different principles.

Combining the two principles can be advantageous, but only in some situations (Ghrayeb, Phojanamongkolkij & Tan, 2009). By creating a hybrid push/pull system the benefits from both systems could be used and result in an increase of profit (Puchkova, Le Romancer & McFarlane, 2016). A hybrid system is the most suitable option for flows that suffer from disruptive behavior and resource breakdowns (Puchkova, Le Romancer & McFarlane, 2016). However, Puchkova, Le Romancer and McFarlane (2016) state that in cases with issues regarding loss of quality of the product or without any disruptive behavior other flow strategies are preferable.

3.3.1.4 Comparing the material flow strategies

The different material flow strategies have different advantages, disadvantages, and environments that they are preferable in. To provide an overview of when to use different strategies a table have been created summarizing the strengths, weaknesses, and preferable environments for the different material flow strategies, see table 10.

Table 10: A summarization of the strengths, weaknesses, and preferable environments for different material flow strategies (Cheng & Podolsky, 1996; Geraghty & Heavey, 2004; Ghrayeb, Phojanamongkolkij & Tan 2009; Krishnamurthy, Suri & Vernon, 2004; Ohno, 1988; Puchkova, Le Romancer & McFarlane, 2016; Spearman & Zasanis, 1992; Teeravaraprug & Stapholdecha, 2004; Zheng & Lu, 2009).

	Push flow	**Pull flow**	**Hybrid push/pull flow**
Advantages	Short lead-times, low work-in-process.	Low inventory levels, easier to control, less congestion, improves quality and reduces cost	A combination of those of push flow and pull flow.
Disadvantages	High inventory costs, reduced service levels, bigger risk of material becoming obsolete.	Longer response times, more difficult to attain cost advantages through economies of scale	A combination of those of push flow and pull flow.
Suitable environment	Production sites that are producing a big variety of products that have very distinctive demand or requirements on the production processes, when complex products are engineered-to-order and produced in small lot sizes.	When the production is level, when the work methods are standardized, when it is a high percentage of throughput material, when it is downstream operations.	When flows suffer from disruptive behavior and resource breakdowns.

3.3.2 Design for a pull system

Redesigning or reengineering a process can be viewed as a tool or method for enabling improvements (O'Neill & Sohal, 1999; Persson, 1995; Van Ackere, Larsen & Morecroft, 1993). A general process reengineering framework considers the company as if it consists of multiple processes, where each of them have their own activities, decisions, information flows, and material flows (Kaplan & Murdock, 1991). The benefit of a general reengineering framework is that it includes cross-functional operations and can connect these with mutual strategic objectives (Kaplan & Murdock, 1991; O'Neill & Sohal, 1999). This means that the framework integrates activities within predetermined processes with the purpose of achieving specific goals. Further, Persson (1995) states that all businesses or segments within a business can be explained as several processes that are linked with each other, and the operations within them can be described as response cycles. Therefore, when redesigning a process, it is of importance to understand the entirety of the process and how it affects other processes within the business (O'Neill & Sohal, 1999). O'Neill and Sohal (1999) further state that one should focus on the goals rather than the task when redesigning a process.

To redesign and integrate strategies between processes a set of concepts were developed by Persson (1995). The three concepts are as follows: (1) operational characteristics of specified operations, (2) structural characteristics of specified process, and (3) managerial or administrative setting of specified process (Persson, 1995). Based upon these concepts Persson (1995) developed nine strategies for redesigning of logistics processes. Table 11 displays the nine principles and their implication.

Table 11: The nine principles for redesigning the logistics processes and their implication (Persson, 1995).

Principle	Implication
Reduce or redistribute lead times	Shorten the lead time by investigating the supply cycles and remove non-value adding activities and prioritize the most important products
Reduce or adapt to the uncertainties	Use available tools and methods for managing uncertainties
Redistribute or increase frequencies	Reduce inventory within processes by increasing frequencies and reduce lot sizes
Eliminate or adapt to expected pattern of demand	The pattern of demand is possible to change and to level the pattern can result in more effective utilization of capacities
Simplify structures, systems, and processes	Reduce the amount of logistics and simplify the processes
Differentiate	Find more efficient methods for categorizing systems, processes, and product groups
Postpone	Creates flexibility for tasks by not handling them until it is necessary
Improve the information processing and the decision support systems	Control systems should be supporting the decision maker and the information process should be consistent, simplified, and able to be substituted
Strengthen the internal and external integration	To help with differentiation internally and outsourcing it is important to have efficient internal and external integration

3.3.2.1 Design barriers for pull systems

Deleernyder et al. (1989) have identified three issues when designing a pull system: (1) identifying problems within the material flow and information flow, (2) flow line loading difficulties, and (3) operational control problems. To counteract these issues the resources and products must be considered at the same time, the workload must be balanced between the flow lines within the material flow, and the interaction between production and inventory level must be controlled (Deleernyder et al., 1989). Some other areas to consider when designing a pull system are if the different processes included are fully aligned in the system and if the flows are oriented with the physical structure of the company (Araújo, Alves and Romero, 2021; Sundar, Balaji & Sathessh Kumar, 2014).

An approach for designing is suggested by Lu, Yang, and Wang (2011) and Darlington et al. (2015) where they are suggesting two different step-by-step models for designing a pull system. These models have been combined to one model consisting of six steps that are displayed in figure 18.

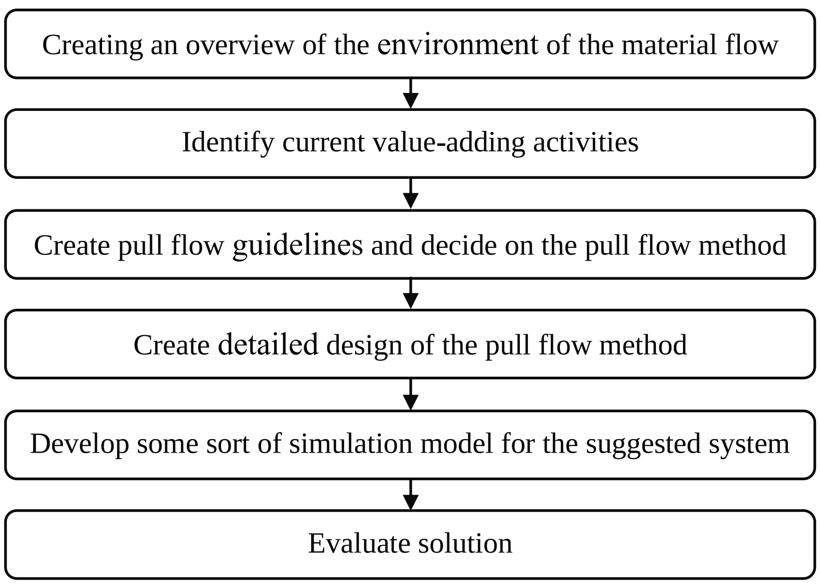


Figure 18: A suggested approach for designing a pull system adapted from Lu, Yang, and Wang (2011) and Darlington et al. (2015).

The first step of creating an overview of the environment of the material flow consists of gaining an understanding of the as-is state of the material flow and constructing a process activity mapping and an information flow mapping (Darlington et al., 2015). Identifying the current value-adding activities is the second step and this is done with the previous step as its base. It will help with highlighting the wastes and potential improvements and can be done by utilizing value stream mapping tools (Darlington et al., 2015; Lu, Yang & Wang, 2011). The third step consists of making decisions regarding whether to create a continuous flow or having it controlled, the cycle time, the pace of production, level scheduling to match production with cycle time, and decide on suitable pull flow methods (Darlington et al., 2015; Lu, Yang & Wang, 2011). When the guidelines are created and the pull flow method have been selected the rules of the system including allowed weekly demand, information systems to support it, and batching rules for the goods are set in the next step of creating a detailed design for the pull flow method (Darlington et al., 2015). Before implementing the developed pull system, it is necessary to test it and this is done by creating a simulation model (Lu, Yang & Wang, 2011). In the last step, the designed system is evaluated based upon the simulations in the previous step and these are compared with the performance of the current system (Lu, Yang & Wang, 2011).

3.3.2.2 Pull flow methods

Within pull systems, it can be distinguished when information regarding demand from the final process is sent and where it is being sent (Gstettner & Kuhn, 1996). Depending on the path the information flow takes different pull methods can be specified (Gstettner & Kuhn, 1996). Not all methods that could be classified as a pull system will be included within this section though. This is because of their characteristics. Three pull methods will be included and investigated within this section. These are: (1) Kanban, (2) Constant Work in Process (CONWIP), and (3) Hybrid Kanban/CONWIP (Gaury, Pierreval & Kleijnen, 2000; Gstettner & Kuhn, 1996). Typically, the choice of strategy is dependent on the given context (Gaury, Pierreval & Kleijnen, 2000).

Kanban is a method that limits the inventory level for each process included within the system by using cards (Gaury, Pierreval & Kleijnen, 2000; Huang & Kusiak, 1996). Gaury, Pierreval, and Kleijnen (2000) explain that the cards travel between two processes, and by regulating the number of cards between the processes, the amount of work allowed between them can be decided. The information flow within a kanban system travels in the opposite direction from the material flow allowing the material to arrive at the processes when they are needed (Huang & Kusiak, 1996). In figure 19 an example of a Kanban system is shown.

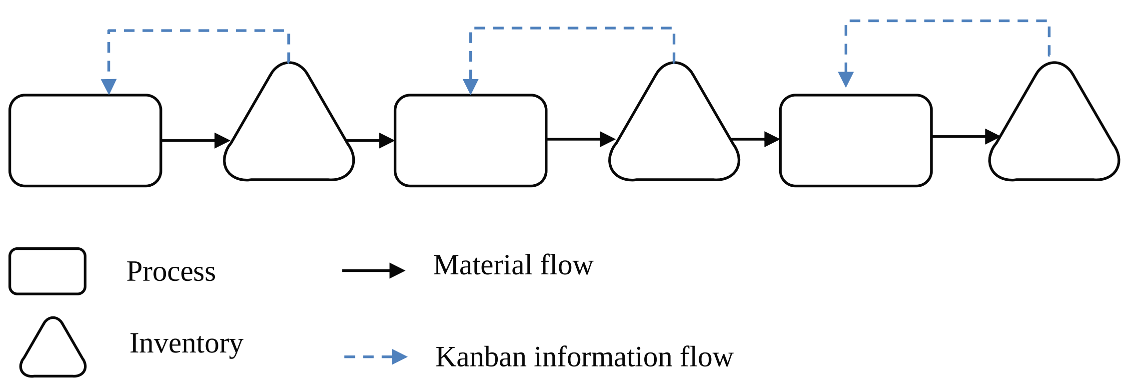


Figure 19: Displays a general Kanban system (Huang & Kusiak, 1996).

The main difference between a CONWIP system and a Kanban system is the path of the information flow (Gstettner & Kuhn, 1996). In a CONWIP system, the information is sent directly from the last process within the system to the first process in the system instead of having it sent between all the processes in between (Gstettner & Kuhn, 1996). There is no blocking between the processes within a CONWIP system due to the fact that the buffer at each process is assumed to be big enough to handle all the cards that are in circulation within the system (Gstettner & Kuhn, 1996). The main idea behind a CONWIP system is that it wants to have a high throughput of material, while simultaneously maintaining low inventory levels (Gaury, Pierreval & Kleijnen, 2000). In a CONWIP system, the same card is looping and controls all processes within the system (Gaury, Pierreval & Kleijnen, 2000). The cards are assigned for a specific system and get removed from the queue system once they are needed at the first process (Spearman, Woodruff & Hopp, 1990). If all cards already are associated with other orders, the new orders need to wait in a queue at the first process within the system (Jaegler et al., 2018). The different flows and interconnections within a generic CONWIP system can be seen in figure 20.

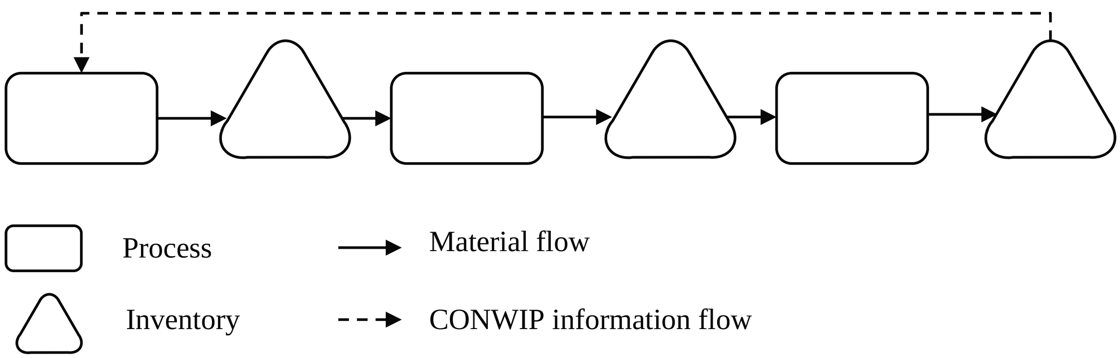


Figure 20: Display of a CONWIP system (Spearman, Woodruff & Hopp, 1990).

The purpose of a hybrid Kanban/CONWIP system is to try to reap the benefits from both methods (Gaury, Pierreval & Kleijnen, 2000). It works like a CONWIP system with the difference that some secondary cells that are controlled by Kanban are added to complement the CONWIP control (Leonardo et al., 2017). A generic hybrid Kanban/CONWIP system is displayed in figure 21.

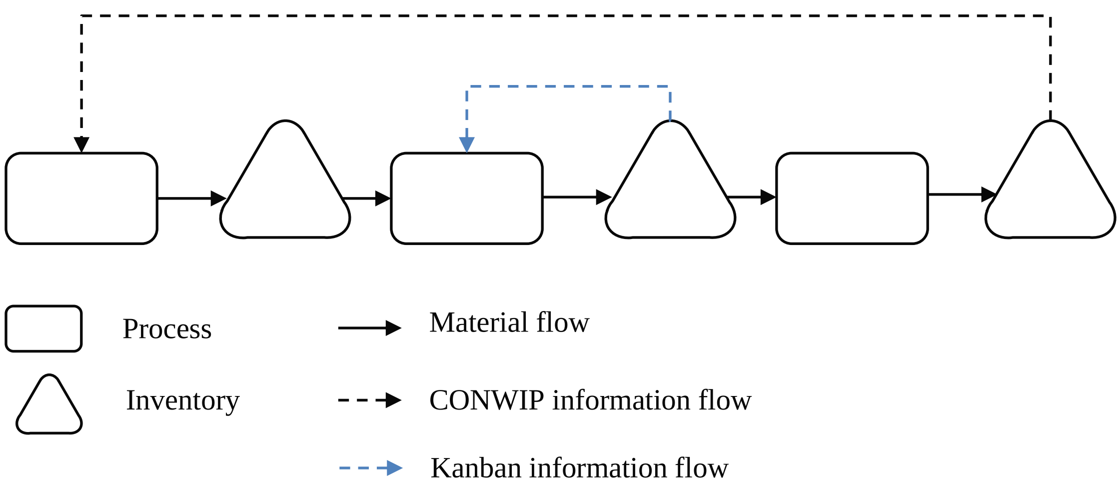


Figure 21: Displays an example of how a hybrid Kanban/CONWIP system could be designed (Gaury, Pierreval & Kleijnen, 2000).

3.3.2.3 When to use different pull flow methods

The different pull flow methods have different advantages and disadvantages (Jaegler et al., 2018; Spearman, Woodruff & Hopp, 1990). Therefore, it is of importance to gain an understanding of in what situations the different pull flow methods are appropriate.

The Kanban method is especially useful in environments where manufacturing is stable and the variability of products is low (Gaury, Pierreval & Kleijnen, 2000; Jaegler et al., 2018). The method has the advantage of allowing control of the inventory at each process (Gaury, Pierreval & Kleijnen, 2000). However, the Kanban method is slow to respond to demand changes (Leonardo et al., 2017). In comparison with Kanban the main advantage of CONWIP is that it can be used within environments where Kanban is not practical and it is more suitable for firms that are operating closer to their maximum capacity (Spearman, Woodruff & Hopp, 1990). Further, it is a more flexible system and is better at handling variety within products and product types (Jaegler et al., 2018). However, an issue with CONWIP is that the inventory levels within the system are not controlled at all processes (Gaury, Pierreval & Kleijnen, 2000). This means that material risks piling up at processes that require more time than others within the system. The hybrid Kanban/CONWIP method have the potential to both have a high throughput at a low level of work in process, while also having the benefit to at the same time have control of the inventory levels at most processes within the system (Gaury, Pierreval & Kleijnen, 2000). However, the method is more complex and difficult to implement than the methods of Kanban and CONWIP (Leonardo et al., 2017). In comparison with Kanban a hybrid system is preferable in situations with longer processes and with a higher degree of variability within the processes (Bonvik, 1996). In table 12 a summarization of the advantages, disadvantages and suitable environment for the different pull flow methods are displayed.

Table 12: A display of the advantages, disadvantages, and suitable environments for different pull flow methods (Bonvik, 1996; Gaury, Pierreval & Kleijnen, 2000; Jaegler et al., 2018; Leonardo et al., 2017; Spearman, Woodruff & Hopp, 1990).

	Kanban	**CONWIP**	**Hybrid Kanban/CONWIP**
Advantages	Control of the inventory at each process	More flexible and better at handling product variabilities	Control of the inventory at most processes and high throughput of material at a low level of work in process
Disadvantages	Slow to respond to change in demand	Inventory is not controlled at each process	More complex and difficult to implement
Suitable environment	Stable manufacturing and low product variability	When operating closer to maximum capacity	When working with longer processes and with a higher degree of variability in the processes

3.4 Information flow

Information sharing is of importance if a firm is to improve the performance of the material flow (Kembro & Selviaridis, 2015; Rai, Patnayakuni & Seth, 2006). Therefore, understanding the information flow and how information is shared can help improve the performance of processes within the supply chain. It has been discovered that transactions that once required the movement of people or goods can now instead be fulfilled through the traveling of information (Barwise & Seligman, 1997). It can be concluded that information flow plays an important role in integrating an internal supply chain (Cagliano, Caniato & Spina, 2005; Lee, Padmanabhan, & Whang, 1997; Singh, 1996). Singh (1996) states that the information must be valid, relevant, and available for it to be useful. Further, it is important to remember that the information by itself does not perform any operations, it is rather people using the information that does (Singh, 1996). Information flow can affect inventory control, the scheduling of production as well as general supply chain planning (Lee, Padmanabhan, & Whang, 1997). In an organization, the information flows either upstream, downstream, horizontally, or from an external source (Chen, 2003).

Within a supply chain three different information flow strategies have been identified: (1) Silent, (2) Communicative, and (3) IT-intensive (Vanpoucke, Boyer & Vereecke, 2009). Vanpoucke, Boyer and Vereecke (2009) state that these strategies are separated depending on their characteristics in terms of the level of information sharing, quality of the information, and what information technology that is utilized within the supply chain. Further, it is stated that the information flow strategy is dependent on contextual factors and that it influences performance factors (Vanpoucke, Boyer & Vereecke, 2009). This means that the choice of strategy affects not only particular processes, but entire systems or the entire supply chain of a company.

3.4.1 Information systems in general

Independent on what pull flow method systems utilize some sort of information flow solution is required (Gstettner & Kuhn, 1996). Therefore, it is important to make certain that the level of information sharing required is supported by the applied information systems available at the company (Vanpoucke, Boyer & Vereecke, 2009). Information systems work as enablers for improving the efficiency of processes regarding integrating, accessing, and using information within the firm (Klein & Rai, 2009).

Information systems are useful tools for managing many internal activities within processes and increasing the information flow within the supply chain (Lee & Leifer, 1992; Rizzi & Zamboni, 1999). For instance, implementing an information system like an ERP system is an effective way to integrate different functions (Rizzi & Zamboni, 1999). Information systems can be considered as a foundation for supporting optimization and redesigns (Rizzi & Zamboni, 1999).

3.4.2 Types of information systems

There exist many types of information systems for sharing information. Two information systems that are common within a warehouse and influence interacting functions are ERP systems and warehouse management systems (WMS) (Kembro, Danielsson & Smajli, 2017).

An ERP system can be described as a system that integrates processes and data that are linked with inventory, planning of production, human resources, and finances (Kembro, Danielsson & Smajli, 2017). The system enables a company to share information between its internal functions (Kembro, Danielsson & Smajli, 2017). Thereby, improving the efficiency of the supply chain. ERP systems are typically used with a relatively long planning time and cover all functions within a supply chain (Faber, de Koster, & Van de Velde, 2002; Kembro, Danielsson & Smajli, 2017; Olhager, 2013).

WMS is used for information regarding incoming and outgoing goods within a warehouse (Kembro, Danielsson, & Smajli, 2017). Kembro, Danielsson and Smajli (2017) and Min (2006) explain that the information system is used with the purpose of gaining an overview of tasks that are completed and tasks that are upcoming by tracking inventory and managing resources. The planning horizon of a WMS is shorter than that of an ERP system and it is required of a WMS to be able to communicate with other information systems for performing some of its tasks (Faber, de Koster, & Van de Velde, 2002).

An information system that can support an ERP system and is used in most manufacturing industries is the manufacturing execution system (MES) (Saenz de Ugarte, Artiba & Pellerin, 2009). MES is used at the entire manufacturing process, and it provides information about production activities across the supply chain (Saenz de Ugarte, Artiba & Pellerin, 2009). The purpose of the system is to ensure that the demand on manufacturing companies can be fulfilled within a specific market and its planning horizon is shorter than that of an ERP system (Saenz de Ugarte, Artiba & Pellerin, 2009).

3.4.3 Tracking technologies

Tracking technologies are used by companies to identify material and keep track of its locations within its supply chain (Chanchaichujit, Balasubramanian & Charmaine, 2020; Huang et al., 2017; Kelepouris & McFarlane, 2010; Zhu, Mukhopadhyay & Kurata, 2012). Within a warehousing and production setting two types of tracking systems are commonly discussed. They are RFID and RTLS (Kelepouris & McFarlane, 2010; Zhu, Mukhopadhyay & Kurata, 2012). RTLS is a development of RFID and is more accurate (Liu et al., 2007; Zhu, Mukhopadhyay & Kurata, 2012).

RFID and RTLS systems consist of two parts. These are a tag and a reader (Kelepouris & McFarlane, 2010; Zhu, Mukhopadhyay & Kurata, 2012). However, they are also reliant on having a linkage with a computer system (Rácz-Szabó et al., 2020; Zhu, Mukhopadhyay & Kurata, 2012). The tag is collecting data in real-time and is then transmitting this data (Zhu, Mukhopadhyay & Kurata, 2012). The difference between RFID and RTLS is the technologies they are using to transmit data. RFID is using radio waves and RTLS uses different types of digital wave technologies such as ultra-wideband and Bluetooth (Liu et al., 2007; Zhu, Mukhopadhyay & Kurata, 2012).

Tracking technologies can help with improving operations and be used as a trigger for different processes (Chanchaichujit, Balasubramanian & Charmaine, 2020; Munoz-Ausecha, Cesar, Ruiz-Rosero & Ramirez-Gonzalez, 2021; Zhu, Mukhopadhyay & Kurata, 2012). Further, it develops collaboration between a company's processes, and it have the potential to both improve the product quality and reduce the production costs (Chanchaichujit, Balasubramanian & Charmaine, 2020; Zhu, Mukhopadhyay & Kurata, 2012). However, tracking technology is relatively expensive, and it is not completely reliable since it can experience disturbances for its waves (Azevedo & Carvalho, 2012; Huang et al., 2017; Kelepouris & McFarlane, 2010; Liu et al., 2007; Zhu, Mukhopadhyay & Kurata, 2012).

The tracking technologies are especially useful for larger companies (Azevedo & Carvalho, 2012; Munoz-Ausecha, Cesar, Ruiz-Rosero & Ramirez-Gonzalez, 2021). It is typically used in sectors that require a closer monitoring of the materials in movement or within complex material flows (Chanchaichujit, Balasubramanian & Charmaine, 2020).

3.4.4 Information flows in manufacturing firms

Firms that have better links between there production and its other functions are performing better (Dimitriadis & Koh, 2005). Dimitriadis and Koh (2005) further state that production units should develop their own information flow links to ensure these are not ignored by any system. Both Powell (2013) and D'Amours et al. (1999) agrees with this view and believes that it can result in reduced costs and shortened lead times.

For a successful implementation of new systems such as a pull system, the implementation is reliant on having a proper organizational communication and information management (Forza & Salvador, 2001). Forza and Salvador (2001) also state that the implementation is required to be process-oriented to improve the performance of the firm. This means that a firm needs to have a holistic view when considering the different activities within the firm. Further, all tasks that are assigned to employees should come with information regarding what they are supposed to do, how they can track their actual performance, and how they can regulate their own process (Forza & Salvador, 2001).

The information flow has different requirements depending on the purpose of the information flow (Forza & Salvador, 2001). Further, most of the identified information needs for manufacturing firms are external and mainly addressed through informal contacts with personal sources (Dimitriadis & Koh, 2005). In other words, this means that most information flows through human interactions. The requirements for an efficient information flow in different situation for manufacturing firms in table 13.

Table 13: A display of what is important to consider regarding the information flow for different situations. Based upon Forza and Salvador (2001).

Information flow for:	Guidelines
Process Control	1. Information showing problems in real-time should flow horizontally. 2. Information showing problems that cannot be dealt with on a lower hierarchical level, exceptions in reports and KPIs should be flowing upwards. 3. The communication is enabled through charts, schemes and graphs that shows the performance of cells, lines, and departments on the shop floor.
Supporting transformation of processes	1. Information flows regarding routines, reported information and identified improvement opportunities should flow vertically upwards to help managers individuating all improvement opportunities. 2. Smaller vertical information flows present orders, directives, and feedback information for the state of the improvement initiatives. 3. There are teams with focus on improvements consisting of different kinds of knowledge for problem solving support that is providing information vertically and horizontally. 4. Make certain that external information is exchanged with suppliers with the purpose of identifying and striving for improvement 5. Efforts for improving are involving all hierarchic levels and focused on providing vertical downwards communication regarding the firm’s priorities competitive-wise.
Planning	1. Gather information on the demand of future market through communication with customers and adapt within the chain through communicating it both horizontally and with external communication channels. 2. Different planning cycles are coordinated based on information gained through smaller bottom-up communication monitoring processes accomplishments. Thereafter communicated to lower hierarchical levels. 3. Decisions made regarding the different planning cycles should involve information flows on all directions. Bottoms-up regarding process capabilities and intense communication both horizontally and externally between the different decision makers.
Flow Control	1. Thinner top-down communication telling detailed plans and faster external communication from customers starts forecast-driven and order-driven operational activities. 2. Fast flow of information regarding actual demand and co-ordination of feedback flow is ensured by intensive communication both internally and externally with suppliers. 3. Tracking of performance and status is gathered and used at lower hierarchic levels and flows to higher hierarchic levels only in report-format.

3.5 Lean principles and tools

The concept of lean has been around since the 80s when the Toyota production system was introduced with the purpose of removing wastes and inconsistencies within a production system (Bhamu & Singh Sangwan, 2014; Jasti & Kodali, 2015). This is supposed to be achieved through the removal of non-value adding activities and improvement of the quality of the product (Bhamu & Singh Sangwan, 2014; Jasti & Kodali, 2015). The term value is defined based upon the customer's perspective (Hallgren & Olhager, 2009). This means that a value-adding activity is an activity that improves the end customer's perception of the product, and a non-value-adding activity is something that does not influence it. There are many tools for the concept of lean and some of the more familiar tools are value stream mapping, Kanban, and pull production (Bhamu & Sangwan, 2014; Jasti & Kodali, 2015). To actively utilize lean thinking it exists five principles to fulfill and these are: (1) the definition of value is based upon how it is perceived by the end customer, (2) the value stream is identified, (3) the purpose of flow is to make certain that the value-creating steps flow, (4) the concept of pull is referring to utilizing a pull schedule, and (5) striving towards achieving perfection by making continuous improvements (Hallgren & Olhager, 2009; Womack & Jones, 1997).

3.5.1 Seven wastes within warehousing and production

In lean, wastes refer to things that add costs without adding value for the end customer (Jasti & Kodali, 2015). Jasti and Kodali (2015), and Hines and Rich (1997) identify seven types of wastes that are related to lean production, and these are (1) defects, (2) unnecessary inventory, (3) waiting, (4) transportation, (5) inappropriate processing, (6) overproduction, and (7) unnecessary motions. When considering wastes within production not all of them are equally researched (Jasti & Kodali, 2015). The wastes can have different meanings depending on the area in which they occur (Abushaikha, Salhieh, & Towers, 2018). Abushaikha, Salhieh and Towers (2018) have been inspired by the wastes within lean production and investigated how these could be translated to a warehouse environment. The seven wastes and what they refer to within production and warehousing are displayed below in table 14.

Table 14: Seven wastes within production and warehousing adapted from Jasti and Kodali (2015), Hines and Rich (1997), and Abushaikha, Salhieh and Towers (2018).

Waste	Definition within production	Definition within warehousing
Defects	Mistakes in production that results in direct costs (re-work or extra work).	Picking wrong quantities or items for orders.
Unnecessary inventory	More goods in inventory than required.	Producing above demand in production may result in accumulated inventory in the warehouse; Safety or buffer stocks in the warehouse.
Waiting	All times when employees are ready to continue their work, but different processes do not allow them. Therefore, the goods are not being worked on.	All times when employees are ready to continue their work, but different processes do not allow them.
Transportation	All unnecessary movement of goods or employees.	All unnecessary movement of goods, employees, or forklifts.
Inappropriate processing	Any occasion when solutions are more complex than necessary.	All occasions when the same information needs to be re-entered; Movements of the same goods by more than one forklift.
Overproduction	Producing more than the demand.	Picking and preparation of goods before these have been ordered.
Unnecessary motions	All movements by employees that is not necessary for the production.	All movements by employees with items not stored at correct storage locations in the warehouse.

3.5.2 Value stream mapping

Value stream mapping tools are used to evaluate if any of the seven wastes are present (Hines & Rich, 1997). Hines and Rich (1997) present seven different value stream mapping tools that depending on the situation are appropriate to use. The tools presented by the authors are the following: (1) Process activity mapping, (2) supply chain response matrix, (3) production variety funnel, (4) quality filter mapping, (5) demand amplifier mapping, (6) decision point analysis, and (7) physical structure. Process activity mapping described by Hines and Rich (1997) is suitable to use to identify wastes of waiting, transport, inappropriate processing, unnecessary motions, and unnecessary inventory. The possibility to identify these wastes indicates that process activity mapping is useful in a scenario where material flow between a warehouse and production should be evaluated. Even though Hines and Rich (1997) present seven tools of VSM, process activity mapping is commonly used interchangeably with VSM (Braglia, Carmignani, & Zammori, 2006;

King, 2019; Langstrand, 2016). Therefore, moving forward VSM is used interchangeably with process activity mapping.

The procedure of VSM described by e.g., Hines and Rich (1997), King (2019), and Langstrand (2016) has been criticized by e.g., Lian and van Langstrand (2002), and Braglia, Carmignani, and Zammori (2006) due to not being applicable in situations where there is not a standard line production with large volumes. Braglia, Carmignani, and Zammori (2006) try to counteract this criticism by developing and presenting a step-by-step guide for VSM in complex production systems. Their step-by-step guide is (1) select a product family, (2) identify machine sharing, (3) identify value stream, (4) map the critical paths, (5) identify and analyze wastes, (6) construct future map, and (7) identify new critical paths. In figure 22 the steps are depicted.

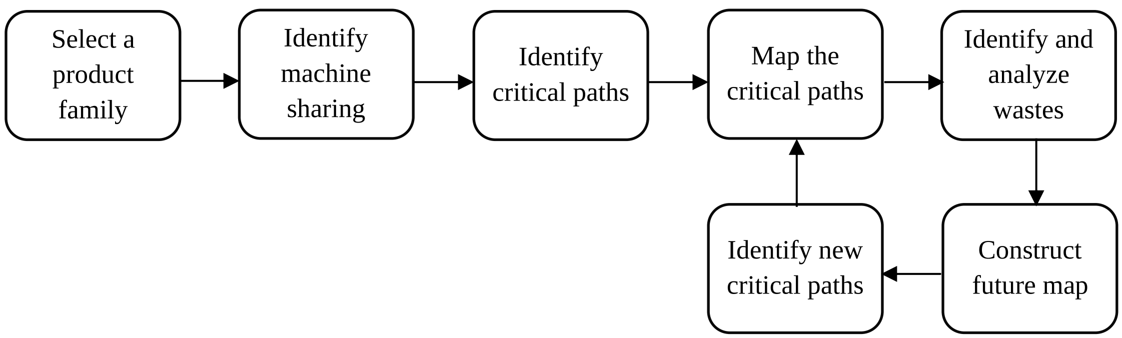


Figure 22: Step-by-step guide for VSM in complex production systems according to Braglia, Carmignani, and Zammori (2006).

In step 1 different product families are identified and defined, and in step 2 the machines that are being shared between the families are identified. Further, in step 3 the path that is critical to the different families is identified. Braglia, Carmignani, and Zammori (2006) have defined the critical path as the processes that a product in a product family needs to move through from the component warehouse to the finished goods warehouse. Continuing, step 4 is mapping the identified critical paths with the help of snapshot data. Examples of data that could be collected are order frequency, inventory level, lead times, and batch sizes. In step 5 the waste is identified with the help of the constructed map of the critical paths. The identified waste is further analyzed to find out its implication. Further, in step 6 a future map is constructed where the solution to the identified waste is displayed. The final step is to identify new critical paths that might emerge from the created solution. Steps 4-7 can be seen as an iterative process.

3.6 Analytical framework

The analytical framework is used as a guideline when conducting the data collection and analysis. The end goal of the analytical framework is to develop two types of propositions. Namely, decision propositions and design propositions. The first type is related to RO3, and it is about determining when a pull system, push system or a hybrid push/pull system is appropriate. The second type concerns RO4 and that is about describing how a pull system can be designed in a specific situation where it is deemed appropriate to have a pull system. The developed analytical framework is inspired by the adapted pull design approach by Lu, Yang, and Wang (2011), and Darlington et al., (2015), see figure 18.

The analytical framework has its starting point in RO1, where the goal is to map the current state, identify the contextual factors at Tetra Pak, and gain an understanding of how the material flow is configured. Contextual factors are defined as things that cannot be changed, but instead factors to adjust according to when redesigning the material flow. Four parts is of interest when mapping the current state. They are (1) the configuration of the production and the warehouse, (2) operations linking the warehouse and the production, (3) material flow characteristics, and (4) information flow characteristics.

Firstly, the configuration of the production and the warehouse regards identifying the layout of the warehouse and the production, how the production is set-up, and the product characteristics. The configuration play an important role in understanding the contextual factors of the warehouse and the production. Secondly, all the operations linking the warehouse and production are of interest. More precisely, picking, distribution, and receiving in production. By understanding these operations, it is easier to identify where wastes are. Thus, it supports waste identification. Thirdly, the material flow characteristics covers dividing the entire material flow into smaller flows of material, demand characteristics (e.g., weight, orders, type of product, to which unloading point), and component characteristics (e.g., number of components). Finally, the information flow needs to be described when mapping the current state. When investigating the material flow at Tetra Pak, three functions are relevant. These are the warehouse, the production, and the order handling. Therefore, it is the information flow interaction between these three functions that should be described and investigated. Described and investigated refers to what systems there are to facilitate information sharing, when the interaction occurs, and how often the interaction occurs. With the four areas investigated and described the current state is mapped and understood, see figure 23.

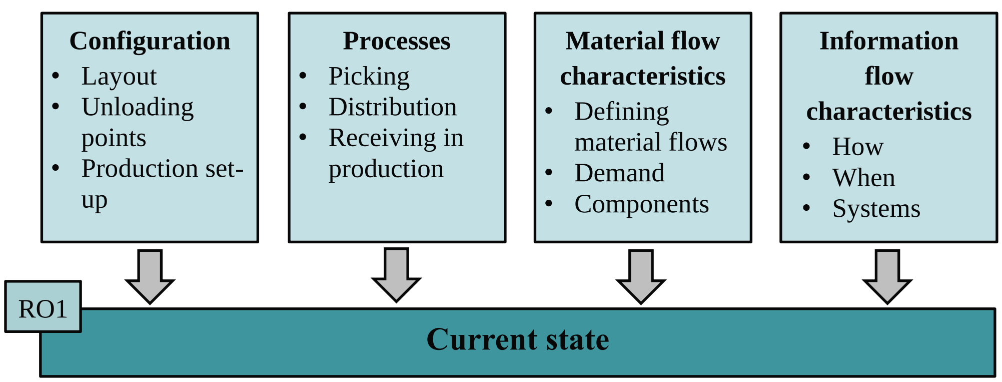


Figure 23: The first part of the analytical framework, which is used to construct and understand the current state.

The analytical framework continues with evaluating the performance of the current state. The performance is evaluated by identifying potential wastes in the current state, meaning that wastes are seen as an indicator of the performance. Inspiration is drawn from the VSM guide presented by Braglia, Carmignani, and Zammori (2006) when identifying the wastes, see figure 22. More precisely the tool is modified to fit the purpose of looking at the waste in a material flow between a component warehouse and the production. Firstly, step one to three is batched together. This regard selecting a product family, identify machine sharing, and identify critical paths. This is done when mapping the current state in which the material flow has been divided into smaller flows of material. Secondly, step four and five is being carried out as they are described by Braglia, Carmignani, and Zammori (2006). These are the steps in which the critical paths are mapped, and wastes are identified and analyzed. Thirdly, the last steps of constructing a future map and identifying new critical paths are not carried out. The knowledge gained both from mapping the current state and waste identification is used as input to the next step, the analysis of the material flow characteristics, see figure 24.

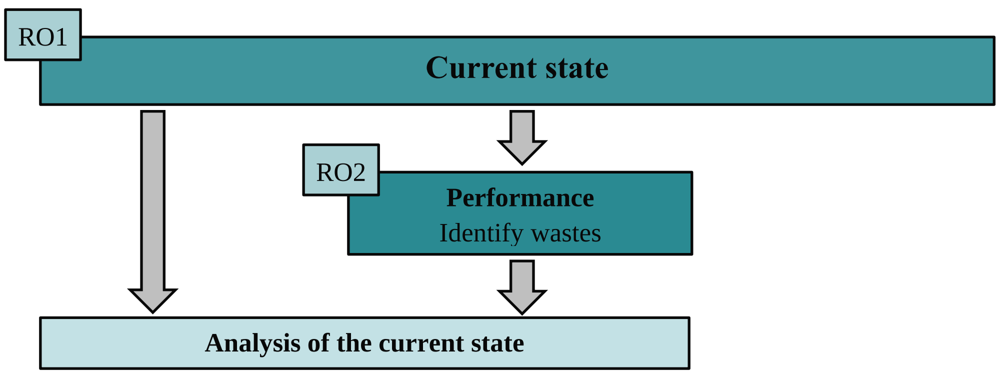


Figure 24: The second part of the analytical framework is to understand the performance of the current systems.

By finishing the evaluation of the performances, the part of understanding the situation is concluded. The next part is to design a fitting system. The output of this is decision propositions and design propositions. Further, the course of action to create the propositions is divided into two steps. Firstly, decision propositions are created by investigating which parts of the material flow that is suitable for utilizing a push system or a pull system at Tetra Pak PCL. Secondly, design propositions are created by designing pull systems in those situations where pull is deemed suitable.

Developing decision propositions is related to RO3. As input to developing decision propositions the current state and the identified wastes are used together with the literature findings from the frame of reference. The first step is to compare the contextual factors and characteristics of the situation at Tetra Pak PPCL with the literature findings on when it is appropriate to use a push or a pull system. The second step is to evaluate if any suitable changes can be implemented to change the decision between pull and push in pull's favor.

Four characteristics were found to be relevant when evaluating if there should be a push system, a pull system, or a hybrid push/pull system. The four characteristics are (1) demand varieties, (2) the complexity of production, (3) the variety of products, and (4) disruptive behaviors. These characteristics have been identified with the help of the frame of reference. Demand variety is how much the volume of material flow varies between the months during a year. There are different methods of measuring demand variety. Jonson and Mattson (2016) mention that two of these methods are mean percentage deviation error (MPE), and absolute mean percentage deviation error (MAPE). Mean percentage deviation error is the ratio between the deviation from the mean demand and the mean demand. Absolute mean percentage deviation error is the ration between the absolute mean demand deviation and the mean demand. The complexity of production is about how stable the production is. To evaluate the complexity criteria such as the number of processes, variety in time of processes, how standardized the processes are, and if the processes are in the same order, are considered. Variety of products is how many different products are produced, but also how large a difference there is between the products produced. For example, there might be four products. However, the only difference between them is the size, then the variety is relatively low. On the other side, if two products have a completely different purpose and are produced in different ways, then the variety is high. Disruptive behavior is the final characteristic and is different from the other three characteristics due to it being an indicator if a change is needed. Thus, if it is much disruptive behavior in a specific material flow, its strategy should be investigated and potentially changed. This characteristic is evaluated with the help of the identified wastes in the previous step of evaluating performance. Wastes are non-value-adding activities. These activities are usually a result of disruptive behaviors. Thus, using them as indicators is suitable.

Further, in the second step different factors could be considered for change such as layout, demand leveling, order structures, etc. However, due to the limitation of time and Tetra Pak PPCL's interest in tracking technologies, the focus in Tetra Pak's situation will be if any tracking technologies could change the decision between utilizing a pull system versus push system into a pull systems favor.

The first and second steps, related to RO3 leads to identified situations at Tetra Pak where either a push system, a pull system or a hybrid push/pull system have been deemed appropriate to utilize. The identified situations are further used to develop decision propositions together and works as an input to the next step of designing a pull system. A summary of the approach to develop decision propositions is presented in figure 25.

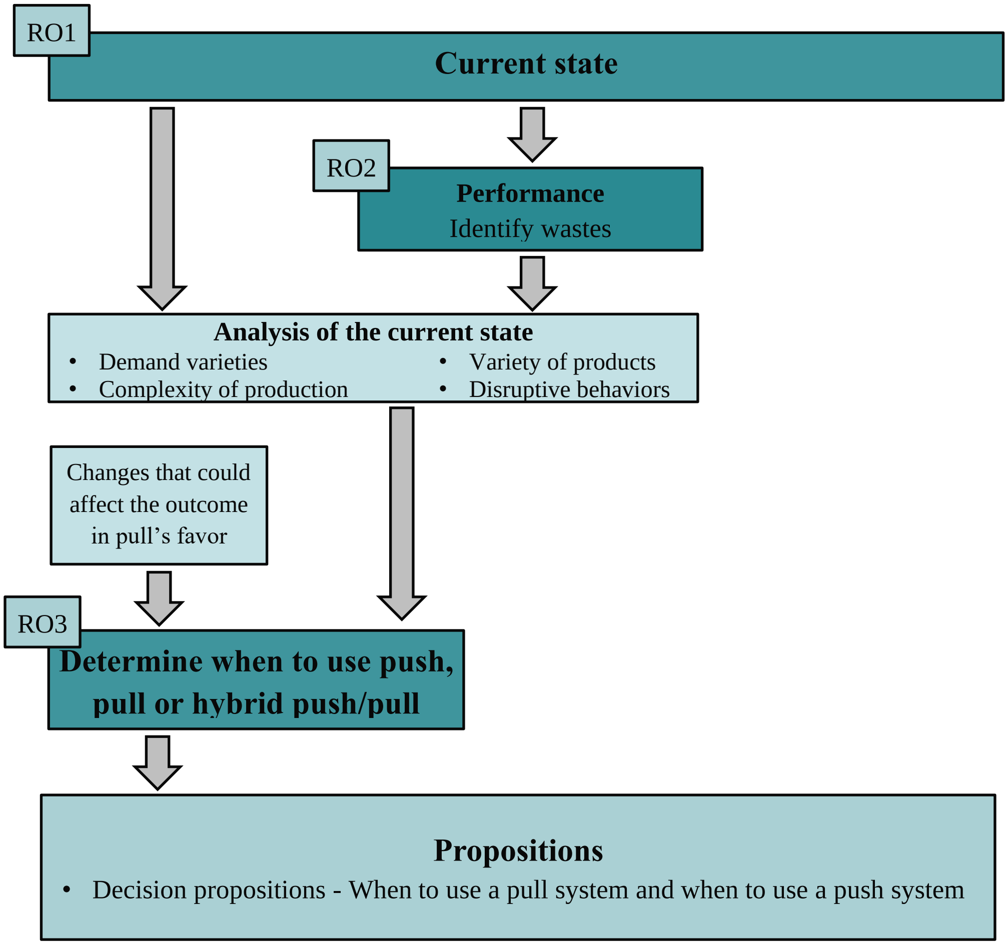


Figure 25: The approach for developing decision propositions for when to use a pull system or a push system.

Developing design propositions is related to RO4. When creating the design propositions the current state and the decision propositions are used as the input. Within developing design propositions there are two steps. The first step is choosing an appropriate type of pull system method and the second step is to suggest adjustments to the current state, so it fits the chosen pull system method. In the first step, the knowledge gained from the current state together with literature about when different methods are appropriate is utilized. As a foundation, it is the literature that is summarized in table 12 that is used when deciding. In the second step, it is adjustments for the set-up of the material- and information flow interaction between the warehouse, production and the order handlers that is of relevance. To develop the adjustments the knowledge gained from the current state is used, together with literature about material flow, information flow, warehouse operations, and lean principles and tools.

From the two steps related to RO4, the output is design propositions and suggested adjustments for Tetra Pak PPCL. It is with the help of the design propositions, the suggested adjustments for Tetra Pak PPCL are created. A summary of the approach for developing design propositions is presented in figure 26.

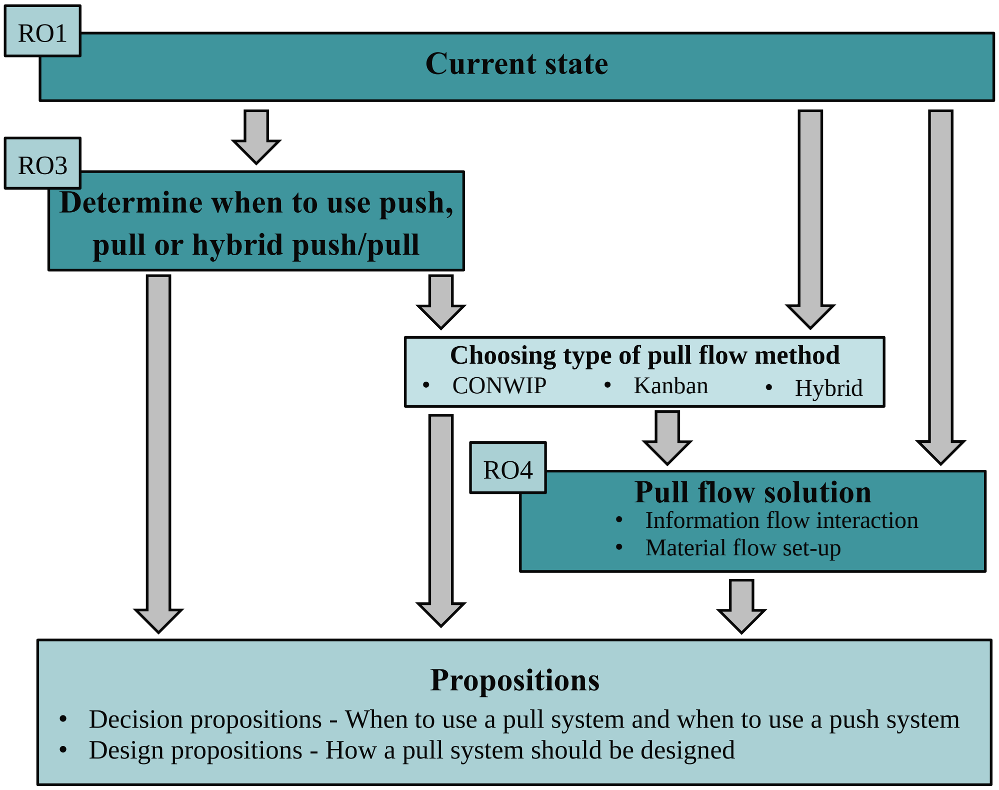


Figure 26: The approach for developing design propositions.

By combining figures 23, 24, 25, and 26 the entire analytical framework can be constructed. The entire analytical framework is presented in figure 27. The output of the analytical framework is decision propositions and design propositions. More precisely the decision propositions consist of when it is appropriate to have a pull system and when is it appropriate to have a push system. Further, the design propositions include how different pull systems should be configured in a specific situation when it is deemed suitable to have a pull system.

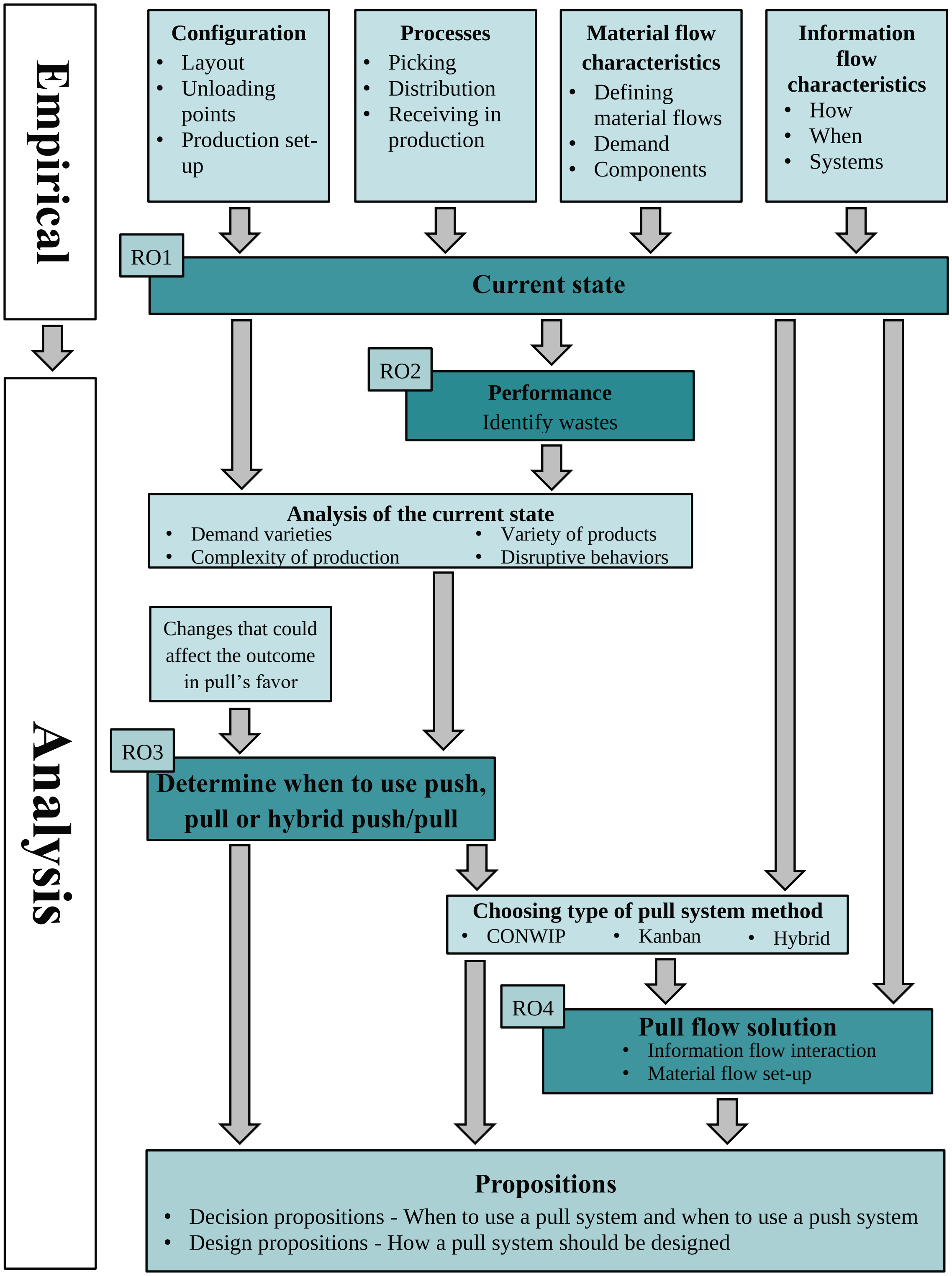


Figure 27: The analytical framework. It is created by combining figures 23, 24, 25, and 26.

4. EMPIRICAL FINDINGS

This chapter will describe the current situation regarding the linkage between the yard, warehouse 111 and the PPCL production site in Lund. The first section will describe the configuration of the warehouse and the production. This includes descriptions of the layout of both functions, existing unloading points, and detailed explanations of the three different product types that PPCL's production site in Lund is producing. The second section is describing the different processes that are included within the material flow between warehouse 111, the yard and the PPCL production site. The characteristics, including dividing the material flow into smaller flows of material, the demand of the material flow and characteristics of the components will be covered in the third section. The fourth and final section describes how information is transferring between the functions. Thus, this chapter satisfies the first research objective of the thesis. The outline of the chapter is summarized in figure 28.

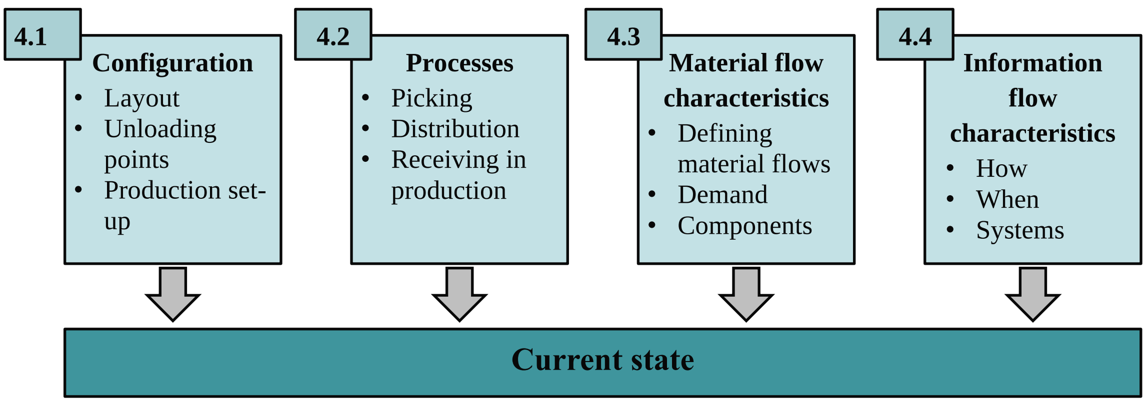


Figure 28: Outline of the empirical findings chapter.

4.1 Warehouse and production configuration

4.1.1 Warehouse and production layout

The warehouse consists of one large building that is divided into two parts and an outside area called the yard consisting of three parts. All material for the PPCL production site flows through warehouse 111 or the yard. The two parts that constitutes warehouse 111 will hereby be referred to as warehouse 111S and warehouse 111N. There exist three different product categories that are storing components at warehouse 111 and the yard. These are Homogenizers/High pressure Pumps (HP), Branded Processing Units (BPU) and tubular heat exchangers (HT). Warehouse 111S is the bigger part of building 111 and the area is separated from 111N by an inner wall. At warehouse 111S components for the three product categories that is frequently picked is being stored. Warehouse 111N is a cold storage warehouse and it stores large components (one item requires one pallet slot) and slow-moving goods. It is also being used as a buffer storage for occasions when material cannot fit into warehouse 111S. The yard is storing pipes, bodies, bundles, and tubes. Further, warehouse 111S also have an area in which pipes are processed. This area is regarded as not being part of the material flow from warehouse 111S to the PPCL production. The layout of warehouse 111 and the layout of the yard areas connected to it can be seen in figure 29.

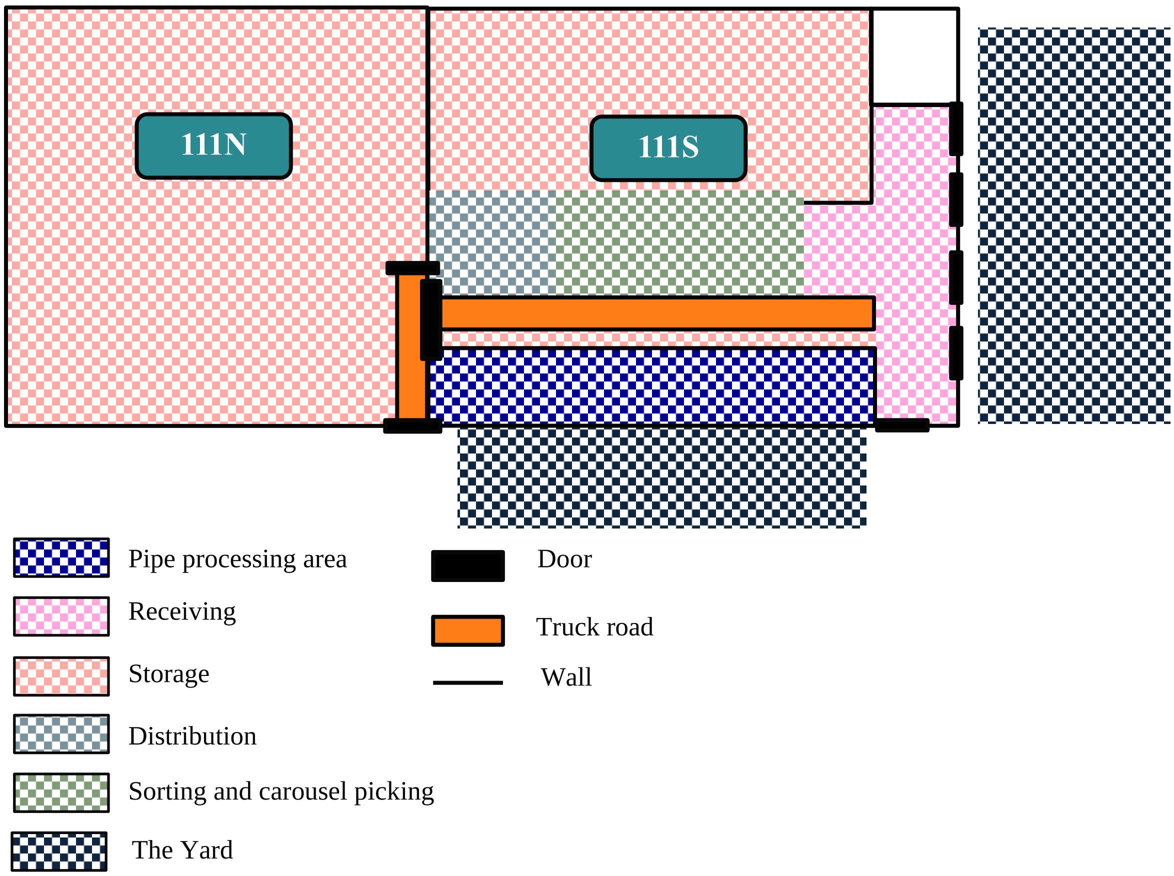


Figure 29: Layout of warehouse 111 and the yard areas connected to it.

The production consists of four buildings that are connected to one another, and the buildings are performing different processes within them. Building 105 is responsible for heat exchangers and homogenizers, building 106 is responsible for manufacturing BPU and BPU testing, building 107 is responsible for assembly of BPU and building 108 the final testing of BPU. Outside of the production site some outdoor storage areas exists that are referred to as the yard. The layout of the production site including where the different processes are being done, the outside storage areas connected to it and the truck roads can be seen in figure 30.

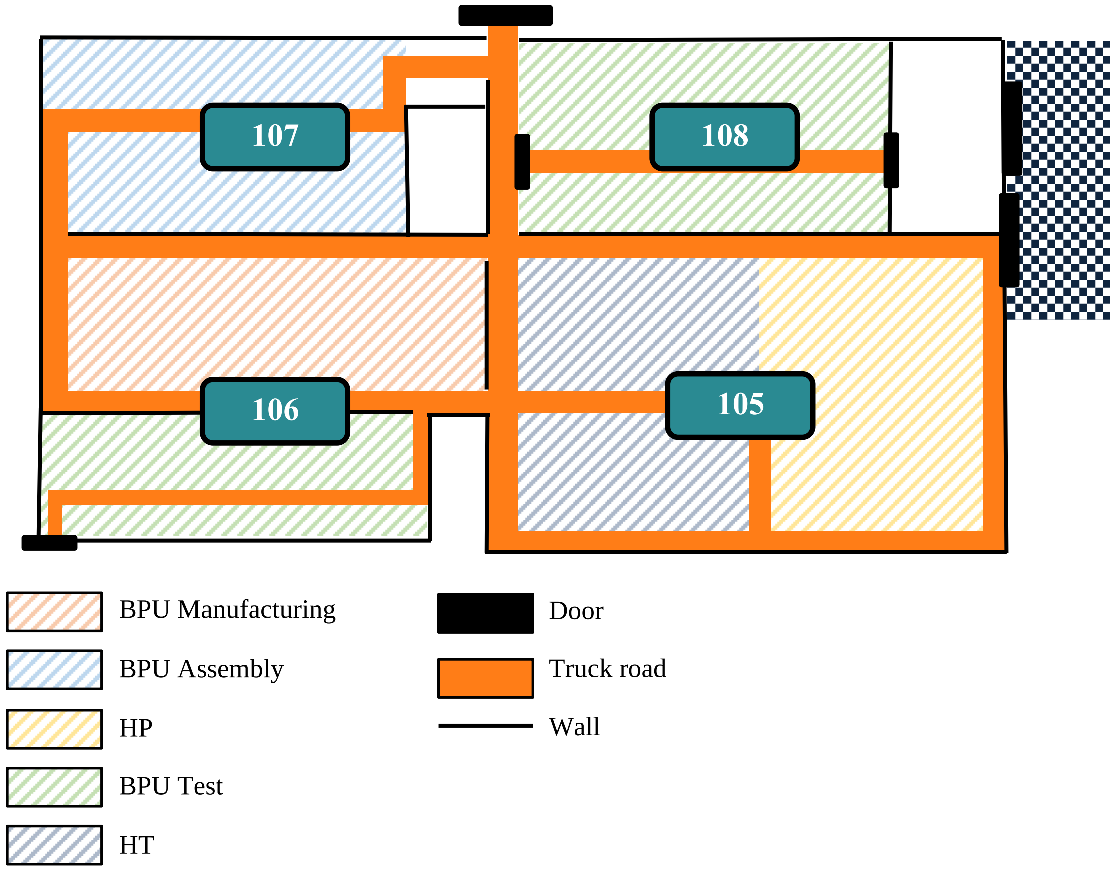


Figure 30: Layout of the PPCL (building 105-108) production site.

4.1.2 Warehouse and production unloading points

The material flow from the warehouse is delivered to so called unloading points. In simple terms unloading points are a designated area that stores the material that is delivered from the warehouse. It is from the unloading point people in respective production process pick their components or people that is kitting retrieve material for kitting. There has been a small change in how the unloading points are set up in the end of 2021, due to component shortages. However, the intention is that Tetra Pak PPCL will move back to the previous set-up. Thus, it is the old setup of unloading points that will be discussed and presented. There are in total 35 unloading points spread out in the warehouse and production, see Appendix II. These have been grouped into 15 unloading point categories based on their location and product type, see Appendix II for the categorization of unloading points

In the PPCL production site 31 out of the 35 unloading points are located and these corresponds to 11 out of the 15 unloading point categories. The unloading point categories are spread out between the different production areas and buildings. In the PPCL production site 11 unloading points and 1 unloading point category are linked to the HP production, 6 unloading points and 3 unloading point categories are linked to the HT production, and 15 unloading points and 9 unloading point categories are linked to the BPU production. Further, the rest of the unloading points and categories are in warehouse 111S. There are 2 unloading points and 1 unloading point category at the pipe processing area and 2 unloading points and 2 unloading point categories within the warehousing part of warehouse 111S.

A detailed list of all existing unloading points with a short description together with their corresponding unloading point category and product type is presented in Appendix II. The location of different unloading categories in warehouse 111 and the PPCL production site can be seen in figure 31.

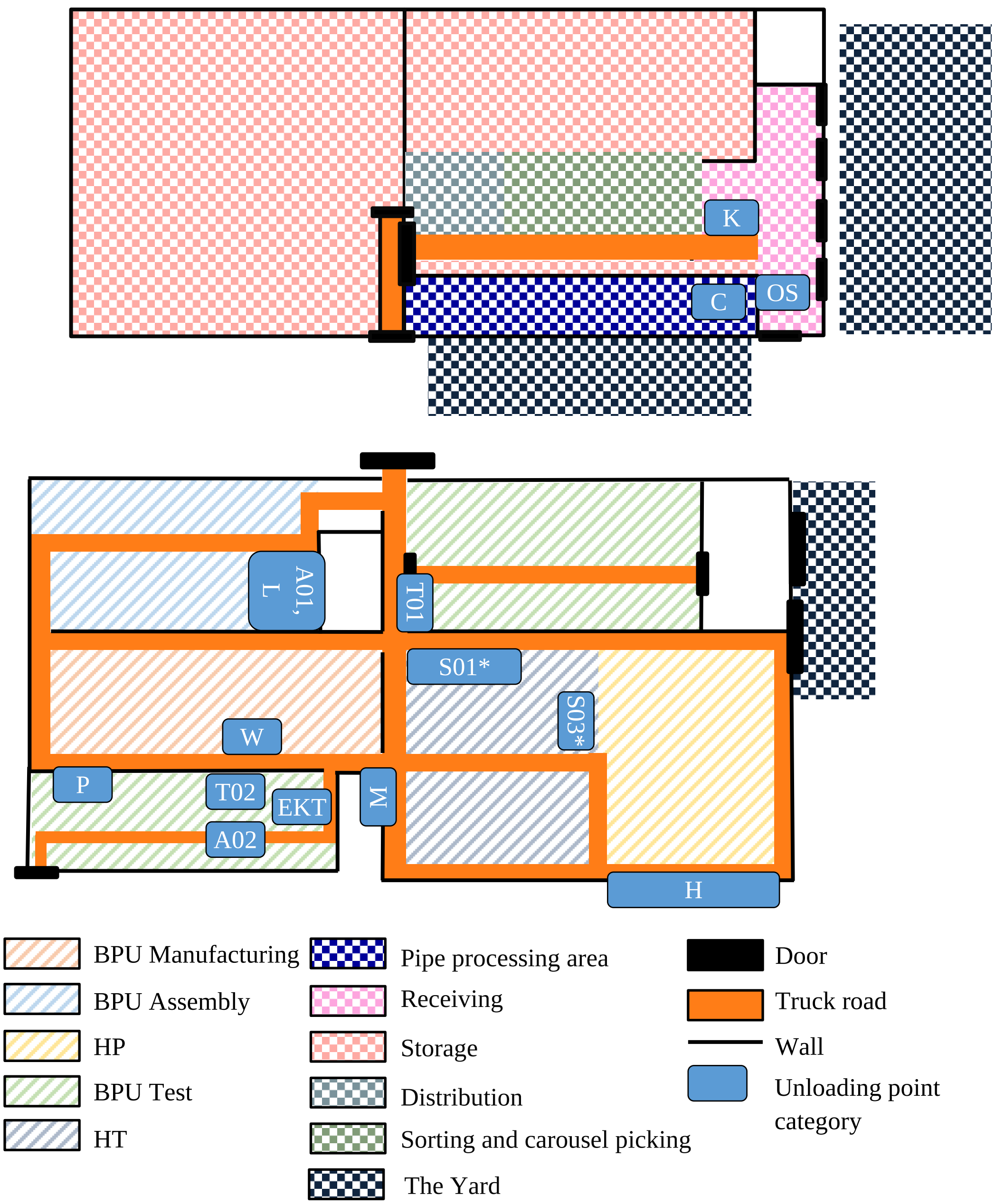


Figure 31: Displays the locations of unloading point categories in the PPCL production site and warehouse 111. For a full list of which unloading points that are included in each of the unloading point categories, see Appendix II. *Unloading points S01 and S03 belongs to the same unloading point category but are displayed as separate in the figure due to their separate locations at the PPCL production site.

4.1.3 Production configuration

The production site is producing three types of products (HP, BPU, and HT). Most of the products are produced according to the production strategy of engineer-to-order. However, in some scenarios when producing HT, they are being produced with a make-to-stock strategy. The make-to-stock strategy in HT productions is used when heat exchanger components are produced. There are significant differences between the productions of the different product types. Therefore, the different production configurations will be presented separately below.

4.1.3.1 BPU - Branded Processing Units

The production of branded processing units is the biggest in volume and it is the most complicated product type being produced at the PPCL production site. There are two different production lines for producing BPU modules, and these are BPU-multi and BPU-special. The difference between the two is that BPU-special is more complex in its productions. The overall structure of BPU production consists of the following three production steps: (1) bending, pre-welding, welding, and grinding, (2) assembly, and (3) testing. The main difference in structure between BPU-special and BPU-multi is within the assembly step. The parts of bending, pre-welding, welding, and grinding and testing is similar in its operations between the ones being assembled in multi-line and the ones assembled in the special line. The products that are being produced in the special line takes longer to produce due to them having more of an engineer-to-order characteristic. The BPU-special production takes between 5-20 workdays to complete in assembly, compared to the BPU-multi production that usually takes 5 workdays in assembly. Approximately in BPU-special line only 1-2 BPU products are started each week and the number for BPU multi-line is 5-10 for the same amount of time.

At the first step for BPU consisting of bending, pre-welding, welding, and grinding the amount of time spent is approximately 6-7 workdays. At this step pipes are initially being bent at the bending area. Then, they are moved to the pre-weld area where they are being prepared for welding by being measured, sorted, some of them are being cut and all of them are being cleaned. Thereafter, they arrive at the welding area where they are being handled according to their order specification before being moved to the last area of the first production step consisting of grinding on the outside of the pipes. At the bending area, some orders are being consolidated. This is done with the purpose of avoiding having to change the machine tools too many times. Already at the next area of pre-welding things are being handled order-by-order again.

The last step at BPU before the products are sent for shipping is the testing part. The testing consists of three different operations in general. These are assembly for test, testing, and dismantling. The testing part varies a lot in time depending on the product to be tested, but also depending on the actual testing of the product. It can take everything from 15-30 workdays in total with assembling, testing, and dismantling. Assembling and dismantling is usually quite stable in the time required, but the testing part is the one that is varying. All parts of the BPU production are striving towards producing at their maximum capacity. However, the testing is the production step that is requiring the longest and most varying amount of time. Therefore, the other steps are customizing when they start their production operations to not overwhelm the people at testing.

4.1.3.2 HT – Tubular Heat Exchangers

There are two different types of productions for the HT product type. These are make-to-stock where components as pipes and tubes are being produced and assembly of the tubular heat exchangers. The make-to-stock production consists of seven different workstations, each responsible for a specific process. The processes can as an example be backside welding or producing mantle components. The assembly part has four different docks for assembling tube heat exchangers. There is a capacity to assemble 4 tubular heat exchangers at the same time, but it is 2-3 tubular heat exchangers that is assembled simultaneously during a normal week. The assembly part is following the concept of make-to-order instead of make-to-stock.

4.1.3.3 HP – Homogenizers/High pressure Pumps

There are a total of 10 different homogenizers being produced at HP. Nine of these have the exact same procedure with the difference being the size of them. The tenth one has some differences in its production procedure, but not a too big of difference from the other nine. The first production operation consists of building the crankcase, and this operation typically takes one day in total. The second procedure is the assembly of the machine itself. When assembling the machine, it is staying at a docking station throughout the entire assembly operation. The homogenizers are normally being produced at the highest pace allowed based on the production capacity. However, with the current shortage of some for the machine essential components homogenizers are not currently being produced at maximum capacity. At the production area it is almost always 9 machines stationed. Usually, it is 5 machines being worked on simultaneously and 4 machines standing at production ready to be worked on next. This is because if a machine is for example fully assembled or if any material for a machine is of shortage workers at production can then begin to work on the next machine. The production time for a homogenizer varies a bit between the different homogenizers. For the smaller ones it takes approximately 20 workhours and for the biggest ones it takes 50 workhours. However, the planned lead time is three days for the smaller ones and four days for the bigger ones.

4.2 Material flow processes

To better understand the current state of the material flow investigated its included processes needs to be understood. The processes included in the material flow are therefore explained.

4.2.1 Picking at warehouse 111S and 111N

The entire process of picking starts at 03:00 when all orders for the coming day except for extra picking orders added during a specific day are printed. These printed orders are then sorted and put-up on a picking wall by the first person in the picking group that arrives at the site. The goal is that all orders should be delivered within 24 hours. This means that there are no considerations regarding what time during the day a specific order arrives in production. Therefore, the pickers are choosing at random in which order the orders should be picked. However, a general rule is that the orders that requires a lot of picking from the carousels are being picked last. This is because it is the carousel picking that start of the picking process of an order. More precisely, everything that is needed from the carousels on a specific order is picked the first and then everything needed from pallet locations. If the picker were to do otherwise and start with orders that contains a lot of picks in the carousel the pallet pickers would have nothing to do for a long time in the beginning of the day.

When picking, the different picks are confirmed with the help of scanning barcodes or by manually registering the picks on a computer. This is the only confirmation that is done in either picking, distribution or when receiving the material in production. There is no confirmation that the right thing is put in the distribution area or that it has arrived at the production site. On occasions the warehouse capacity is not sufficient for handling all the picking-orders for a specific day. However, this rarely happens.

4.2.2 Picking and Distribution at the Yard

For the processes of picking and distribution at the yard there is two persons responsible for carrying out these processes. Further, picking and distribution from the yard is interlinked, meaning that the processes are carried out by the same person and at the same time. When something is picked it is thereafter delivered directly to a designated unloading point. This is because of that the components that are picked from the yard are large. Thus, these are requiring an entire truck to be moved to the unloading points. The yard does not deliver material to all unloading points. The affected unloading points are S01, C01, C02, all M, and W03 (see Appendix II). Furthermore, most of the material that is being delivered from the yard is transported through door 108 (see figure 30). It is only the material that should be delivered to HP that is delivered through door 105 (see figure 30).

4.2.3 Distribution warehouse 111S and 111N

Material that flows from warehouse 111 to the PPCL production is handled in different ways. Smaller materials are transferred simultaneously with other smaller materials by putting them on different wagons such as pallet wagons and picking wagons. Theses wagons are put onto trolleys when ready for distribution. The trolleys containing the wagons are interlinked to other trolleys forming a trainlike structure, see figure 32. All the interlinked trolleys are then being moved with a truck. The wagons placed in the trolleys are being dropped off at designated unloading points located at the PPCL production. The rule is that one wagon only houses components for one order. This type of train is on an average day departing from the warehouse to the production on three occasions.

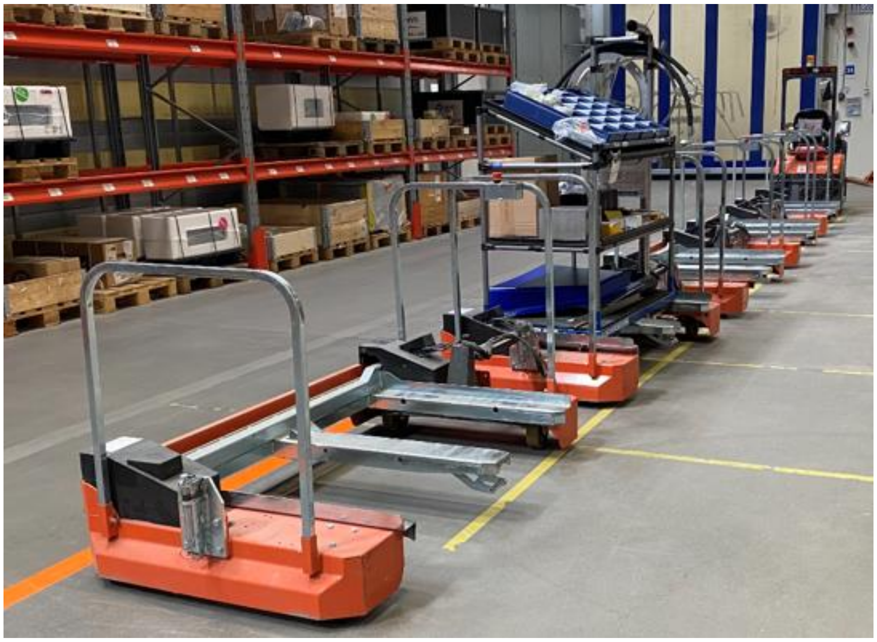


Figure 32: Train with interlinked trollies and a wagon placed on one of the interlinked trollies

Larger material that is being moved to the PPCL production is instead handled with trucks steering them directly from the distribution area to their designated unloading point. Further, in situations with materials that are of lack at the production site it exists a specific wagon these can be placed within. This wagon is moved as soon as possible to the PPCL production when material is dropped within it. The specific wagon is also being used for small orders that only consists of one or two order lines. A physical sign placed at the specific wagon aware the distributor that it contains material of shortage. Further, in some scenarios components that there is a lack of is being picked up directly from inbound by the person needing the component in production.

In addition to the distribution of material from the warehouse to production, there are also some materials that are sent from the warehouse to other companies. These companies process the material and send it back to Tetra Pak. This happens with two types of material. These types are tubes for BPU and tube inserts for HT.

4.2.4 Receiving in production

There are many different unloading point categories at the PPCL production. The categories are dedicated to different product types and different production processes. The distributor is not making any signal that material have been delivered. The only communication between the distributor and the receivers at the PPCL production is instead if the material cannot be delivered to the dedicated unloading point due to it being full. In those cases, this is solved by making room for the material at a close location where the material can be delivered to instead. Further, if the wrong material has been delivered the personnel at the PPCL production calls someone at the warehouse making them aware that the wrong material has been delivered. Then the distributor makes certain to replace the wrongfully picked material with the material that should have been delivered. The material is delivered in accordance with a schedule and workers at production are unaware of at what time during a specific day that they can expect the material to be delivered at.

BPU can be divided into four different parts that are manufacturing, multi-assembly, special assembly, and testing. All material required for a specific part of BPU is delivered simultaneously according to the production schedule at its dedicated unloading points without any regards to which day they are required in production. This has according to interviewees resulted in difficulties especially for the first day of production since a lot of components is at the unloading points simultaneously. For some products that are being assembled at the multi-line these can be delivered on two occasions instead of one. For the unloading points dedicated to BPU (see Appendix II) there is no specific arrangement for how material should be delivered. Further, for some orders it happens that all required material cannot be delivered due to that material being of shortage.

For the last part of BPU production when it is time for testing it happens that more material than is required is delivered. This is when orders have been updated a few times before reaching this part of the production. This results in more material being added to the orders, while the material that is no longer required have not been removed. Also, some material that are delivered to the testing part of BPU is delivered to a dedicated outside storing area. When the material is needed workers at the testing area then need to go outside to collect the required material. On occasions more material can be delivered to the same specific outside location. On those occasions workers from testing need to move other material that have been delivered to the same location before they can collect the material that they are needing. This is because other material is blocking the required material.

For the product type of HT there are different unloading points to receive material at. Typically, one unloading point covers approximately 3-4 different workstations. All materials required for an order is picked at the same time and then unloaded at the designated unloading points simultaneously. The material is supposed to be at the PPCL production at the day that production is supposed to begin. On the occasions when it has not arrived the first thing to do is see if the missing material is of shortage and after that see if there has been a wrong pick.

If the production is not keeping up to its schedule the material is of risk to be standing in production longer than it is supposed to. Most movements of material to production are being done according to a push schedule, but those components that are being used a lot is being moved according to a Kanban strategy. Apart from this there are also some parts of the material for the tubular heat exchangers that is being delivered to outside of the entrance to the PPCL production. When these are required at production they must be picked by workers from production and brought to the station that they are needed at. The material for HT has dedicated delivering locations outside of the production site. However, when collecting the material from outside of the production site it can on occasions happen that other materials that have been distributed to the outside location is blocking the access to the required material. In those situations, it is therefore needed that those materials are moved out of the way and then put-back into the storing location when collecting the required material.

At the HP area material is being delivered on 2-4 occasions at the PPCL production for one order. On the first occasion the material for the crankcase is delivered and depending on the size of the product the rest of the machine is delivered on 1-3 occasions on the following days. There is on most times room for the new material to be unloaded at the HP area upon its arrival. However, it happens that material needs to be moved around to make space for new material to be unloaded. This is happening on occasions when they have not been able to follow their planned production schedule at the production. If there are much material at the production, then it can on occasions be troublesome to find the required material. Then different materials need to be moved around to find the needed material. It can take up to 30 minutes of time to find the right material in these situations. The material that is going to be used on a certain day in production is supposed to arrive at production the day before. If the material has not arrived the day prior the production start risks being delayed with a few hours because it cannot start at the beginning of the day. This have only happened on a few occasions though.

4.3 The characteristics of the material flow

The strategy for how material is moved between warehouse 111 and the PPCL production varies depending on what material that is being moved. Most of the material is being moved based on a schedule. Therefore, materials are being pushed out from the warehouse based on a picking schedule. However, some material is instead being moved according to a Kanban strategy. The material that has been selected to be moved with a Kanban strategy have been chosen to do so based on two different reasons. It is either due to the appropriateness of the material or based upon requests from operators in production. This has resulted in that two types of components are being moved with a Kanban strategy. The first type is components that are small, standardized, and that are being used in large quantities. Examples of this type are bolts and seals. The second type is components that is being used by the meter and it is not specified exactly how much is needed in a product; examples of the second type is cables. There is a total of 12 different Kanban stations at the PPCL production that the warehouse is responsible for replenishing. The locations of the Kanban stations are presented in figure 33.

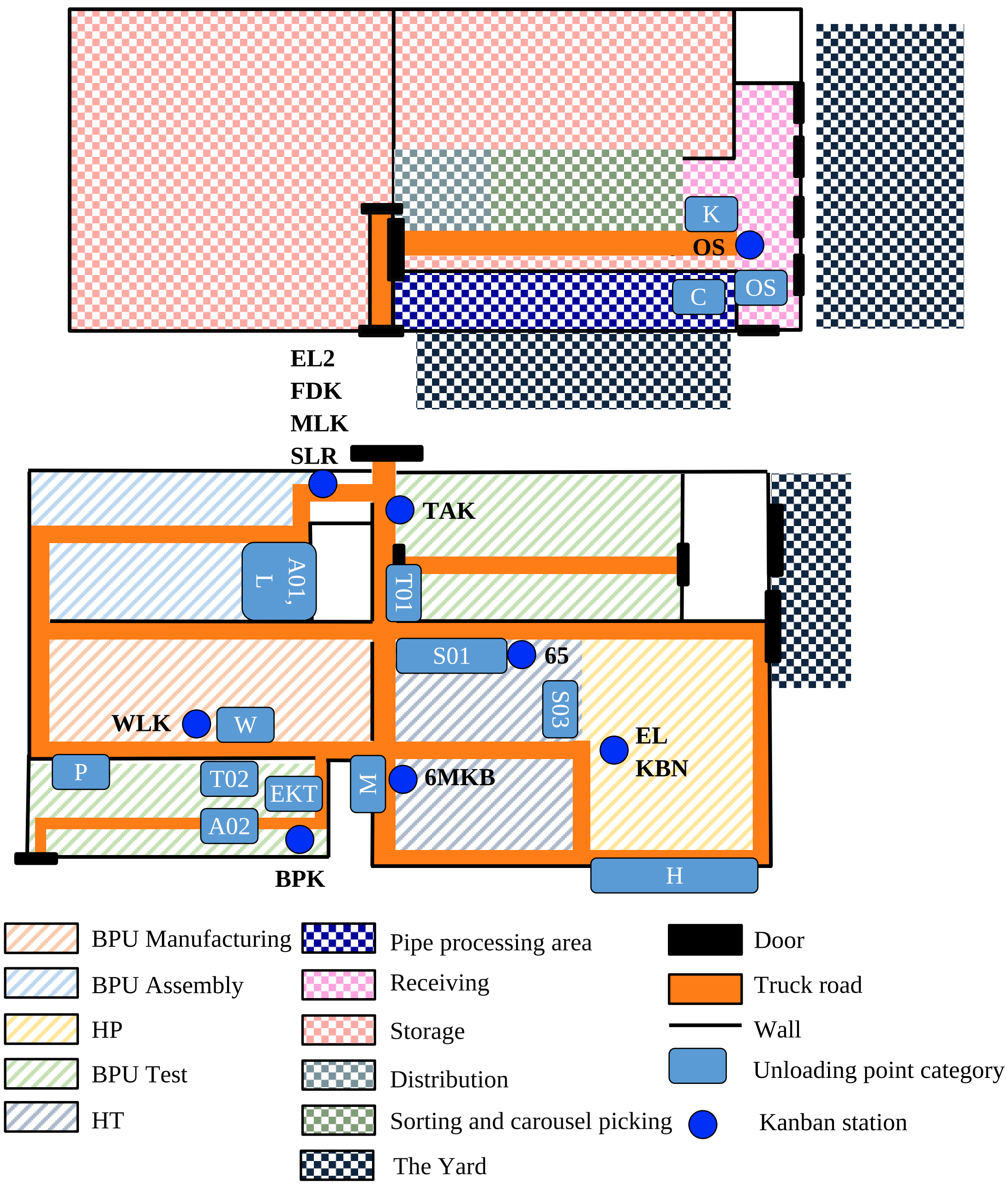


Figure 33: The figure displays the locations of all Kanban stations (blue circle).

There are a few components in the material flow that are being moved with a pull strategy. The movements of these materials are handled by employees at the PPCL production. These components are pipes to the HT make-to-stock production, frames to assembly of BPU, pipes to the manufacturing of BPU, and modules for testing BPU. The set-up of these movements of components are as follows: (1) At assembly of BPU and testing of BPU when a frame or a module is needed employees from these parts of the PPCL production gets the frame or the module from the yard themselves, and (2) At HP and manufacturing of BPU when a crate of pipes is emptied a new one is picked up at the yard by employees from these parts of the PPCL production.

4.3.1 Defining material flows

The entire material flow from warehouse 111 and the yard to the PPCL production have been divided into seven different flows of material. This has been done to simplify the analysis of the characteristics of the material flow. The entire material flow has been divided as presented in table 15.

Table 15: Table of which unloading points that are included in each of the defined parts of the material flow. In Appendix III the different material flows are depicted.

Flow	Unloading point categories belonging to it
HT – MTS	M, X, W03
HT – assembly	S
HP	H
BPU – multi assembly	L
BPU – special assembly	A01
BPU – test	T
BPU – manufacturing	W02, A02

Unloading points categories K, P, EKT, C, and OS are not part of any defined flows presented in table 15. This is because they are not used for any material deliveries from warehouse 111 to the PPCL production.

4.3.2 Demand characteristics

The material that is moved within the material flow is not affected by any demand variety worth considering when evaluating the material flow. The two months when less material is moved between warehouse 111 and the PPCL production is July and December. However, these are also the months in which the number of available staff at the functions are the lowest. The number of transfer orders moved between the warehouse and the production site for each month aggregated over 2019 and 2022 can be seen in figure 34.

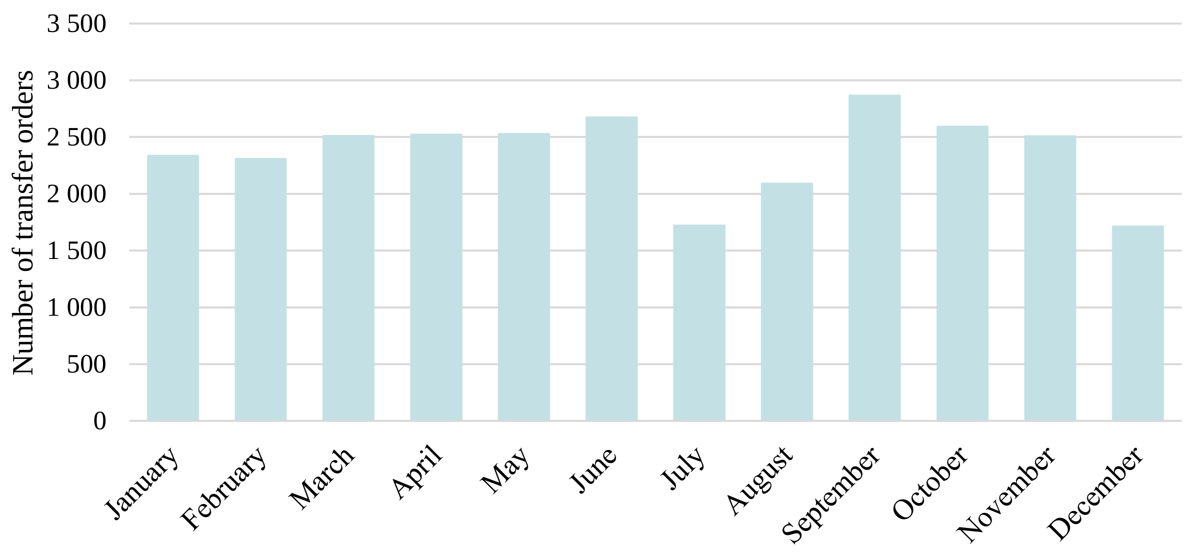


Figure 34: Display of the number of transfer orders delivered between warehouse 111 and the PPCL production during the time-period 2019-03-01 to 2022-02-28.

There are however demand variations for some of the seven different defined material flows if these are considered individually, see Appendix IV. The material flows that are experiencing the most demand variations are HT – MTS and HT – assembly. The material flows that are experiencing the least demand variations are HP and BPU – manufacturing. These defined flows are experiencing almost no variations at all between different months. Further, the variations are more random at HT – MTS than any of the other material flows, making it harder to predict the demand of that material flow. However, none of the material flows are experiencing any big variations in demand between the different months.

Materials are not delivered equally frequent to all the different unloading points. Some of the unloading points have more frequent deliveries and it varies a lot between the most common ones and the ones that are visited more rarely. This includes both when controlling the number of visits to the different unloading points and when considering the amount of weight delivered to the different unloading points. Figure 35 and 36 displays how many order lines that are related to each defined material flow and the weight that have been delivered to each of them. The figures tells that the HP flow is the one with the most order lines and the most weight moved within it.

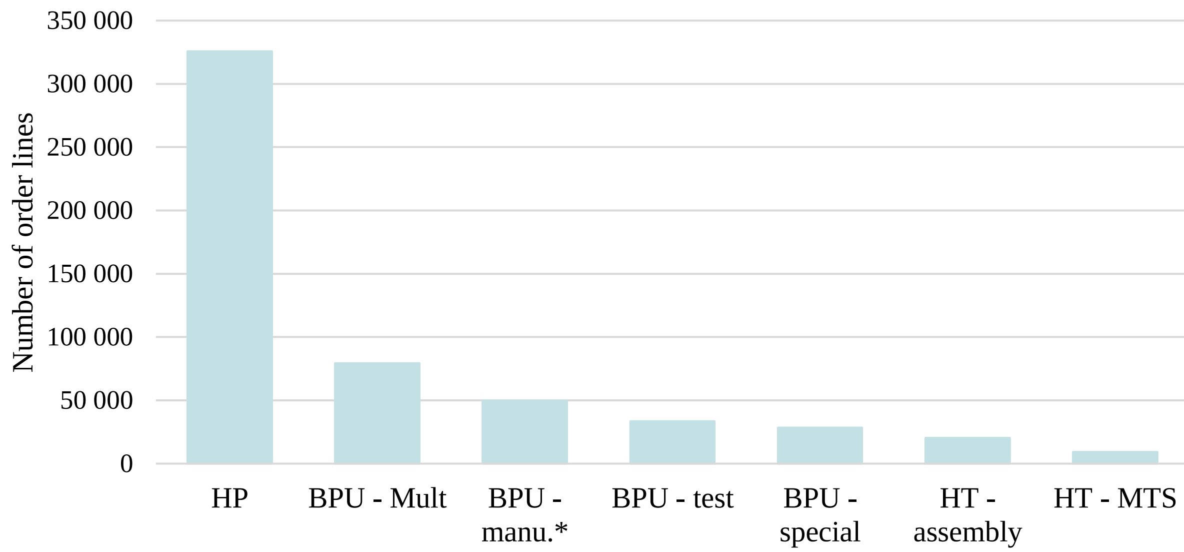


Figure 35: Display of the number of picking lines flown in each of the material flows defined in table 15 during the during the time-period 2019-03-01 to 2022-02-28. *BPU – Manu. is an abbreviation for BPU – Manufacturing.

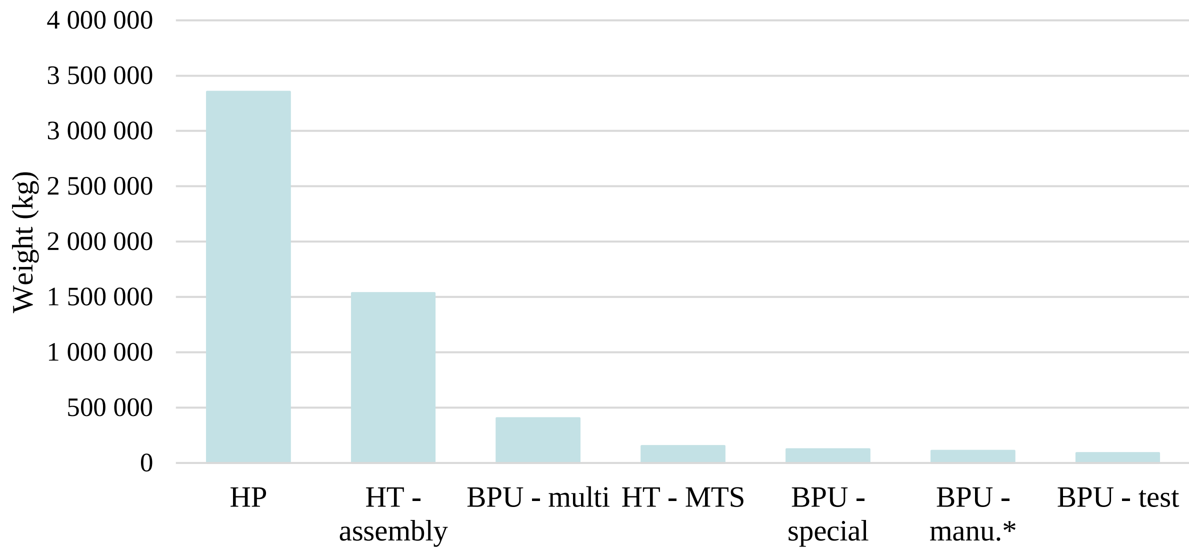


Figure 36: Display of the amount of weight flown trough each of the defined material flows in table 15 during the time-period 2019-03-01 to 2022-02-28. *BPU – Manu. is an abbreviation for BPU – Manufacturing.

Further, the total amount of transfer orders dedicated to the different defined material flows are available within the data collected from the ERP system. That data tells that the material flow with the most transfer orders completed are HP. Figure 37 displays the total number of completed transfer orders for each of the defined material flows.

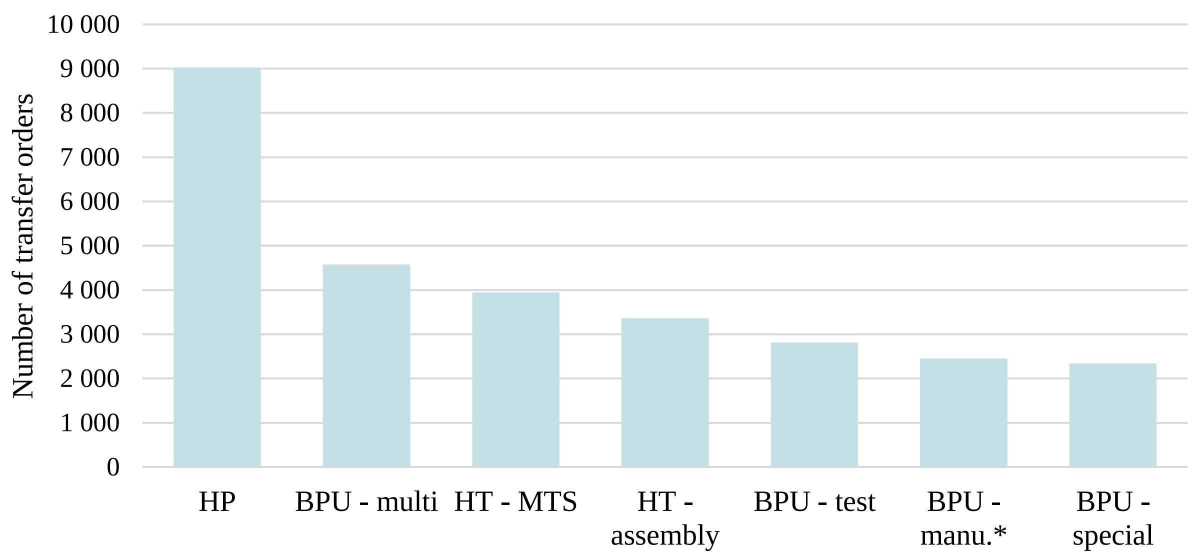


Figure 37: Display of the number of completed transfer orders for each of the defined material flows in table 15 during the time-period 2019-03-01 to 2022-02-28. *BPU – Manu. is an abbreviation for BPU – Manufacturing.

Almost all the material in the material flow enters through one specific entrance located in building 108 and thereafter depending on where the material is supposed to be delivered flows in different directions within the PPCL production. The material that does not enter the PPCL production through building 108 enters it through an entrance located in building 105 instead. The material flow to the different unloading point categories can be seen in figure 38 that shows the material flow as a heat map, where the size of the purple line shows the amount of material flowing in different paths.

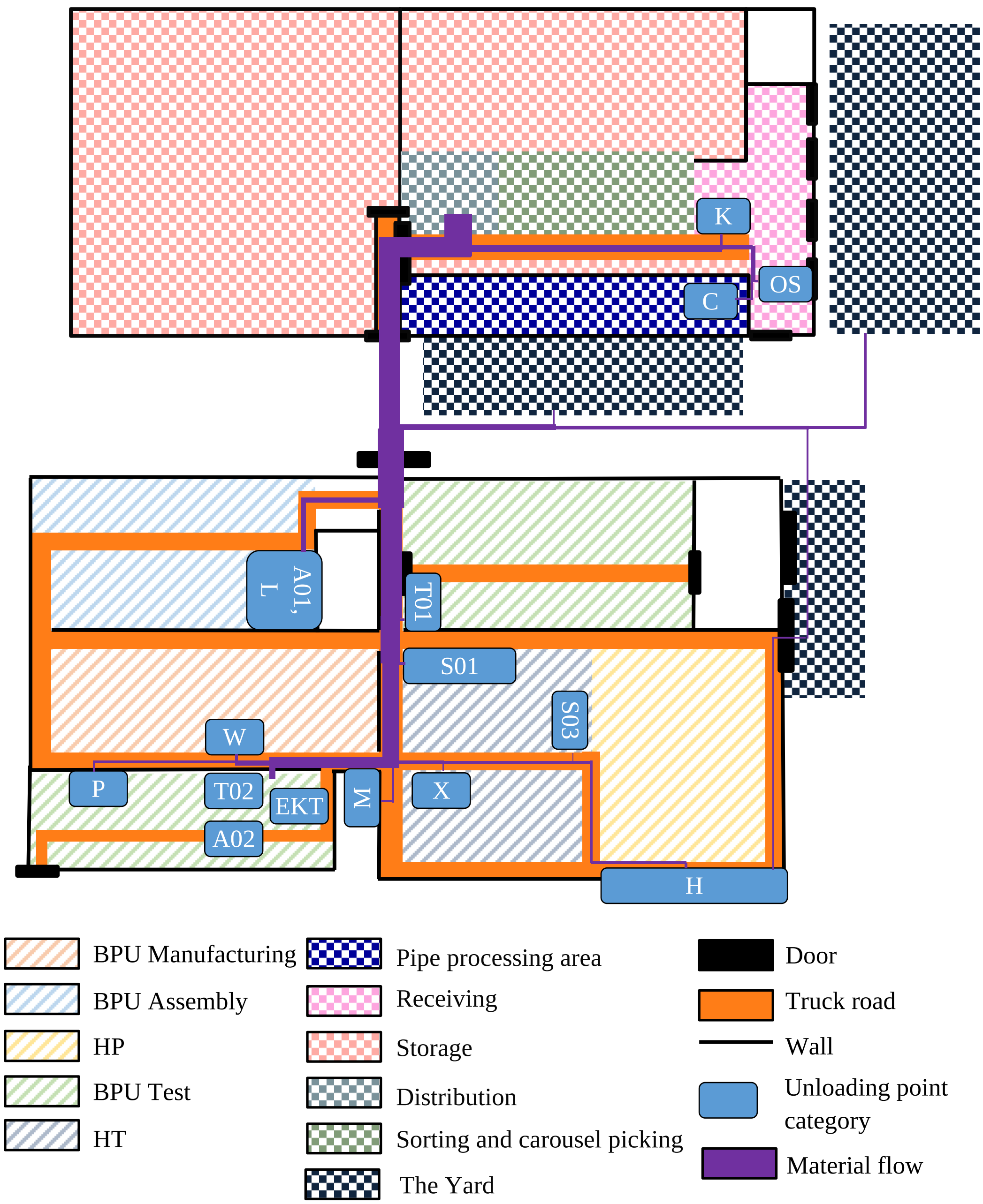


Figure 38: A heat map over the material flow at the PPCL production. The purple line represents the material flow to the different unloading point categories. The thickness of the purple line is logarithmic proportional to the number of transfer orders. Every purple line that is pointed into an unloading point represent material being delivered to that unloading point. If there are not an unloading point at the end of a purple line it means that material is being distributed from that location.

4.3.3 Component characteristics

There is no material that is being delivered to more than one specific unloading point according to the data from the ERP system. This means that the different unloading points all have unique material delivered to them. Further, there is a big difference regarding the amount of different material that is delivered to the unloading points dedicated to the different defined material flows. In total there are 9 590 different components that have flown between warehouse 111 and the PPCL production during the time-period 2019-03-01 to 2022-02-28. The defined material flow that is receiving the most unique components is HP, while HT – MTS is the defined material flow receiving the least number of unique components. The number of unique components delivered within each of the defined material flows can be seen in figure 39.

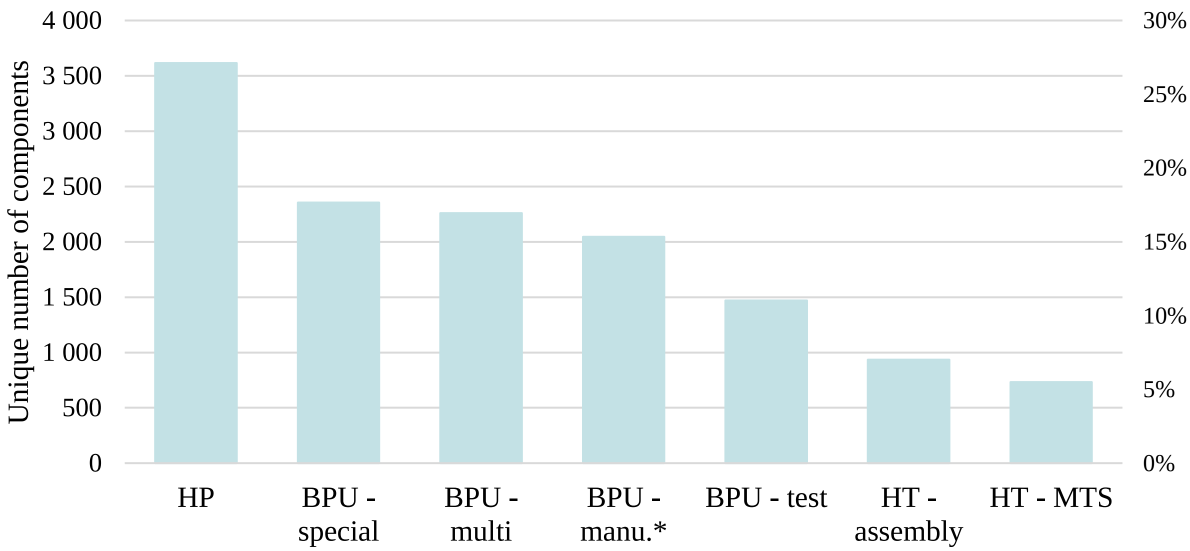


Figure 39: Display of the number of unique components delivered in the different defined material flows during the time-period 2019-03-01 to 2022-02-28.

4.4 The characteristics of the information flow

The three functions that are of relevance regarding the information flow related to the material flow at Tetra Pak PPCL are the warehouse, the production, and the order handling departments for respective product type. The predominated system that is used to communicate between functions is their ERP system, which is used by every function in one way or another. Outside the ERP system the production has a manufacturing execution system. However, it is basically an interface of the ERP system. Meaning that the manufacturing execution system only gathers data from the ERP system and presents it in a nicer way. Further, the warehouse has an WMS module outside of the ERP system. However, the WMS is only used for internal information handling. Thus, being of no relevance to the communication between the functions.

The most important information flow between the functions is when orders are released. With the release of an order, it is confirmed that the order should be produced. It is the order handler that is responsible for releasing the order. When an order is released picking-orders, and official production schedules are created and scheduled. Without releasing the order, the warehouse will not receive any picking-orders and the production will not see that something should be produced. The release of the order is handled different for the different product types. For HP the orders are released the day prior to when production is scheduled, for BPU the orders are released three days prior, and for HT the order is released 16 hours before the order is planned to arrive in production. That BPU releases its orders three days prior to its production start is resulting in that the picks required for its last processes of testing are released 2-3 weeks prior to when they are needed at the testing area

After the release, the material on the created picking-order cannot be changed. Therefore, if it is discovered that an item is missing on the picking-order it requires the creation of a new picking-order for the item to be picked. This is something that the order handler does in the ERP system and communicates it to the warehouse through the system. Furthermore, currently when an order is released the entire order is released. This means that all the picks and production times are scheduled. Thus, resulting in that even if the production falls behind or are before schedule the pick will be picked based on the predefined schedule. However, to counteract this it exists a leveler for all planned productions. The leveler is used as a lifeline when production is running late. The leveler is a few hours or days depending on the product type that the order handler can use to postpone the release of an order depending on how the situation is within the warehouse and at the production site.

Interviewees mention that there is a possibility to release picks for individual operations one at a time in an order to better handle variation in production time. However, some interviewees mention some concerns about this function due to it increasing the workload related to order releasing drastically.

As it stands today there is little information shared between the warehouse and production. The information that is shared is mostly done face-to-face or through conventional means such as emails or telephone. A typical situation in which communication is being done directly between the warehouse and the production is when some material has been damaged at the production site and need to be replaced. Otherwise, if there are any problems the order handler is usually used as an intermediary. The order handler then makes sure that the information reaches the relevant person. The information shared between the order handler and production is a bit varying depending on the product type. For HP there are daily meetings scheduled where the status at the production is discussed to make the order handler aware of if the order should be released or not. The order handler for HT does not have daily meetings with the production. Instead, the communication between them is done through the ERP system or through email/phone on occasions when it is necessary. At BPU the communication is mostly done through the release of orders. However, they do have daily meetings where they discuss if there are any problems with the planned production for BPU. If issues were to occur through these meetings an alternative production plan needs to be made. The information interaction between the three different functions can be seen in figure 40.

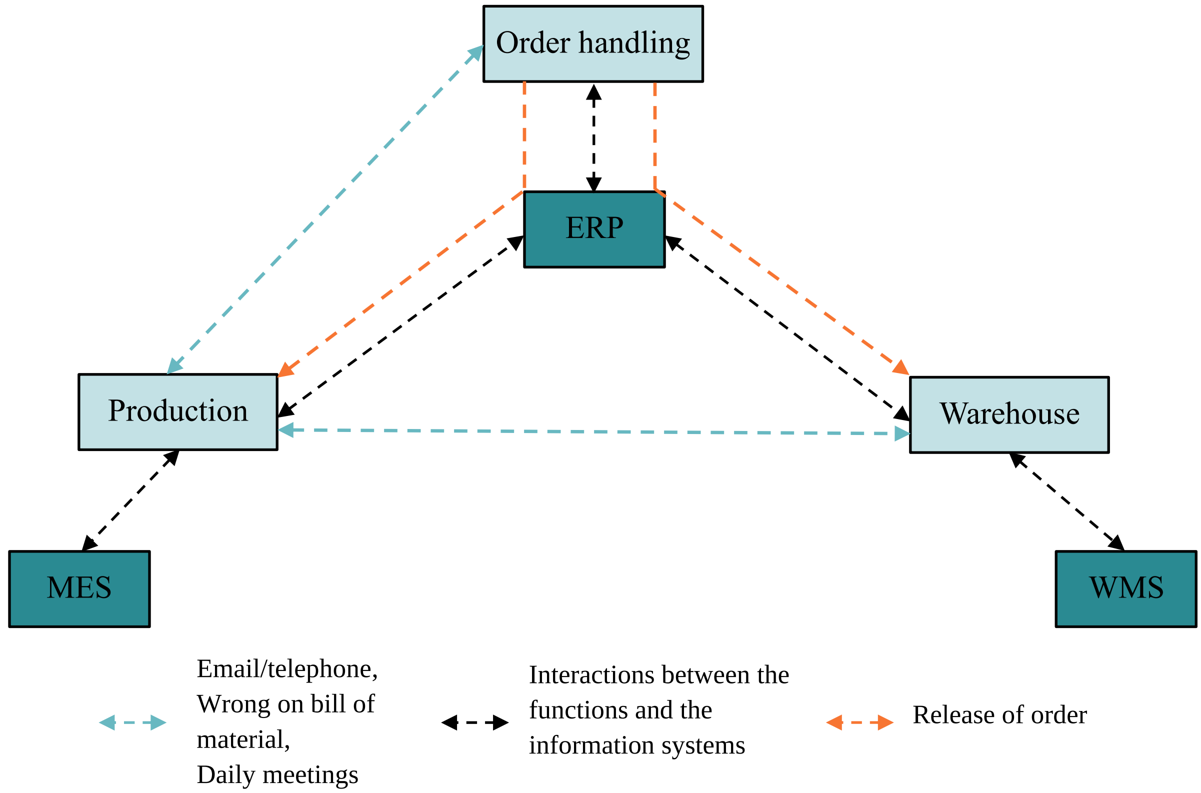


Figure 40: Displays the information interaction between the three functions production, warehouse, and order handling.

5. ANALYSIS

The analysis chapter has been divided into two parts. The first part is to determine when it is appropriate to utilize a pull system. The second part consists of designing a pull system for the defined material flows where it has been deemed appropriate. The outline of the analysis chapter is presented in figure 41.

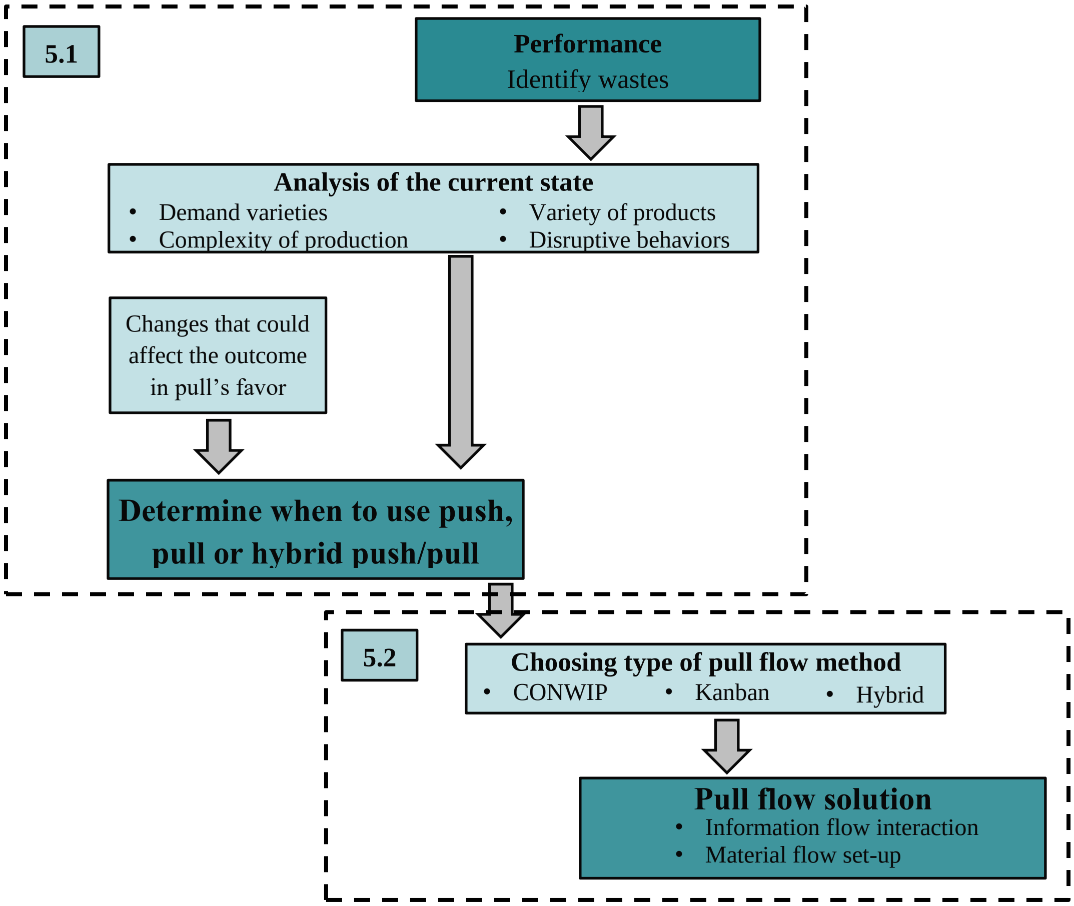


Figure 41: Outline of the analysis chapter.

5.1 Identifying when a pull system is appropriate to utilize

Identifying when a pull system is appropriate to utilize has been divided into four parts, and it is in part two and three the decision propositions are created. Firstly, wastes were identified to evaluate the performance of the material flow. Secondly, the seven identified material flows (see table 15) were analyzed to find out which flows that are suitable as push, pull or hybrid push/pull. Thirdly, changes that could affect the outcome of push or pull were analyzed, more precisely how tracking technology could affect the decision. Finally, in part 4, the proposed decision propositions and recommendations for Tetra Pak were summarized. The outline of creating decision propositions by identifying when it is appropriate to utilize a pull system is summarized in figure 42.

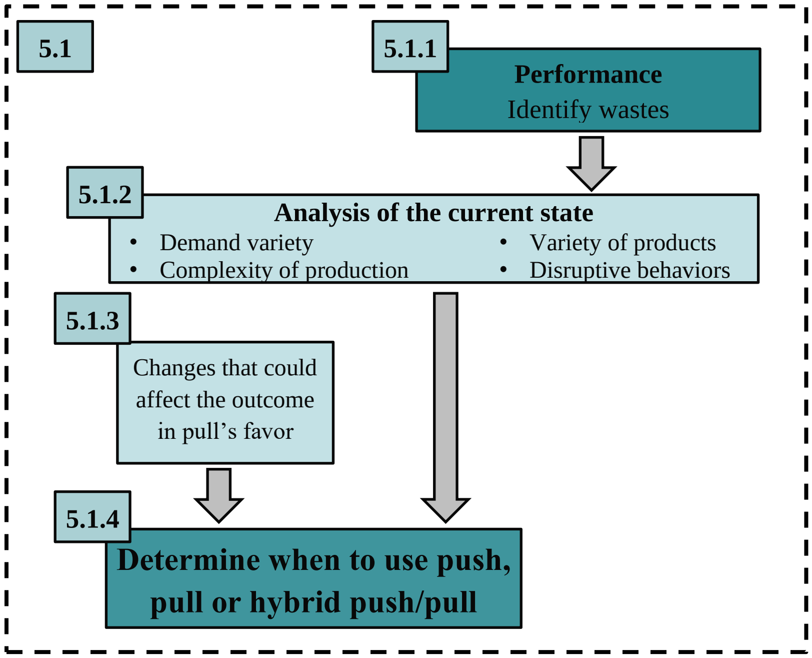


Figure 42: Outline of developing decision proposition by identifying when it is appropriate to utilize a pull system.

5.1.1 Performance - Identifying wastes

Based on the empirical chapter the processes included in the scope have been mapped to increase the understanding of the flow and simplify the process of identifying wastes in the flows of the material. This has been done with the purpose of giving an indication on how the seven defined material flows are currently performing. The mapped processes can be seen in figure 43.

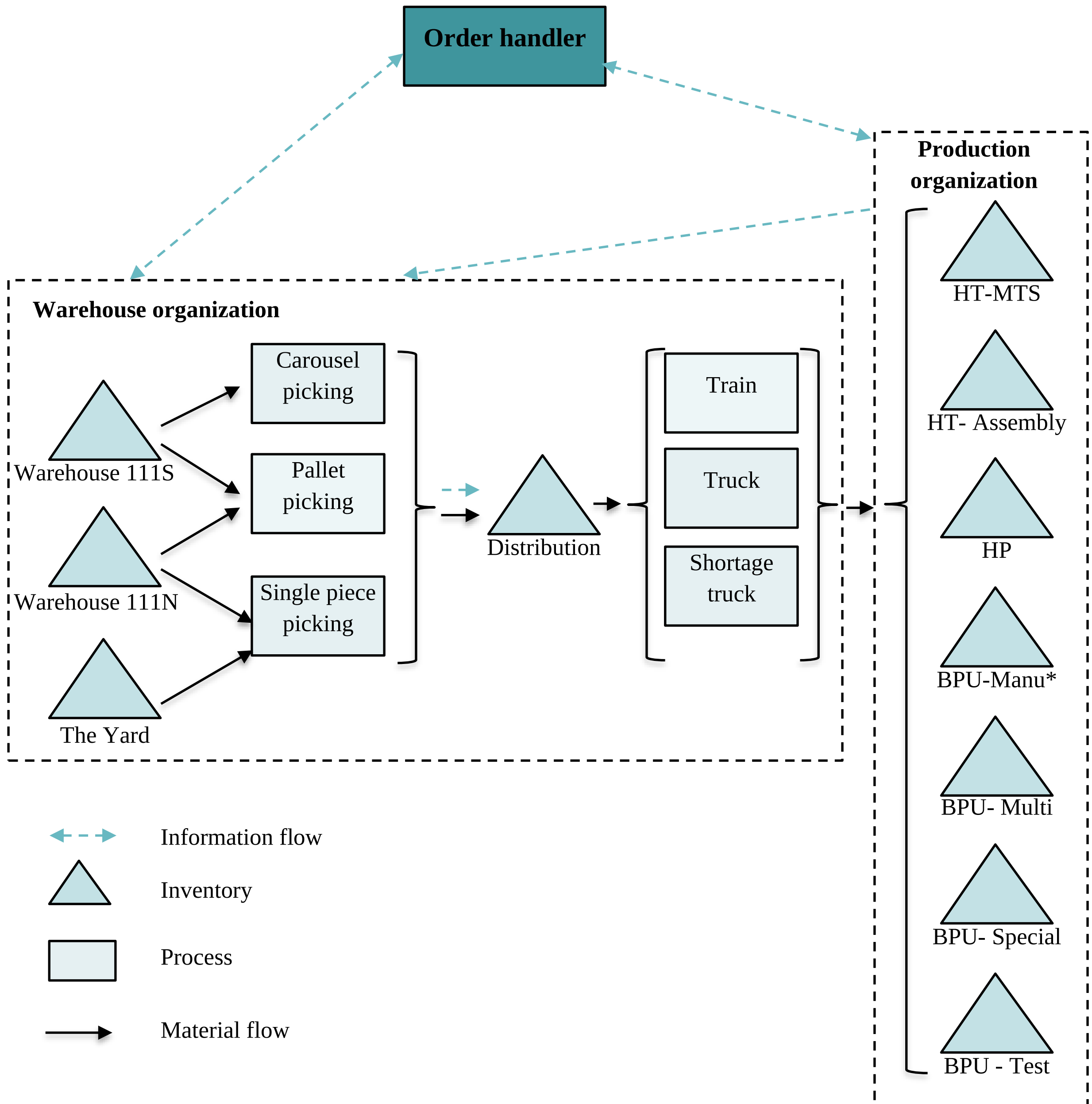


Figure 43: Mapping of the current processes. *BPU – Manu. is an abbreviation for BPU – Manufacturing.

It exists seven different kinds of wastes that can be identified at different processes. Out of those seven wastes three have been deemed irrelevant when evaluating the material flow between warehouse 111 and the PPCL production. These wastes are defects, overprocessing and overproduction. Even though the same waste has been identified at more than one process, the severity of the specific waste can vary between the processes. Resulting in that some of the wastes are identified to be more severe at certain processes than others. The severity of the waste has been evaluated based on the impact of the identified waste, at what frequency the waste occurs and how many wastes that have been identified within a specific kind of waste. Demand size for a specific defined material flow is an example of something that has been considered when evaluating the severity of an identified waste.

5.1.1.1 Unnecessary inventory

The waste of unnecessary inventory has been identified at BPU – multi, BPU – special, BPU – test, BPU – manufacturing, and HP. Unnecessary inventory results in that material can be laying for a while at the different unloading point. For all the flows, one reason for unnecessary inventory is that material is being pushed out to the production site according to their schedules with little or no communication if the production is on schedule. Consequently, this is causing material to be delivered to the production site when it is not needed. Thereby, resulting in unnecessary inventory at the production site. This was particularly noticeable at BPU – test which is the last step in BPU production. Much could have happened since the picking order for BPU – test was released. Further, the unnecessary inventory at BPU – multi and BPU – special is due to all the material for one order is pushed out one day before production start even though the production time is between 5-30 days. At HP, the strategy is to have more machines at the production site than what is being worked on. There is almost as many machines just standing at the production site as it is machines being worked upon. Thereby, resulting in inventory at the production site that is there without much purpose.

The severity of unnecessary inventory waste is not equal for all five defined material flows. It is deemed to be the highest at HP because of three reasons. Firstly, it is the only material flow that have an expressed strategy of keeping much safety stock material in production. Secondly, both production personnel and warehouse personnel expressed that the unloading points related to the HP material flow commonly was full. Thirdly, it is the material flow that has the largest variety in components and the highest number of transfer orders, see figure 37 and 39. The severity at BPU – special and BPU – multi is medium due to these defined material flows having quite a large variety of components and a decent amount of transfer orders, see figure 37 and 39. However, the problem of unnecessary inventory was according to the interviewees only noticeable at the first day of production. Therefore, even though it causes wastes, these wastes are only disrupting the production processes temporarily. The wastes are therefore considered to be manageable. Continuing, at BPU – test and BPU – manufacturing the components that arrive are small and the demand is relatively low. Thus, the consequence of unnecessary inventory is low. Resulting in low severity of unnecessary inventory at theses flows.

At HT – MTS and HT – assembly material is also being delivered all at once, but for those two flows of material the employees are not experiencing any issues related to it. This is mostly due to how the production is following its schedule and the relatively low amount of material dedicated to these two material flows. Therefore, it is not considered as a waste for HT – MTS and HT - assembly.

5.1.1.2 Waiting

At HP, the deliverance of material is sometimes delayed and not delivered the day before production is planned to start. This causes a delay in production and resulting in workers at production having to wait for the material to arrive. Not having any delivery timeslots during a day result in the workers at production being unaware of when material will arrive. This can be of varying time and makes it hard for the production workers to plan for what they can do that specific day. However, this rarely happens. Therefore, the severity of the waste is deemed to be of low level.

At all defined flows it can occur times of waiting at some processes when the material that is required is of shortage at Tetra Pak PPCL. This, results in some operations having to wait for the material of shortage to arrive before they can begin. The material of shortage can take long time to arrive from the suppliers due to it being a general shortage of materials around the world. This causes many products to not be produced according to their production schedule and thereby also being delivered to customers later than planned. This is deemed a more severe waste, but also a waste that is hard to counteract with a change of material flow strategy.

5.1.1.3 Transportation

During transportation for HT – MTS and HT – assembly it can occur wastes. This is because the material that has been made-to-stock at HT - MTS, even though it will be used at HT – assembly is always transported from the PPCL production to warehouse 111, and then back to the PPCL production again. Thus, resulting in unnecessary transportation of the material. This is done to have control of the material produced at HT – MTS and because not all material is going to be used at HT – assembly immediately. Therefore, this waste is deemed to be of relatively low severity, but a waste that could potentially be removed with some adjustments.

5.1.1.4 Unnecessary motions

There are unnecessary motions occurring for the HT – MTS, HT – assembly, BPU - manufacturing and BPU - test flows. This is because some of these flows require material that is unloaded outside of the production. People from production need to collect this material themselves. The material that is delivered outside of the production is delivered to specific designated locations. However, when delivering the material to these locations there is no control of if the material delivered previously have been picked by workers at production before more material is delivered to the same location outside of production. Thus, it can result in workers at production being required to move other materials before being able to collect the material that they are requiring at a certain moment. If this were to change though and make the distributors distribute this material into the production instead it would increase their workload simultaneously as it decreases the workload of some of the workers at the production. Thus, making it an aspect to consider for this specific waste. This identified waste at HT – MTS, HT – assembly, and BPU – test is deemed to be of medium severity due to how it causes disruptions in the production operations and how it is required for the workers to remove other material for them before they can collect their required material on occasions.

At BPU – multi, BPU – special, and HP on occasions they need to go and search for their required material at the unloading points since all material for production is delivered simultaneously. Thus, also resulting in unnecessary motions. With these three defined flows having a lot of material delivered to them (see figure 37) it causes difficulties for the production workers receiving the material since they are required to sort some of the material delivered. However, the amount of time that the searching and sorting part is requiring is not too long. Thus, the severity of the unnecessary motions this is causing is deemed to be low.

5.1.1.5 Summary of all identified wastes

There have been several wastes identified, explained, and evaluated. All the identified wastes at the different processes and their severity level can be seen in table 16.

Table 16: Display of which waste categories that have been identified to occur at the different processes and how severe they are deemed to be.

	Unnecessary inventory	Waiting	Transportation	Unnecessary motion
HT – MTS	--	High	Low	Medium
HT – assembly	--	High	Low	Medium
HP	High	High	--	Low
BPU – manufacturing	Low	High	--	Medium
BPU – multi	Medium	High	--	Low
BPU – special	Medium	High	--	Low
BPU – test	Low	High	--	Medium

5.1.2 Analysis of the current state

The seven defined material flow is evaluated with regards to the four characteristics demand variety, variety of products, the complexity of production, and disruptive behavior. The purpose of evaluating these characteristics is to understand when a push system or a pull system is suitable. Due to the seven defined material flows at Tetra Pak PPCL not having complex enough set-ups the hybrid push/pull system is not an option needed to be analyzed. The reason that these defined flows are not complex enough is because they only include movements of material between two different processes.

To evaluate the defined material flows some principles about the characteristics have been used. The foundation for developing the principles was the frame of reference and the empirical findings. The frame of reference was used as the basis and the empirical findings was used to understand the characteristics in a real context.

The complexity of production is regarded as the most important characteristic. This is in line with the literature, where complexity in production is a big factor for not using a pull system. Meaning that if the complexity is high a push system is favored. On the contrary, if the complexity is low a pull system is favored. The empirical findings lead to that the following parameters were useful to understand and analyze the complexity criterion (1) variety in time of processes, (2) how standardized the processes are, and (3) if the processes are in the same order.

Further, the variety of products is regarded to be of medium importance. This characteristic could have a high impact on the decision and there is a difference in the variety of products between the different flows at Tetra Pak PPCL. However, the differences between products at most of the flows are small. This results in the suggestion that variety in products should not be regarded to be as important as complexity in production. In line with the literature, the result of a high variety of products is that a push system is favored. On the contrary, low variety of products favors a pull system. The empirical findings suggested that the variety of products should be analyzed with regards to how many different products that are produced and how large a difference there is between the products produced.

Continuing, demand variety is regarded to be of lower importance than complexity in production and variety of products. The argument for this is that at Tetra Pak PPCL there is a low demand variety, and the demand variety that has been noticed can be derived from less personnel working during those periods of time. If the demand variety is high a push system is favored. On the contrary, low demand variety favors a pull system. This is supported in the literature findings, where it is presented that demand variety hampers implementations of a pull system.

The discussion of complexity in production, variety of products, and demand variety has led to the following two decision propositions:

Decision proposition 1: When demand variation is low, complexity in production is low, and variety of products is low, a pull system should be adopted to achieve a suitable material flow.

Decision proposition 2: When the complexity of production is high, and the variation of products is high a push system should be adopted to achieve a suitable material flow.

Disruptive behaviors are seen as indicators that a change concerning the material flow system could be of benefit. This characteristic is related to wastes. Wastes are indicators of that something is not working as it should and the identified wastes are in this case related to the material flow. Meaning that if the disruptive behaviors are high there are many and/or high impacting wastes in the specific material flow. Suggesting that something should be changed. Thus, if the evaluated material flow is a push system and the disruptive behavior is high a change to a pull system could be favorable. Thus, a third decision proposition is created.

Decision proposition 3: When there is disruptive behavior, it is an indicator that the company potentially should change material flow strategy to remove wastes.

The three developed propositions have been used to evaluate and decide which material flows at Tetra Pak PPCL that should utilize a push system or a pull system. To facilitate the evaluation the material flows has been divided into three categories. The categories are A – flows, B – flows, and C – flows. A – flows include material flows HP, HT – assembly, and BPU – test, B – flows include material flows BPU – special, and BPU – multi, and C – flows include material flows HT – MTS, and BPU – manufacturing.

5.1.2.1 A – flows

HP, HT-assembly, and BPU-test have similar characteristics and will therefore be discussed simultaneously, in relation to *decision proposition 1* and *decision proposition 3*. All three have relatively low demand variety, see Appendix III. Out of the 7 defined material flows HP has the lowest demand variety. The order handler mentioned that they try to start two orders per day, which could be one factor why low demand variety is observed. Similarly, in BPU - test a low demand variety is observed. However, a little bit higher than HP. Since BPU- test is the last process in BPU production, the demand variation is a consequence of variations in the previous steps. Even though it is a consequence, a bullwhip effect is not observed. Meaning, that there is less variety observed in the BPU – test than in the other process. One of the reasons for this could be that BPU – test is regarded as a bottleneck, both by order handlers and team leaders and delays are expected to occur in this process. Therefore, when production is delayed due to demand variation in processes before the test, the test process has time to catch up. The demand variety characteristics at HT – assembly are that the time-period December to September is stable at a certain level and the time-period September to December is somewhat stable, but at a higher demand level. In summary, the three A – flows display some demand variety. However, it is relatively low for all of them.

The level of complexity in production concerning the material flows is also similar between the three A – flows. However, the arguments related to their complexity are somewhat different for the three material flows. HP's production processes are complex regarding its operations but, consists of few steps. Also, there is a standard in how the operations are carried out. Both the order in which processes are performed and regarding how long the lead times for producing products are. This results in a relatively low complexity in production. Comparatively, HT – assembly only consists of one procedure, which is the assembly of the product. The production, however, has a variety in time ranging from 1-3 workdays depending on the specified capacity of the product that is produced. Finally, BPU – test has a generic structure of assembly-for-test, testing, and dismantling. Out of the three parts, assembly-for-test is the only one that retrieves material from the warehouse. Assembly-for-test is a stable procedure according to interviews, it always takes three days, and it is always on the third day that the material from the warehouse is needed. In summary, the complexity in production in the three flows are seen as low.

The level of variation in production is also relatively similar in the three A – flows. HP and HT – assembly have the same type of variety, where there are a few different products, and the only difference between them is their sizes. However, there is one exception in HP where 1 out of the 10 products is built on a different platform. This results in that there is a variety. However, the variety does not complicate the production of the product significantly. BPU – test, has products that vary greatly from one another. However, Tetra Pak PPCL are building standard modules, and these modules are what is connected at the assembly for test in BPU – test. In summary, the variety in products is seen as low for the three defined material flows.

The analysis and discussion of A – flows together with *decision proposition 1* implies that it is suitable to have pull systems at the three A – flows. Category A – flows can also be analyzed regarding *decision proposition 3* by discussing the knowledge gained from the waste identification. Table 16 show that the category A – flows have a high waste in the form of waiting. The reason for this is much related to shortage of material. However, for HP it is also due to the uncertainty of when material is being delivered. This results in less control over the material. One consequence of this at HP is that they currently have a safety stock of almost double the amount that they can produce. This has also been described as a waste. Further, the same level of waste in unnecessary inventory has not been observed at BPU – test or HT – assembly. At these two flows waste in the form of unnecessary motion has been observed instead. In summary, there are wastes in all flows in category A that can be affected by changing the material flow strategy. Therefore, based upon *decision proposition 3* the A – flows are suitable for a change of material flow strategy.

Table 17 summarizes the discussion about the different A – flow characteristics.

Table 17: The characteristics of the A – flows. They are shown through a rating system between 1-5, with 5 indicating that a specific flow has a lot of that specific characteristic and 1 indicating that the specific flow has very little of that specific characteristic

	HP	HT - assembly	BPU - test
Demand variation	1	2	2
Complexity of production	1	1	2
Variety of products	1	2	2
Disruptive behavior	3	2	2
Suggested material flow strategy	Pull	Pull	Pull

5.1.2.2 B – flows

With regards to *decision proposition 2* BPU – multi and BPU – special will be discussed, due to them having similar material flow characteristics. Category B – flows have a high level of complexity in production. The complexity is especially demonstrated in BPU – special. At this production step interviewees presented a situation where the manufacturing processes are carried out in different orders not only depending on the product but, also regarding the order. This increases the complexity tremendously at BPU – special. This type of complexity was not as clear at BPU – multi. However, it was somewhat present. At BPU – multi different products in the line require different process steps and production times. Furthermore, when it comes to stability in the length of processes it is a large variety in BPU – special. This is a consequence of the variety of processes needed and the order that the processes are performed in. In summary, the complexity in production is high for category B – flows and the main driver is that there are few standards in operation procedures.

Category B - flows have a high variation in products. Compared to the material flows in category A, the variety of products in category B is not only the size. Rather, the difference is both in function and size. This means that the variety increases. At the same time, the product is commonly engineered-to-order, where small things are changed depending on the needs of the customer. This means that even though it is the same module with the same function that is produced there are differences in the production, as for example the locations of fixings.

The analysis and discussion of category B – flows show that the complexity in production is high, and the variety of products is high. Thus, this knowledge together with *decision proposition 2* suggests that it is suitable to have a push system. Furthermore, category B – flows can also be analyzed and discussed regarding *proposition 3*. Category B – flows all have high wastes in the form of waiting. However, this is due to component shortages. Therefore, it is not a factor that would change if the material flow system were to be changed. Nevertheless, the material flows are having medium unnecessary inventory and low unnecessary motion. This is a potential indicator that a change in the material flow system could be beneficial. However, the high complexity makes it unreasonable to suggest such a change in the current context. If, however, there would be some sort of change that would decrease the complexity of production it could be of interest to investigate this further. Therefore, category B – flows will be discussed in section *5.1.3 How tracking technologies affects the choice of material flow system* to see if any changes could be made to the context to benefit a change of material flow system for the B – flows.

Table 18 summarizes the discussion about the different B – flow characteristics.

Table 18: The characteristics of the B – flows. They are shown through a rating system between 1-5, with 5 indicating that a specific flow has a lot of that specific characteristic and 1 indicating that the specific flow has very little of that specific characteristic

	BPU – multi	BPU – special
Demand variation	2	2
Complexity of production	4	5
Variety of products	4	5
Disruptive behavior	3	3
Suggested material flow strategy	Push	Push

5.1.2.3 C – Flows

Two out of the predefined flows are yet to be discussed. These are HT – MTS and BPU – manufacturing. Category C – flows are flows where it is not as obvious whether they should be using a push system or a pull system. Therefore, these flows will be discussed and analyzed with the usage of *decision proposition 1, decision proposition 2, and decision proposition 3*.

Category C – flows demand variety is quite similar between HT – MTS and BPU – manufacturing, but also when comparing it with category B – flows, see Appendix IV. Compared to category A –

flows the demand variation of category C – flows are higher. Nevertheless, like the other categories, there is a lower demand during July and December. However, these are the months with the least amount of work hours. Having a bit of demand variations is an indicator that pull is not suitable. However, demand variation is not regarded to be of as big relevance as the rest of the material characteristics. Meaning that it is not possible to make any conclusions from this characteristic alone.

Complexity in production is argued to be decently high for category C – flows. It is not as high as category B – flows, but higher than category A – flows. The complexity in Category C – flows is a consequence of the order consolidating rule in the bending process for BPU – manufacturing, and the order consolidating in the different production stations at HT – MTS. Further, the operations performed at BPU – manufacturing is of a complex character.

The variation in products is similar to the variation of products for category C – flows. It is not as high as Category B – flows, but not as low as category A – flows. At BPU – manufacturing many different sizes of pipes and many nonstandard welding operations are required. This is resulting in BPU – manufacturing having a high variety of products due to the different welding operations performed and the different pipe sizes. Similarly, at HT – MTS the driving factor behind the variation of products is the different sizes of the components that are being produced.

The discussed situation where demand variation is relatively low and complexity in production and variation in production are of a medium level is not a precise fit with either *decision proposition 1 or 2*. Thus, it is not possible by only using these propositions to decide which material flow systems that are suitable. Also, since these two defined material flows are characteristics-wise somewhere in-between the characteristics of A – flows and B – flows no new decision proposition will be added to help with determining what material flow system that will be used for this situation. Instead, these two defined material flows require to be further analyzed based on *decision proposition 3*.

At BPU – manufacturing the biggest waste is waiting. However, this is due to component shortage, which in this situation cannot be affected by the choice of material flow system. Other than that, there was little waste identified for these two defined material flows. Combining this with *decision proposition 3*, it is suggested that BPU – manufacturing continues to use its current material flow system. Another reason for this is that BPU – manufacturing is at the beginning of the internal material flow in production. Thus, it is easier to plan and release orders accurately for this process. Continuing, HT – MTS also has its main waste identified as waiting with the reason for this being component shortage. Thus, with *decision proposition 3,* it is recommended not to change the current material flow system for HT – MTS either. Furthermore, this recommendation is emphasized by the fact that most of the materials at HT – MTS that creates the unnecessary inventory already has a pull solution.

Table 19 summarizes the discussion about the different C – flow characteristics.

Table 19: The characteristics of the C – flows. They are shown through a rating system between 1-5, with 5 indicating that a specific flow has a lot of that specific characteristic and 1 indicating that the specific flow has very little of that specific characteristic

	BPU – manufacturing	HT - MTS
Demand variation	3	3
Complexity of production	3	2
Variety of products	4	3
Disruptive behavior	2	2
Suggested material flow strategy	Push	Push

5.1.3 How tracking technologies affects the choice of material flow system

Tracking technologies can enhance the control of the material at all its stages. Thus, it creates an opportunity for more complex productions to use material flow systems with higher requirements on control of the material. For the seven defined material flows some of these could potentially utilize a pull system to lower some of their identified wastes such as unnecessary inventory by the implementation of tracking technologies.

One categorization of the material flows, namely category B – flows can be considered to have high production complexity and much disruptive behavior, see table 18. Category C – flows are considered to have less disruptive behavior in its material flow and lower complexity in production than B – flows, see table 18 and 19. The lower disruptive behavior at C – flows indicates that these flows are functioning more proper than the B – flows and as a result are in less need of adjustments to its system. Further, the lower complexity in production results in these flows being in less need of improved control of the material in the material flow. Therefore, C - flows are of less interest to investigate regarding how implementation of tracking technologies could affect the choice of material flows system through the improve of control of the material in the material flow. However, if the disruptive behavior at the C – flows were to increase it would be of interest to investigate these flows.

Characteristics of material flows that are suitable for implementing tracking technologies are that it should be implemented in complex productions with increasing requirements on keeping track of different materials, which is corresponding with the characteristics of the B – flows. With the implementation of tracking technologies, it could result in less wastes in the form of unnecessary inventory because of the better control of the material. By better control of the material smaller inventory buffers would be required. Further, with better control of the material it would enable for the order handlers to better plan the releases of orders and decrease the wastes in the form of waiting and unnecessary motions. These wastes could be decreased because of the possibility of releasing the orders at more appropriate times with more exact estimations for how much time different operations requires. Further, it would enable for material to be more divided in its deliveries. Thus, reducing the waste of having people in production needing to search for their material at the unloading points. This is because of that it would not be as much material at the unloading points simultaneously as before.

The implementation would however require some planning for the possibilities to become true. If there is no plan for how to benefit from the tracking technologies, it would be of no point to make such an investment at Tetra Pak PPCL. Further, if the planning is incorrect, it could risk stopping the entire production on occasions and result in increase of wastes instead of the removal of wastes. Also, if the technology is not functioning properly, it would affect the material flow negatively by transferring incorrect information.

Depending on how complex the production is deemed to be there is also a choice on what sort of tracking technology that is required. The more precise it is required to be due to the increase of complexity, the bigger the investment it would also result in. Two options to choose between are RFID and RTLS, where RTLS is the more precise and more expensive of the two. This is another factor that is required to analyze when deciding upon implementing tracking technologies.

All in all, this results in an analysis consisting of both possible advantages to gain from the implementation of tracking technologies for the material flow at Tetra Pak PPCL, but also some risks that comes along with it. The discussed opportunities and risks with such an implementation can be seen in table 20.

Table 20: Display of the opportunities and risks of implementing tracking technologies for the material flow at Tetra Pak PPCL.

Risks	Opportunities
• Big investment • Requires thorough planning • If planning is incorrect it can result in stops in production • The tracking technology could be broken/disturbed	• Reduce inventory • Reduce unnecessary motions • Less waiting • More precise planning

Therefore, with a potential implementation of tracking technologies for the defined material flows at Tetra Pak PPCL it could result in a possibility of switching from a push system to a pull system for B – flows due to the improved control of the material within the defined material flows. By that resulting in a more precise planning of the production and more accessible information for involved functions on all occasions. This has led to the creation of the following decision proposition:

Decision proposition 4: Material flows with a high complexity in production and much disruptive behavior, should if tracking technology is implemented and the control of the material is improved use a pull system.

This proposition indicates at Tetra Pak PPCL that their B – flows, if they were to implement tracking technologies for the movement of material between warehouse 111, the yard and the PPCL production could utilize a pull system. With implementing a pull system for the B – flows the disruptive behavior could be lowered through the improved control of material within the material flows. Further, if the disruptive behavior at the C – flows were to increase these flows could be worth to investigate whether they also should utilize a pull system instead.

5.1.4 Summary of decision propositions

A suitable material flow system has been determined for each of the seven defined material flow. Further, for some of the defined material flows it have been analyzed how the implementation of tracking technologies could affect the choice of suitable material flow system. In total 4 decision propositions have been created. The decision propositions are summarized in table 21.

Table 21: Display of the 4 decision propositions.

Decision propsitions	
Proposition 1	*When demand variation is low, complexity in production is low, and variety of products is low, a pull system should be adopted to achieve a suitable material flow.*
Proposition 2	*When the complexity of production is high, and the variation of products is high a push system should be adopted to achieve a suitable material flow.*
Proposition 3	*When there is disruptive behavior, it is an indicator that the company potentially should change material flow strategy to remove wastes.*
Proposition 4	*Material flows with a high complexity in production and much disruptive behavior, should if tracking technology is implemented and the control of the material is improved use a pull system.*

The first three propositions were used to analyze and decide when to use a push system or a pull system at Tetra Pak PPCL and have thereby led to the implication of what material flow system that is suitable for each of the seven defined material flows. Further, the fourth proposition implicated how the implementation of tracking technology could make it worth to re-investigate what material flow system that is the most suitable for two of the defined material flows. To summarize the analysis of suitable material flow strategies for each of the defined material flows a table has been created, see table 22. The table is displaying the characteristics of each of the seven defined material flows.

Table 22: Display of how the seven defined material flows is rated regarding specific characteristics and the suggested material flow strategy. The rating of 1 indicates that the specific material flow has very little of that characteristic and a rating of 5 indicates that a specific material flow has very much of that characteristic.

	HP	HT – assembly	BPU – test	BPU – multi	BPU – special	BPU – manufacturing	HT – MTS
Demand variation	1	2	2	2	2	3	3
Complexity of production	1	1	2	4	5	3	2
Variety of products	1	2	2	4	5	4	3
Disruptive behavior	3	2	2	3	3	2	2
Suggested material flow strategy	Pull	Pull	Pull	Push	Push	Push	Push

5.2 Design propositions

In this section design propositions are created. This have been done in two separate steps. The first step of deciding on appropriate pull flow method was conducted with the purpose of creating an understanding of what material flow characteristics that are suitable for specific pull flow methods. By doing this it was possible to determine which of the pull flow methods that are the most suitable for the material flows deemed to be appropriate to utilize a pull system, see table 19. In the second part the material flow and information flow interactions for the material flows deemed appropriate to utilize a pull system are analyzed. Adjustments are suggested for improving these interactions and to create a pull system. The outline is summarized in figure 44.

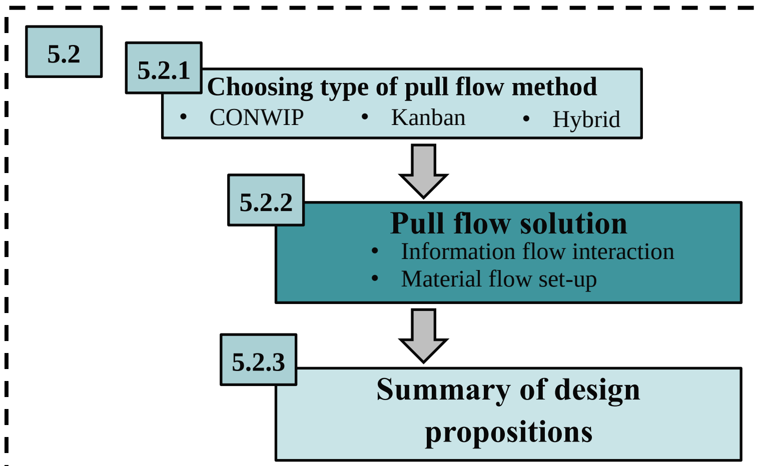


Figure 44: Outline of developing design proposition.

5.2.1 Deciding on appropriate pull flow method

After deciding on appropriate material flows to utilize a pull system, the next step in designing a pull system regards the choice of the most appropriate pull flow method. When deciding on the most appropriate pull flow method, three different options have been investigated in the frame of reference. Namely Kanban, CONWIP and a hybrid between Kanban/CONWIP. The pull flow methods have different advantages, disadvantages, and suitable environments. Therefore, the characteristics of the material flows should be analyzed with these parameters in mind.

The material flows of HP, HT – assembly and BPU – test have been deemed suitable for utilizing a pull system. These flows have the characteristics of low demand variation, low production complexity, low product variability and some disruptive behavior. These flows are not fully following their production schedules and requires some flexibility in their material flow systems.

With the given situation of shortages of certain materials for the production processes it is necessary with a more flexible pull system able to adjust to changes affecting the production schedules. This is because the component shortage for some specific components can cause abrupt changes in the scheduled productions. Also, the demand of specific material at production can risk changing drastically due to the given situation. This is because the shortage of components slows down specific production operations and as a result some material will be required later than originally planned at the production site.

The control of the material at each process is not deemed to be of the most utter importance. This is because the flows of material that the system is being designed for is only between two specific functions and not involving that many processes in its flow. With less processes included in the material flow, the importance of control of the material at each process stage is not as big as within a more complex and longer material flow. Further, none of the processes for these three defined material flows are particularly long or complex.

The production processes at these flows are supposed to be working closer to their maximum capacity. By that meaning that they are operating as much as they possibly can at their specific processes. At the production processes it is aimed at having their workers performing production operations and not spend times on unnecessary activities as much as possible. The production at the different processes is relatively stable. However, the flows have been experiencing some disruptive behavior affecting the stability of production.

There is some variety in products produced at these flows. Even, though the products produced at these three defined flows are similar to some extent there is still some variability in some of the production processes. Further, there is a difference regarding how much time that is required to produce a product at one of the production parts for the three defined material flows. Indicating the variability in the products handled at the production areas. However, the variety of products is regarded as relatively low for the three analyzed material flows.

The option of Hybrid Kanban/CONWIP is deemed unsuitable for these three defined material flows because it is regarded to be a too complicated system for a material flow with these low number of operations included within it. The processes are not considered to be varying that much or being long enough to motivate the choice of the hybrid pull flow method. Further, analyzing the characteristics of the three defined material flows with the environments suitable for a Kanban strategy and a CONWIP strategy it is decided that the CONWIP strategy is the more suitable option. This is because of the characteristics of the three material flows. With a situation requiring a system able to be somewhat flexible and able to handle a variety of products CONWIP is more suitable. Continuing, the control requirements on the pull system are not high due to few and not highly complex processes included in the material flows. The productions are striving towards operating closer to their maximum capacity. This is further motivating the choice of CONWIP as the most suitable pull flow method. The requirements of the three defined material flows compared with the abilities of the pull flow methods is presented in table 23.

Table 23: The requirements of the defined material flows compared with the abilities of the pull flow methods.

	A-flow requirements	**Kanban characteristics**	**CONWIP characteristics**	**Hybrid Kanban/CONWIP characteristics**
Flexibility	Medium	Low	Medium	Medium
Variety of products	Medium	Low	Medium	Medium
Material flow complexity	Low	Low	Low	Medium
Control requirements	Low	Medium	Low	Medium
Handling of maximum production operations	High	Medium	High	High

Thus, this have resulted in the creation of the following three design propositions:

Design proposition 1.1: When requirements on flexibility is low, process complexity is low, control of material is medium and when handling products of low variety not too close to the maximum production capacity a Kanban system should be adapted as a suitable pull flow method.

Design proposition 1.2: When requirements on flexibility is medium, process complexity is low, control of material is medium and when handling products of medium variety close to the maximum production capacity a CONWIP system should be adapted as a suitable pull flow method.

Design proposition 1.3: When the complexity of production is higher than a Kanban or CONWIP system can handle, and the requirements on the control of the material is at least medium a Hybrid Kanban/CONWIP system should be adapted as a suitable pull flow method.

The three design propositions have upon their creation led to the specific implication for Tetra Pak PPCL that they should use a CONWIP system for the three material flows that have been deemed appropriate for utilizing a pull system.

5.2.2 Material- and information flow set-up

With a pull flow method decided it is time to create the design for the material- and information interaction. In a CONWIP system the information interaction is based upon having a limitation regarding the entire system instead of between each process. The flow is regulated by having the last process within the system control when material should start moving.

For the three defined material flows where a CONWIP system is suggested this means that it is the production processes that should control when orders should be released. As of now orders are released with a varying time for the three defined flows depending on if they are producing BPU, HT or HP. However, when designing the information interaction for the suggested CONWIP system new guidelines for all three defined material flows will be suggested. To start with it is of importance that there is a communication between the three functions. This is important because of that a proper communication can prevent the creation of bottlenecks at different processes due to material being delivered to them before it is needed.

As of today, most production leaders are communicating with the order handlers regarding how they are up to track with their production schedules. However, there is no communication between the warehouse and the order handler upon the releases of orders for any of the three product types. This causes that on occasions the warehouse capacity is not sufficient for handling all their picking orders for specific days. With a communication from the order handler with both functions involved in the order it would be easier to control the movement of the material and plan in accordance with it. Further, daily communication with the production would prevent the release of orders that the production is not yet ready to handle or possibly orders could be released earlier if the opportunity arises. Thus, resulting in lower inventory at the production site and a better control of the material flow between the two functions. It would also reduce the wastes of unnecessary motions and waiting since it would be more obvious and precise regarding when material will arrive at the production site. As a result of this the following design proposition has been created:

Design proposition 2.1: When utilizing a pull system between functions one should make sure that the order handler is communicating with all involved functions for it to be a functioning material flow.

Based on the design proposition the three material flows that a pull system is suggested for should do some changes to how they are currently handling the movement of material. The order handler for these flows should make certain that they are having daily communication with the production leaders for the defined material flows. On these meetings they should discuss how the current progress at production is preceding and if they are able to follow the scheduled production plan. Further, they should discuss if any issues have arisen that could affect future planned productions. Also, they should discuss the release of orders, and these should only be released if production believes themselves to be able to handle the order according to its schedule. The order handler should also communicate with the warehouse when releasing more prioritized orders. The communication should regard how orders are prioritized and which orders that should be picked first at the warehouse. This would prevent waiting at the PPCL production for the more critical productions and material that is of shortage would be dedicated to the most important orders for a specific day. Thus, resulting in more of the planned productions being able to follow their production schedules. Design proposition 2.1 and its implications at Tetra Pak is summarized in table 24.

Table 24: Design proposition 2.1 and its implications at Tetra Pak.

Design proposition	Implication at Tetra Pak
2.1 When utilizing a pull system between functions one should make sure that the order handler is communicating with all involved functions for it to be a functioning material flow.	• Have the order handler communicate daily with team leaders in production regarding: (1) if they are following their production schedule, (2) if any issues have arisen, and (3) the release of future orders. • Communicate with the warehouse upon order releases of higher priority to notify how these are prioritized against other released orders.

A pull system requires a set-up where it is the production that directly or indirectly decides when material should be pulled into production, compared to when the material is being pushed out according to how it is scheduled in the ERP system. As it currently stands at Tetra Pak PPCL, the overall strategy is to push out material according to the plan in the ERP system. Moreover, there is one confirmation step, the so-called release of order. The number of picking orders that are being scheduled by a release is depending on the size of the order and the type of product. The current set-up of the A-flows is a bit varying between the three defined material flows. BPU – test, which is the final step of the BPU production, the order releases occur between 2-3 weeks before the picking for BPU – test happens. Both HT – assembly and HP releases its picking order closer to the actual pick then BPU – test. HT – assembly's order handler releases the order 1 day before the actual pick and 2 days before the material is needed at production. HP has a different strategy where the goal is to always have four production orders as a safety stock at their unloading points. The current set-up of the A – flows does not follow the pull philosophy, therefore *design proposition 2.2* is formulated.

Design proposition 2.2: To facilitate a pull system the order releases should directly or indirectly be released by people in production as close to production start as possible.

More concretely for Tetra Pak this results in three suggestions. Firstly, the release of BPU – test's picking order should be delayed so it happens closer to the production start. The team leader at production mentioned that the warehouse material was always needed on the third day of assembly-for-test. Thus, it is suggested that employees at production should indicate to the order handlers when assembly-for-test starts. Upon indication the order handler should release the related picking order for material required from the warehouse on the same day as assembly-for-test has started. Secondly, HT – assembly should implement a more structured way where team leaders at production indicates that there is capacity to release an order. Thirdly, HP should continue with having the team leader indicating when an order should be released. However, they should try to reduce their safety stock to two orders instead of their current four and with that release their orders closer to when they are needed in production. This would decrease the wastes of unnecessary motions by making it easier for employees at production to find their needed material and simplify the distribution process since there would be less material at the production site taking up unnecessary space. To be able to reduce the safety stock for HP the reliability in time of deliver is mentioned by interviewees to be essential. Design proposition 2.2 and its implications at Tetra Pak is summarized in table 25.

Table 25: Design proposition 2.2 and its implications at Tetra Pak.

Design proposition	Implication at Tetra Pak
2.2 To facilitate a pull system the order releases should directly or indirectly be released by people in production as close to production start as possible.	• Have separate order releases for BPU – test and release these orders when assembly-for-test starts. • Decrease the safety stock at HP production. • Make the team leader at production responsible for informing the order handler if the order can be released.

At production there is currently no awareness of when material will be delivered during a day. For some material flows this is not of the biggest importance, but for those material flows that are suggested to utilize a pull system this creates an issue. At material flows utilizing a push system this is not the same issue because the planning for push systems is not as sensitive for minor faults as pull systems. Also, in a pull system the orders are released at a later stage and are therefore more sensitive to the delays regarding its distribution.

Having a delivery timeslot each day of approximately 8.5 hours results in unnecessary waiting in production at those occasions when production is supposed to start for a specific day and material have still not been delivered. It gives the employees at production less control of their production and creates an uncertainty regarding the arrival of the material. To prevent this issue for pull systems that are having a smaller production inventory than a push system, delivery timeslots could be used to simplify for people at production when they are planning their daily routines. If they are better aware of at what time during the day material will be delivered to the PPCL production, it could help preventing unnecessary waiting for them and provide better control of their production. Further, it could help with the planning for pull systems since they would have a better knowledge regarding when material is going to be delivered to them during the day. Thus, this has resulted in the following design proposition:

Design proposition 2.3: When a pull system is used the distribution part should provide smaller delivery time slots to reduce the need for inventory at the receiving end.

This design proposition results in some suggested adjustments for the material flow between warehouse 111, the yard, and the production site. Exact delivery time slots will not be possible to provide with the current contextual factors. However, some prioritization for what orders that are being picked first and what orders that are being picked last is possible to do. What should be done is that the picking orders should be sorted at the warehouse at the start of the day. This would make certain that the orders will be picked in an order creating a better awareness of at what time during the day different production areas can expect to receive their material. Thus, resulting in an easier planning for the production leaders at the production site. The orders should be sorted according to the following: (1) Orders that are dedicated to pull systems should be picked before orders that are dedicated for push systems, and (2) Material that is of shortage should always be prioritized to be picked as fast as possible regardless of which defined material flow it belongs to.

The sorting of the orders should be done by the one arriving first at the warehouse. Whether they are being picked within a pull system or a push system is determined by their unloading points and can be sorted based upon that. All picking orders that are concerning material of shortage can be placed in a specific picking folder that the pickers should always start picking first. Through sorting of this kind, a sort of time slot for distribution can be created. Design proposition 2.3 and its implications at Tetra Pak is summarized in table 26.

Table 26: Design proposition 2.2 and its implications at Tetra Pak.

Design proposition	Implication at Tetra Pak
2.3 When a pull system is used the distribution part should provide smaller delivery time slots to reduce the need for inventory at the receiving end.	• Sorting of picking orders at the start of each day. It should be sorted according to the following prioritization: (1) material of shortage, and (2) if the material is within a pull system or a push system.

To further improve the control of the material and increase the suitability of a pull system more available status updates for the material need to be introduced in the material flow. Currently, the only accurate status update on the material in the material flow between warehouse 111 and the PPCL production is that the picking process has started. No further status updates are available for the picking order. The picking order is instead closed in batches with other picking orders at the end of each workday. This results in that it is not possible to know the actual time at which a picking order could have been closed and considered as completed. This creates uncertainties for production employees. They are not aware of how the picking process for their required material is proceeding apart from that the process has started. They do not know whether the material is ready for distribution or if the material has been delivered. Therefore, the following design proposition is presented and suggested.

Design proposition 2.4: To increase the control of the material in a material flow, the warehouse employees should make the status of a picking order more precise, and available for the production employees.

More concretely at Tetra Pak PPCL, the warehouse employees should indicate in their current ERP system, when a picking order starts, when it is at the distribution area, and when the order has been delivered. Further, it should be possible to check the status of a picking order in an easy way for employees at production. This could be enabled within the ERP system by adding functions that upon confirmation signals that the material is about to be picked, that it has been picked and is ready for distribution, and that it has been delivered to its distribution destination. Design proposition 2.4 and its implications at Tetra Pak is summarized in table 27.

Table 27: Design proposition 2.4 and its implications at Tetra Pak.

Design proposition	Implication at Tetra Pak
2.4: To increase the control of the material in a material flow, the warehouse employees should make the status of a picking order more precise, and available for the production employees.	• Introduce more status updates for the picking orders. There should be information for when a picking order starts, when it arrives at the distribution area, and when it has been delivered to the production area. This should be easily accessible for production employees.

5.2.3 Summary of design propositions

The first part of developing design propositions was to identify an appropriate pull system method. This resulted in the first three design propositions, see table 28. Based on these propositions it was deemed most suitable to have a CONWIP system at Tetra Pak PPCL for those material flows where a pull system is appropriate to utilize with the current context.

Table 28: Displays the three first design propositions that were concluded from the discussion in section *5.2.1 Deciding on appropriate pull flow method.*

Design propsitions	
Proposition 1.1	*When requirements on flexibility is low, process complexity is low, control of material is medium and when handling products of low variety not too close to the maximum production capacity a Kanban system should be adapted as a suitable pull flow method.*
Proposition 1.2	*When requirements on flexibility is medium, process complexity is low, control of material is medium and when handling products of medium variety close to the maximum production capacity a CONWIP system should be adapted as a suitable pull flow method.*
Proposition 1.3	*When the complexity of production is higher than a Kanban or CONWIP system can handle, and the requirements on the control of the material is at least medium a Hybrid Kanban/CONWIP system should be adapted as a suitable pull flow method.*

The second part was to develop a set-up for the pull system and suggest adjustments to the current material flow systems for Tetra Pak PPCL. This led to the creation of four design propositions. A summarization of the four design propositions and the implications these result in for Tetra Pak PPCL can be seen in table 29.

Table 29: Present the four design propositions that were concluded from the discussion in section *5.2.2 Material- and information flow set-up* together with the implication of the proposition at Tetra Pak.

Design propositions	**Implication at Tetra Pak**
2.1 When utilizing a pull system between functions one should make sure that the order handler is communicating with all involved functions for it to be a functioning material flow.	• Have the order handler communicate daily with team leaders in production regarding: (1) if they are following their production schedule, (2) if any issues have arisen, and (3) the release of future orders. • Communicate with the warehouse upon order releases of higher priority to notify how these are prioritized against other released orders.
2.2 To facilitate a pull system the order releases should directly or indirectly be released by people in production as close to production start as possible.	• Have separate order releases for BPU – test and release these orders when assembly-for-test starts. • Decrease the safety stock at HP production. • Make the team leader at production responsible for informing the order handler if the order can be released.
2.3 When a pull system is used the distribution part should provide smaller delivery time slots to reduce the need for inventory at the receiving end.	• Sorting of picking orders at the start of each day. It should be sorted according to the following prioritization: (1) material of shortage, and (2) if the material is within a pull system or a push system.
2.4: To increase the control of the material in a material flow, the warehouse employees should make the status of a picking order more precise, and available for the production employees.	• Introduce more status updates for the picking orders. There should be information for when a picking order starts, when it arrives at the distribution area, and when it has been delivered to the production area. This should be easily accessible for production employees.

6. THE APPLICABILITY OF THE PROPOSITIONS

In this chapter the applicability of the created decision- and design propositions and their implications for Tetra Pak PPCL are discussed. The applicability has been evaluated through a workshop focusing on discussing the propositions in general and to discuss whether their implications at Tetra Pak PPCL are applicable or not. The propositions have been divided into three different categories. Firstly, the decision propositions that have led to indications regarding when it is appropriate to utilize a pull system are discussed. Secondly, design propositions 1.1, 1.2 and 1.3 are discussed, since they implicate what sort of pull method that should be used when it is deemed appropriate to utilize such a system. Thirdly, design propositions 2.1, 2.2, 2.3, and 2.4 are investigated since they implicate changes that should be made to the current material flow system. The results from these three parts are then summarized in a table where the applicability of the decision- and design propositions are shown. The outline of chapter 6 is presented in figure 45.

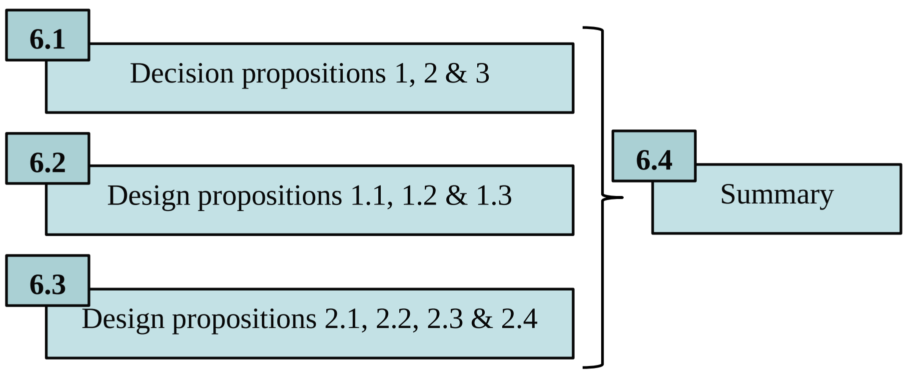


Figure 45: Displays the outline of the applicability of the propositions chapter.

6.1 Applicability of decision propositions

The first three decision propositions were discussed at the workshop. The fourth decision proposition regarding tracking technologies was not discussed at the workshop. This is because the fourth decision proposition does not have any direct implications for Tetra Pak PPCL. To begin with the three decision propositions discussed were presented and the process of creating them was explained. After that, the propositions were evaluated on a more general basis, and it was explained why the propositions states what they do. Thereafter, special considerations were then taken regarding the decision propositions implications for Tetra Pak PPCL.

When discussing the implications, the focus was primarily if the evaluation of the defined material flows seemed reasonable. For the two flows HP and HT – assembly the workshop participants shared the view in that these should be utilizing a pull system rather than a push system. However, originally, they were a bit more questioning whether BPU – test should be utilizing a pull system or a push system. After some discussing the participants were convinced that also BPU – test could benefit from utilizing a pull system instead of a push system. Another flow that was a topic discussed was HT – MTS. The participants of the workshop believed the production related to that flow not to be as complex as had been deemed in the analysis of the flow. However, after discussing it further they could understand the reasoning behind the result from the analysis.

Regarding the decision propositions it was concluded that they seemed usable and their implications for Tetra Pak PPCL were applicable, see table 30.

Table 30: The implications and their applicability at Tetra Pak PPCL for decision propositions 1, 2, and 3.

Proposition	Implication for Tetra Pak PPCL	Applicability
Decision propositions 1,2, and 3.	• **Pull systems**: HP, HT – assembly, and BPU – test. • **Push systems**: BPU – special, BPU – multi, BPU – manufacturing, and HT – MTS	• Reasonable implications. • Could be further investigated if HT – MTS could be utilizing a pull system too.

6.2 Applicability of design propositions 1.1, 1.2, and 1.3

The implication of design propositions 1.1, 1.2, and 1.3, that is, the chosen pull method of CONWIP was discussed during the workshop. To begin with a discussion about the decision parameters flexibility, variety of product, material flow complexity, control requirement, and handling of maximum capacity was held. The primary focus on this discussion was complexity. The workshop participants agreed that complexity was an important part when deciding pull method and that it was relatively low at the material flows that was chosen to be pull. Further, if Tetra Pak PPCL are working close to maximum was discussed. The workshop participants said that they were close to maximum. However, it was described as a complex parameter because of the use of staffing agencies when there is a capacity shortage. Nevertheless, it was concluded that Tetra Pak PPCL does not have a large buffer capacity.

The presented solution of CONWIP was seen as applicable and reasonable by the workshop participants. However, it was discussed if there would be any difference between a CONWIP solution and a Kanban solution in practice. The conclusion from the discussion is that it would probably be a small difference in the studied environment at Tetra Pak PPCL. However, if a Kanban would be implemented there was a large probability that the production would use it as a CONWIP. Thus, it was better to implement a CONWIP from the beginning.

For the design propositions 1.1, 1.2, and 1.3 it was concluded that they were reasonable and their implication of a CONWIP method recommendation were applicable for Tetra Pak PPCL, see table 31.

Table 31: The implications and their applicability at Tetra Pak PPCL for design propositions 1.1, 1.2, and 1.3.

Proposition	Implication for Tetra Pak PPCL	Applicability
Design propositions 1.1, 1.2 & 1.3	• The CONWIP pull method is recommended for the defined material flows where utilizing a pull system has been deemed appropriate	• Reasonable implication

6.3 Applicability of design propositions 2.1, 2.2, 2.3 and 2.4

In total it was four different design propositions that were discussed when focusing upon implications that suggested changes to Tetra Pak PPCL's current material flow system. The design propositions when discussed on a more general basis were found to be reasonable by the workshop participants. Further, the implications for Tetra Pak PPCL were discussed more thoroughly.

The first proposition, implicating that there should be communication between the order handler and all involved functions at Tetra Pak PPCL with more clear guidelines for how this communication should be handled were something that the participants of the workshop were positive towards. Particularly the implication of how there should be an increased communication between the order handler and the warehouse as the communication between them is almost non-existent today. This was a proposition that was deemed to be applicable for Tetra Pak PPCL, see table 32.

Table 32: The implications and their applicability at Tetra Pak PPCL for design propositions 2.1.

Proposition	Implication for Tetra Pak PPCL	Applicability
Design propositions 2.1	• Have the order handler communicate daily with team leaders in production regarding: (1) if they are following their production schedule, (2) if any issues have arisen, and (3) the release of future orders. • Communicate with the warehouse upon order releases of higher priority to notify how these are prioritized against other released orders.	• Applicable and something that should be implemented.

That releases of orders should be closer to the actual start of production was also a proposition whose implication seemed reasonable. However, it was discussed that it was more difficult to apply at Tetra Pak PPCL. The part with lowering the safety stock at HP was applicable but releasing the orders later at BPU – test would be more difficult. A method discussed to solve this at BPU – test was if one of the operations included in the release of the order could be moved to be released outside of that order. That would enable for the release of orders for BPU – test to be closer to the operation of assembly-for-test. Changing the order set-up was discussed to be easier to accomplish than making changes within the order, which could have been an alternative. The implication and applicability for design proposition 2.2 is summarized in table 33.

Table 33: The implications and their applicability at Tetra Pak PPCL for design propositions 2.2.

Proposition	Implication for Tetra Pak PPCL	Applicability
Design propositions 2.2	• Have separate order releases for BPU – test and release these orders when assembly-for-test starts. • Decrease the safety stock at HP production. • Make the team leader at production responsible for informing the order handler if the order can be released.	• Have a separate release of an order for BPU – test was seen as applicable if the order set-up was rearranged. • The safety stock at HP was seen as to large. Thus, reducing it was reasonable and applicable. • Having the team leader responsible for informing that an order can be released is applicable.

The third proposition were implicating that there should be different time slots for when material should be distributed to the different flows of material during the day. For this proposition it was discussed that when regarding material that is of shortage it can be difficult to identify what material that is of shortage. There are usually not many shortages of material to be picked during the morning and then during the day it is hard to identify which picks that are for shortage of material. There is not one specific person that always knows whether the material to be picked are of shortage or not. However, the prioritization of distributing material of shortage first is something that is being strived towards having. Regarding sorting between the push and pull, it could be achieved by dividing it by unloading points. This is something that could be possible and something that could be applied at Tetra Pak PPCL without any complications. The implication and applicability for design proposition 2.3 is summarized in table 34.

Table 34: The implications and their applicability at Tetra Pak PPCL for design propositions 2.3.

Proposition	Implication for Tetra Pak PPCL	Applicability
Design propositions 2.3	• Sorting of picking orders at the start of each day. It should be sorted according to the following prioritization: (1) material of shortage, and (2) if the material is within a pull system or a push system.	• It is hard to see in the system if a material is of shortage and the pickers are often unaware of if a material is of shortage or not. This reduced the applicability • Sorting the material by if they are delivered within a pull flow or push flow is possible and would be applicable.

The last design proposition was the one that the participants of the workshop found the hardest to apply at Tetra Pak PPCL. They saw the benefits of it. However, the possibility to implement it with the current system would be low. Currently, it would be possible to see when an order has been picked, but harder to see where in the process it is. It could potentially be applied if some ERP module were to be added that could help with confirming the delivery of material at the PPCL production. However, the current system at Tetra Pak PPCL cannot handle performing this suggested implication by itself. Therefore, it would require some bigger investments and for that it would be necessary to further display the benefits of this proposition. The defined material flows could be made more visible by making some confirmations being performed more manually and outside of the system, but it would complicate it more than it would help. Therefore, it would be hard to apply this implication at Tetra Pak PPCL given the current situation. The implication and applicability for design proposition 2.4 is summarized in table 35.

Table 35: The implications and their applicability at Tetra Pak PPCL for design propositions 2.4.

Proposition	Implication for Tetra Pak PPCL	Applicability
Design propositions 2.4	• Introduce more status updates for the picking orders. There should be information for when a picking order starts, when it arrives at the distribution area, and when it has been delivered to the production area. This should be easily accessible for production employees.	• It would be useful. However, not possible to implement with the current ERP system.

In general, the four design propositions seems reasonable. However, not all of them seems applicable at Tetra Pak PPCL in its current state. The first three design propositions are applicable, but the fourth design proposition had the problem of being difficult to implement. It would require an upgrade to the current ERP-system and that would require more investigation of the benefits of the fourth design proposition before such an investment would be made. However, with such an investment the fourth design proposition would be applicable.

6.4 Summary of applicability of propositions

With the implications of the different design propositions evaluated by a workshop their applicability for Tetra Pak PPCL have been investigated. To summarize it, the propositions in general have been deemed to be of value, but not all of them can be applied at Tetra Pak PPCL. Table 36 summarizes how applicable the different propositions are at Tetra Pak PPCL.

Table 36: Displays how reasonable and applicable the design- and decision propositions are for Tetra Pak PPCL.

Proposition	Implication for Tetra Pak PPCL	Applicability
Decision propositions.	• **Pull systems**: HP, HT – assembly, and BPU – test. • **Push systems**: BPU – special, BPU – multi, BPU – manufacturing, and HT – MTS	• Reasonable implications. • Could be further investigated if HT – MTS could be utilizing a pull system too.
Design propositions 1.1, 1.2 & 1.3	• The CONWIP pull method is recommended for the defined material flows where utilizing a pull system has been deemed appropriate	• Reasonable implication
Design propositions 2.1	• Have the order handler communicate daily with team leaders in production regarding: (1) if they are following their production schedule, (2) if any issues have arisen, and (3) the release of future orders. • Communicate with the warehouse upon order releases of higher priority to notify how these are prioritized against other released orders.	• Applicable and something that should be implemented.
Design propositions 2.2	• Have separate order releases for BPU – test and release these orders when assembly-for-test starts. • Decrease the safety stock at HP production. • Make the team leader at production responsible for informing the order handler if the order can be released.	• Have a separate release of an order for BPU – test was seen as applicable if the order set-up was rearranged. • The safety stock at HP was seen as to large. Thus, reducing it was reasonable and applicable. • Having the team leader responsible for informing that an order can be released is applicable.
Design propositions 2.3	• Sorting of picking orders at the start of each day. It should be sorted according to the following prioritization: (1) material of shortage, and (2) if the material is within a pull system or a push system.	• It is hard to see in the system if a material is of shortage and the pickers are often unaware of if a material is of shortage or not. This reduced the applicability • Sorting the material by if they are delivered within a pull flow or push flow is possible and would be applicable.
Design propositions 2.4	• Introduce more status updates for the picking orders. There should be information for when a picking order starts, when it arrives at the distribution area, and when it has been delivered to the production area. This should be easily accessible for production employees.	• It would be useful. However, not possible to implement with the current ERP system.

7. CONCLUSION

To conclude the master thesis three different areas are discussed. To begin with a discussion regarding how the purpose of the master thesis have been achieved is held. Thereafter, its contribution to research and Tetra Pak PPCL is discussed. Finally, the limitations of the thesis and suggested future research is presented and commented upon.

7.1 Fulfilling the purpose

The purpose of this master thesis was to *create decision– and design propositions for determining when it is appropriate to utilize a pull system and how a pull system can be designed at Tetra Pak PPCL*. The intention of the purpose was to contribute to existing literature regarding how to link warehouse with production and how to determine an appropriate material flow system. A design science approach was used to fulfill this purpose by the creation of an artifact in the shape of an analytical framework. To begin with the structure of the research process was developed based on the design science research strategy. Thereafter, a thorough literature study was performed to prepare for the later parts and an analytical framework for fulfilling the purpose was created. Through own observations, secondary data and interviews an understanding of the current state was gained and the current state was then analyzed with the use of available literature and the analytical framework. Once, the analysis was completed it led to the creation of decision propositions and design propositions that provided Tetra Pak PPCL with recommendations for their material flow between warehouse 111, the yard, and the PPCL production. To achieve the purpose a total of four research objectives was formulated to use as guidelines.

RO1: *Describe the current state of the material flow between warehouse 111, the yard, and the PPCL production.*

The first objective was accomplished within the empirical findings chapter. It was achieved in four parts. The parts consisted of detailed descriptions of the material flows configuration, the processes involved, the characteristics of the material flow, and the characteristics of the information flow. Data about the four parts were gathered by conducting 13 interviews and 7 observations together with analyzing 8 documents and raw ERP data. This objective can be viewed as a preparation for the three objectives to come, since it is used as a foundation for them.

RO2: *Identify how the current material flow between warehouse 111, the yard, and the PPCL production is performing.*

In this objective the performance of the material flow was investigated by identifying wastes within the material flow. The four kinds of wastes identified was unnecessary motions, waiting, unnecessary inventory, and transportation. The waste identification was based on the empirical findings created by fulfilling RO1. In this objective it was concluded that the most obvious waste to potentially be eliminated was that of unnecessary inventory.

RO3: *Determine which parts of the material flow between warehouse 111, the yard, and the PPCL production that are suitable for a pull system.*

The entirety of the material flow was divided into seven smaller material flows for enabling a better solution and analysis of the material flow. This was done when mapping the current state. Each of the seven material flows were analyzed based on four different parameters. The parameters were demand variety, complexity of production, product variety, and disruptive behavior. The first three parameters indicated how suitable the defined material flows where when considering the environment in which it was to potentially be implemented in. The fourth parameter of disruptive behavior instead were an indication of how the current material flow system is functioning. The parameters were based on literature in which these parameters have been identified to be of importance to consider when choosing the appropriate material flow system. In the end it was concluded that three of the seven identified material flows are suitable for utilizing a pull system. Further, how the decision would be affected if tracking technologies were to be implemented was investigated. This was of interest for two of the defined material flows and it was analyzed how improved control of the material in the flow could affect the decision in favor of implementing a pull system. This analysis was conducted with the use of the frame of reference combined with the identified characteristics of the material flow.

RO4: *Define, at determined suitable parts, how the material flow between warehouse 111, the yard, and the PPCL production can be set-up as a pull system.*

For the three material flows deemed to be suitable for the implementation of a pull system these were analyzed further. To begin with an analysis to determine the most suitable pull flow method was conducted. This analysis was based on characteristics of material flows and comparing them with what the suitable environment for the different pull flow methods are. The suitable environment for the pull flow method was based on literature in the frame of reference. It was decided that for the given situation the pull flow method of CONWIP were the most appropriate for the three material flows deemed suitable to implement a pull system for. Once the suitable pull flow method was decided guidelines within four different areas were created. The areas where guidelines were established was the areas where the current material flow solution were identified to be problematic. The guidelines were created based on the current state of the material flow, the frame of reference, the analysis of the current state, and with the pull flow method decided to be CONWIP.

Fulfilling the purpose with the help of the four research objectives and with the usage of the analytical framework led to the creation of four decision propositions and seven design propositions.

7.2 Contribution

The theoretical contribution of the thesis is within three different areas. It has contributed within the areas of: (1) providing knowledge on how to link the two functions of warehouse and production, (2) how to compare different material flow systems and determine the most appropriate one, and (3) with developing an analytical framework for how to compare material flow systems and how to design pull systems. Both creating solutions for the linkage between the two functions of warehouse and production and comparing on which occasions a push system or a pull system is the most suitable have been found to be of lack within todays research (Davarzani & Norrman, 2015; Jolayemi & Olorunniwo, 2004; Krishnamurthy, Suri & Vernon, 2004; Manzini, 2012). To reduce these gaps decision and design propositions has been created.

Jolayemi and Olorunniwo (2004), Manzini (2012), and Davarzani and Norrman (2015) emphasizes that there is a lack of research with linking warehouse and production with a holistic view. The authors of this thesis realizes that a fully holistic view has not been achieved when fulfilling the purpose, but by conducting interviews and observations with both functions a holistic view has to some extent been accomplished.

The analytical framework is a tool that can help with future research regarding deciding on the most appropriate material flow system and with designing pull systems. Thus, it can contribute with helping future researchers analyze material flow systems and design pull systems.

The practical contribution for Tetra Pak PPCL is through the propositions created with the usage of the analytical framework. First, Tetra Pak PPCL have been provided with a detailed mapping of their current material flow between warehouse 111 and the PPCL production. Secondly, the entire material flow has been divided into seven smaller material flows where the performance has been analyzed and material flow strategies has been suggested for the different material flows. Thirdly, it has been investigated how a future implementation of tracking technologies could affect the material flows and potentially utilize a pull system for more of the defined material flows. Finally, adjustments to those material flows which are regarded to be suitable for utilizing a pull system has been developed and presented. To summarize the contribution for Tetra Pak PPCL, it can be said that Tetra Pak PPCLs material flow have been analyzed and changes for it with the purpose of improving it have been suggested.

7.3 Limitations and future research

A limitation for this thesis is that a single case was used when applying the analytical framework. This decreases the possibility of generalizability. Therefore, it would be interesting to see how the analytical framework would function at different companies that are interested in adopting more of a pull philosophy in their material flow. This would increase the possibility to see the potential usefulness of the analytical framework. Further, it would also increase the knowledge about the propositions because it would be possible to see how they are applicable for different companies. All in all, with a multi-case study the generalizability would increase.

Within a design research process, it is common to implement the solutions and test the solution in a real scenario. This was something that due to time limitations and feasibility was not possible. As a compromise, a workshop was used where the applicability of the propositions were discussed. With this compromise it was possible to discuss the potential improvement. However, by implementing the propositions it would have increased the possibility of seeing what quantitative improvements that would be achieved. Thus, as an extension of the research project, an implementation would be interesting.

When evaluating the current situation there was a lack of quantitative data about the current material flow between warehouse 111 and the PPCL production. The available data was about the demand. However, it would have been useful to have had lead times, service levels, etc. The consequence of this was that the empirical findings were mostly from qualitative sources such as observations and interviews. This further resulted in that assumptions and interpretations were needed when constructing the current state.

During the research, the authors realized that it was not possible to construct a complete pull flow solution for the entire material flows, due to the complexity. This was the reason that RO3 was added. Even though RO3 was added, the final solutions are not exact pull system solutions. This is because of the complexity of the evaluated system. Therefore, it would have been interesting to evaluate if any potential changes could be implemented to reduce the complexity. Currently, when evaluating if any possible changes could affect the complexity, it is information technologies that are discussed. However, this is only a small part of what affects complexity. Things such as changing the set-up of production processes, the layout, and the order set-up could have been interesting to also consider. Further, it would have been interesting to apply the analytical framework for another more complex material flow to make the option of hybrid push/pull relevant to analyze.

It is worth pointing out that the situation at Tetra Pak PPCL during the thesis was affected by covid-19 and component shortage. Consequently, the empirical findings, the analysis and the conclusions might be different from what they would have been during more normal circumstances. Further, the authors have during the project wondered if it exits wastes outside of the material flow between the warehouse and production at Tetra Pak PPCL. The hypothesis is that a lot of wastes at Tetra Pak PPCL are related to the material flow between the internal processes in production. If this would be true, the benefits of changing the material flow strategy between the warehouse, the yard and the PPCL production might not be as beneficial as expected. Therefore, as an extension of the project or as a different project it would have been interesting to investigate the internal material flow in production.

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APPENDIX

Appendix I - Interview guide

To someone with knowledge regarding transfer of material between the warehouse and production with the train:

1. Can you explain the working tasks for the train-driver?
2. How is it determined when a train delivery is going to be done?
    a) Is it driving between the functions continuously throughout a day or is it rather driving according to some sort of schedule?
3. How do you receive information regarding where and how much material that will be delivered by the train to the different unloading points?
4. How are train-deliveries confirmed?
5. How is the train allowed to drive within the warehouse?
6. How is the train allowed to drive within the production site?
7. Are there any guidelines regarding how the train should drive within the warehouse?
8. Are there any guidelines regarding how the train should drive within the production site?
    a) If it is going to multiple unloading points
    b) If it is only going to one unloading point
9. Who is responsible for unloading materials from the train?
10. Are there any special requirements for how material should be handled on the train?
11. Does it happen that the unloading point to which the material is destined is already occupied?
    a) What do you do if that happens?
12. Do you experience any issues with how your role is functioning today?
13. Is there anything else you think could be of value for us knowing regarding the role as driver of the train?

To someone that is responsible for moving material from the warehouse to the production site by truck:

14. Can you explain what your working tasks are?
15. How many truck drivers are you on a normal day?
16. How many trucks are available for performing this task?
17. How are you notified that material should be moved from the warehouse to the production site?
18. How do you receive information on which unloading point at the production site the material should be moved to?
19. How does the confirmation of a delivery work?
20. How is the truck allowed to move within the warehouse?
    a) Are there any limitations?
21. How are you allowed to move within the production site?

a) Are there any limitations?

22. Are there any guidelines regarding how you should move within the warehouse?
23. Are there any guidelines regarding how you should move within the production site?
    a) If you are going to multiple unloading points (Are they moving more than one material simultaneously?)
    b) If you are going to only one unloading point
24. Does it happen that the unloading point to which the material is destined is already occupied?
    a) What do you do if that happens?
25. Are there any special handling requirements regarding some of the material that is being moved between the warehouse and the production site?
26. Do you experience any issues regarding the movement of material between the warehouse and the production site?
27. Do you experience any issues regarding your different working tasks?
28. Is there something else you think could be of value for us to know regarding the movement of material from the warehouse to the production site by truck?

To someone that is working with picking at the warehouse:

29. Can you explain your working tasks as a picker?
30. How do you receive information on what that should be picked and where it is located?
31. How do you confirm the picks that you do?
32. How do you as a picker remedy a wrong pick?
33. How are you as a picker allowed to move within the warehouse?
34. Are there any guidelines regarding how you as a picker should move within the warehouse when picking more than one order-line at the same time?
35. Are you experiencing any issues with how the role as a picker is functioning today?
36. Is there something else you think could be of value for us knowing regarding the role of a picker?

To someone that is working at the production site at one of the unloading points where a lot of material is being delivered:

37. Can you explain your role in production?
38. Can you explain the entire production flow at your area of responsibility?
    a) How often does material arrive to the different processes/stations?
    b) Can you describe the processes at the different stations?
39. How do you receive information regarding the deliverance of material to one of the unloading points?
40. How long would you estimate that material is typically standing on one of the unloading points before being moved?
41. What happens if one of the unloading points the material was destined for is already occupied?

42. Does it happen that material is delivered at other unloading points due to their destined unloading point already being occupied?
43. How do you inform the warehouse that there is a shortage of a certain material at the production site?
44. What do you do if the wrong material has been delivered to the unloading point?
45. Does it happened that it is hard to find the right material at the unloading points?
46. Do you experience any issues with the material movement from the warehouse to the production site as it is functioning today?
47. Is there something else you think could be of value for us knowing regarding this process?

To someone that is working with the information flow between and within the warehouse and the production site:

48. What system/systems is being used for handling information regarding picking and movement of material from the warehouse to the production site?
49. Can you explain a bit about how the systems/systems are working?
50. What kind of information is the system/systems able to handle?
51. Can you explain how it is determined what and how something should be picked?
    a) How are orders consolidated?
        - Picking
        - Production
    b) What orders are consolidated?
        - Picking
        - Production
52. Do the system/systems take any considerations to what the current situation at the production site is? (E.g., if the production is producing according to its schedule or not)
53. How does the system notify what should be picked?
54. How are eventual wrong picks handled within the system/systems?
55. Are there any possibilities for the system/systems to retrieve information from the production site?
56. Do you see any problems with the system/systems?
57. Is there something else that could be valuable for us to know regarding the information flow between the warehouse and the production site and the different information systems involved within it?

To someone that has overall knowledge regarding the flow of material between the warehouse and the production site:
Purpose: Gain knowledge of how the current material flow is built

58. Can you tell us a bit about how the material flow is constructed?
59. What strategies are applied when moving material between the warehouse and the production site?

a) What orders are consolidated? (Are there any other areas apart from welding that this is being done within)

60. How is it determined what should be Kanban?
61. What movements of material are being done with Kanban and what movements of material are not?
62. How is it handled if orders are changed by the order handler?
    a) If the time is changed?
    b) If components within the order are added or removed?
    c) If the order is cancelled?
63. How is it determined if an order can be created and added to the system?
    a) How is an order added to the system?
64. What processes are included in a production order?
    a) How are these processes triggering picking orders?
    b) How are orders released?
    c) How can orders be released?
65. The material for homogenizers is divided into multiple picking-orders. How is it working at other production processes?
66. Do you experience any issues with how the material flow is currently constructed?
67. Is there something else you think could be of value for us knowing regarding the flow of material between the warehouse and the production site?

To someone with knowledge regarding the handling of orders

68. Can you tell us a bit about your role?
    a) What are your responsibilities?
69. Can you describe a typical order-handling process?
70. Can you describe what kinds of orders you are handling?
    a) What is typically specified within an order?
71. How many different types of products are you handling?
    a) How big is the difference between the product types?
    b) What is the difference between the product types?
72. Do you divide the orders you receive?
    a) What is the strategy when dividing the order?
    b) How many production steps exists?
    c) How complex are the different production steps?
    d) Are there some limitations regarding this process?
73. How is the order linked with picking and different production processes?
    a) How do the bill of material for a specific product lead to when material is picked and to where it is delivered at the production site?
    b) How much material is shipped simultaneously?
    c) How divided between the different production processes is picking? (Is all material picked at once and delivered or is it picked separately for each stage of production)

74. What kind of communication do you have with production?
    a) How do you communicate with production regarding the release of orders?
75. What kind of communication do you have with the warehouse?
    a) How do you communicate with the warehouse regarding the release of orders?
76. Do you experience any issues with how the order handling process is currently?
77. Is there something else you think could be of value for us knowing regarding the order-handling process?

Appendix II - Unloading points

Product	Category	Unloading Point	Description
BPU	A01	A01	Assembly special montage (building 107)
BPU	A02	A02	Assembly special weld material
Other	C	C01	Pipeprocessing area small pipes
Other	C	C02	Pipeprocessing area
BPU	EKT	EKT	Welding material for kitting, not being used anymore
Other	OS*	OS*	BPU outsourced
HP	H	H01	Homogenizer dock 1-3
HP	H	H02	Homogenizer – crank case
HP	H	H03	Homogenizer – pre-assembly
HP	H	H06	Homogenizer station 1
HP	H	H07	Homogenizer station 2
HP	H	H08	Homogenizer station 3
HP	H	H09	Homogenizer station 4
HP	H	H10	Homogenizer station 5
HP	H	H11	Homogenizer
HP	H	H12	Homogenizer – spare parts
HP	H	H14	Homogenizer
Other	K	K01	Warehouse (Building 111 south) kitting
BPU	L	L11	Assembly (building 107) – multiline
BPU	L	L12	Assembly (building 107) – multiline
BPU	L	L13	Assembly (building 107) – multiline
BPU	L	L31	Assembly (building 107) – flexdos
BPU	L	L32	Assembly (building 107) – flexdos
BPU	L	L33	Assembly (building 107) – flexdos
HT	M	M21	Tubular heat exchanger
HT	M	M31	Tubular heat exchanger
HT	M	M41	Tubular heat exchanger
Other	P	P01	Consolidating parts, not being used anymore
Other	Q	QC	Warehouse quality controll
Other	Q	QXR	Warehouse quality controll
HT	S	S01	Tubular heat exchanger assembly
HT	S	S03	Tubular heat exchanger assembly
BPU	T01	T01	BPU test area
BPU	T02	T02	BPU test area in pilot area
BPU	W	W02	Weld line BPU
HT	W	W03	Weld line HP
HT	X	X01	Bending of small pipes

* This is not the real name of the unloading point. It has been anonymized due to it being the name of the supplier.

Appendix III – Material flow routes

In this Appendix the material flow routes of the seven defined material flows (see table 15) are presented, see figure 46, 47, 48, 49, 50, 51 and 52. The color coding for all the routing figures are presented in figure 53.

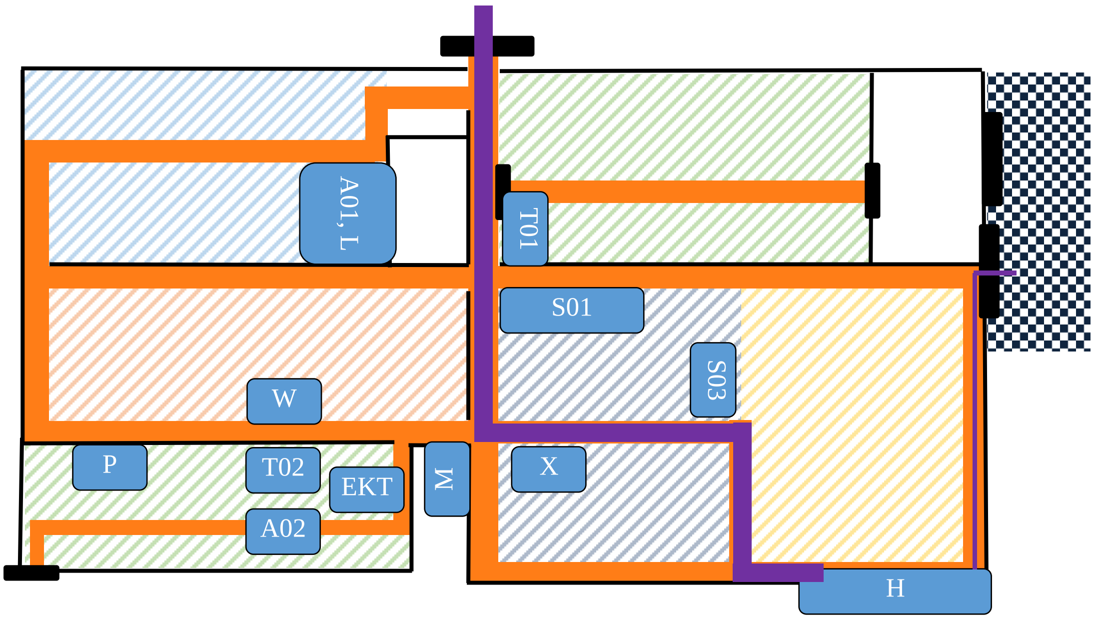


Figure 46: Material flow route of HP.

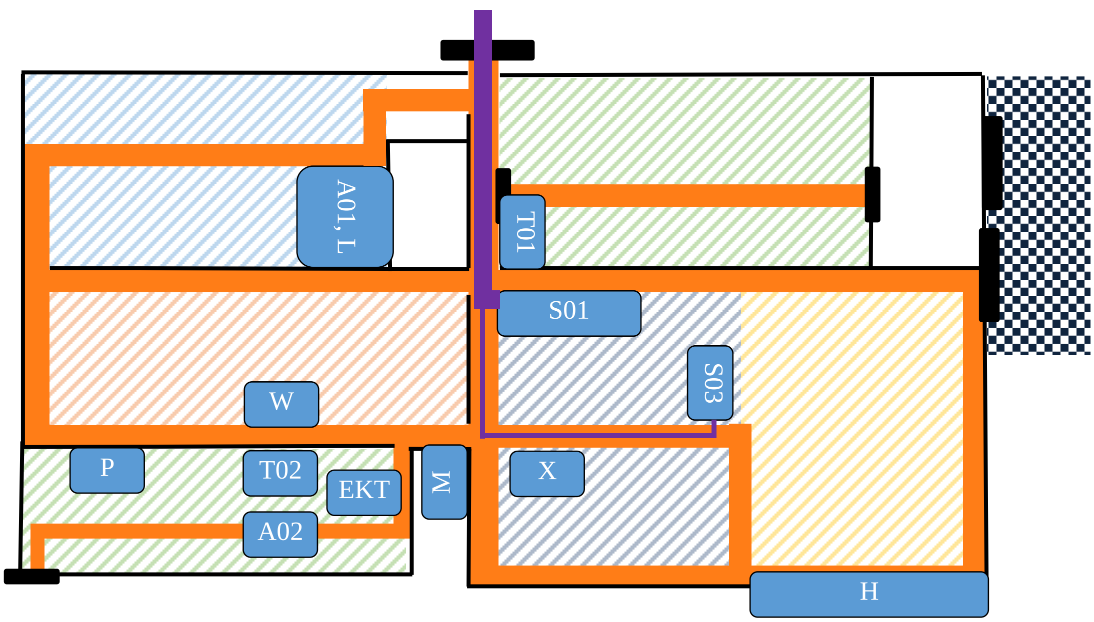


Figure 47: Material flow route of HT – assembly.

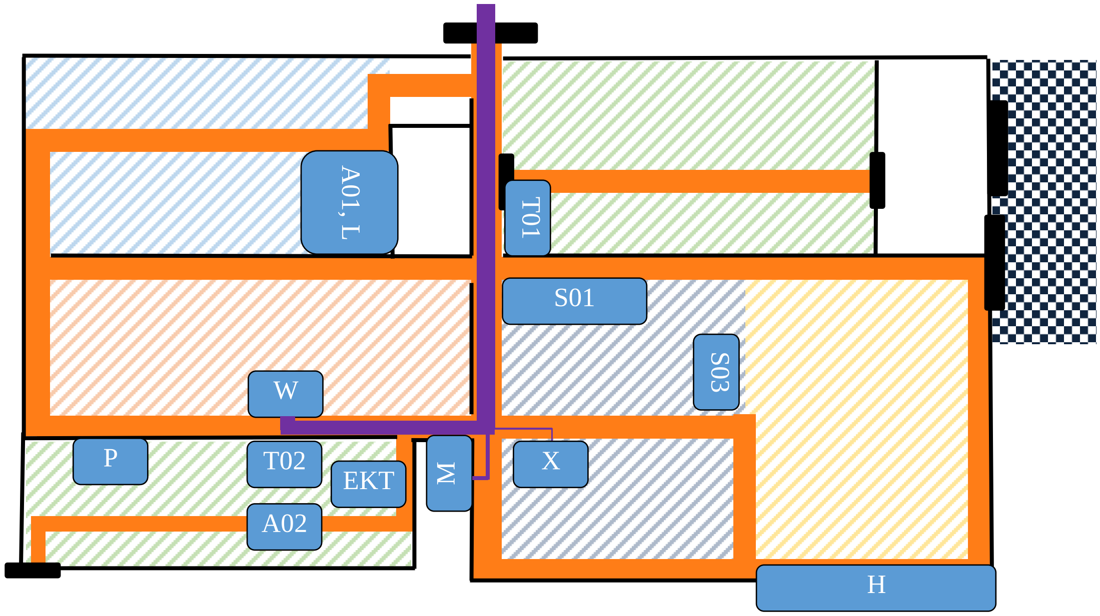


Figure 48: Material flow route of HT – MTS.

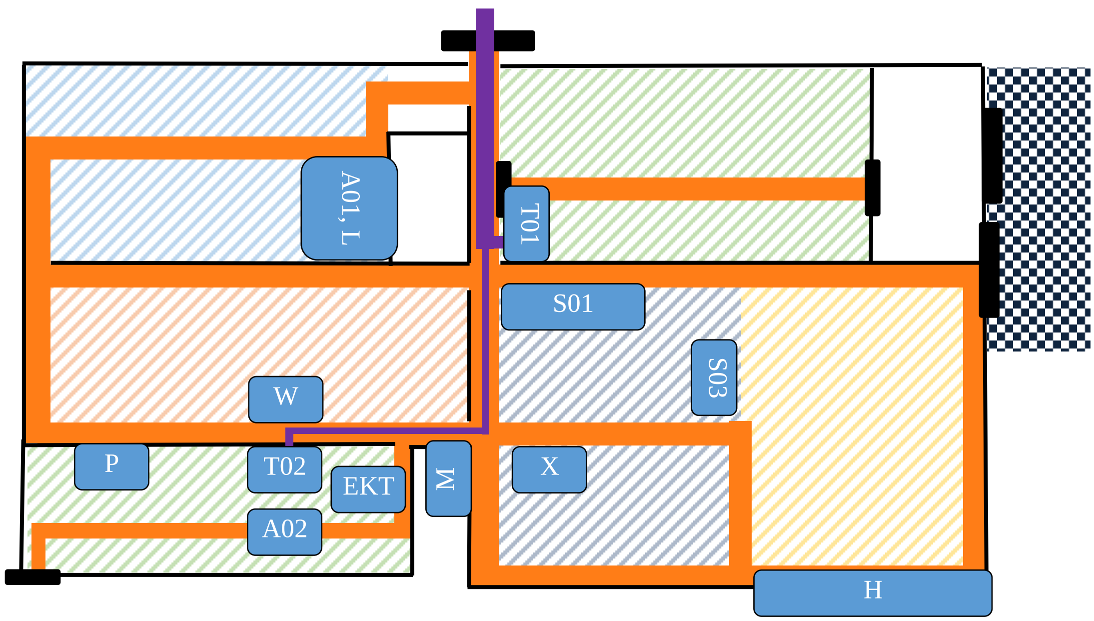


Figure 49: Material flow route of BPU – test.

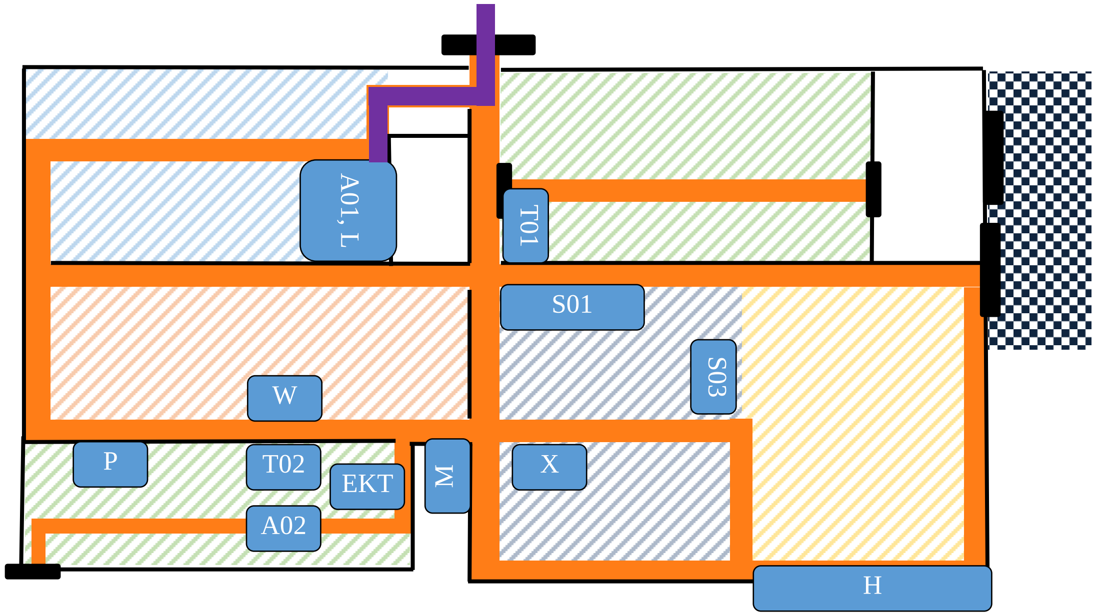


Figure 50: Material flow route of BPU – multi.

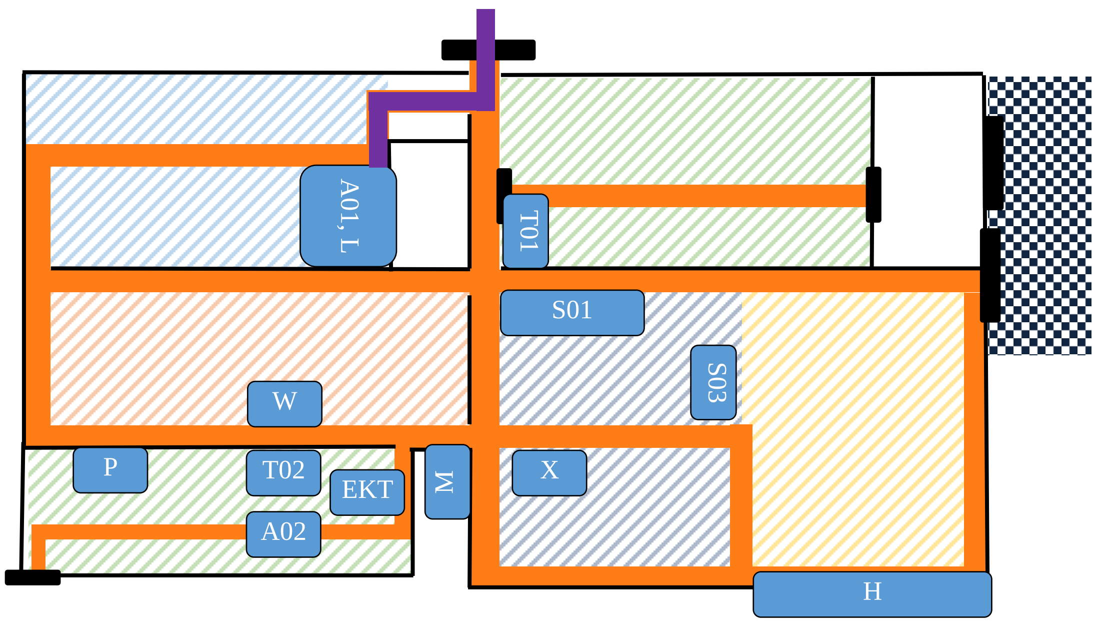


Figure 51: Material flow route of BPU – special.

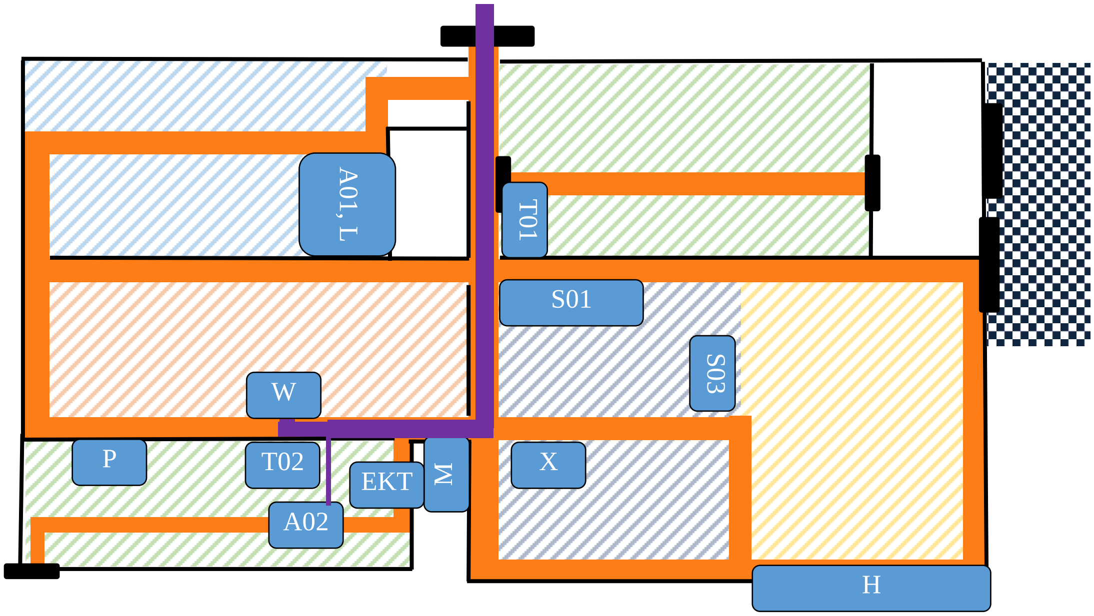


Figure 52: Material flow route of BPU – manufacturing.

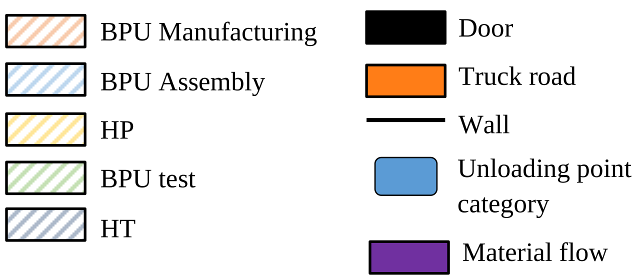
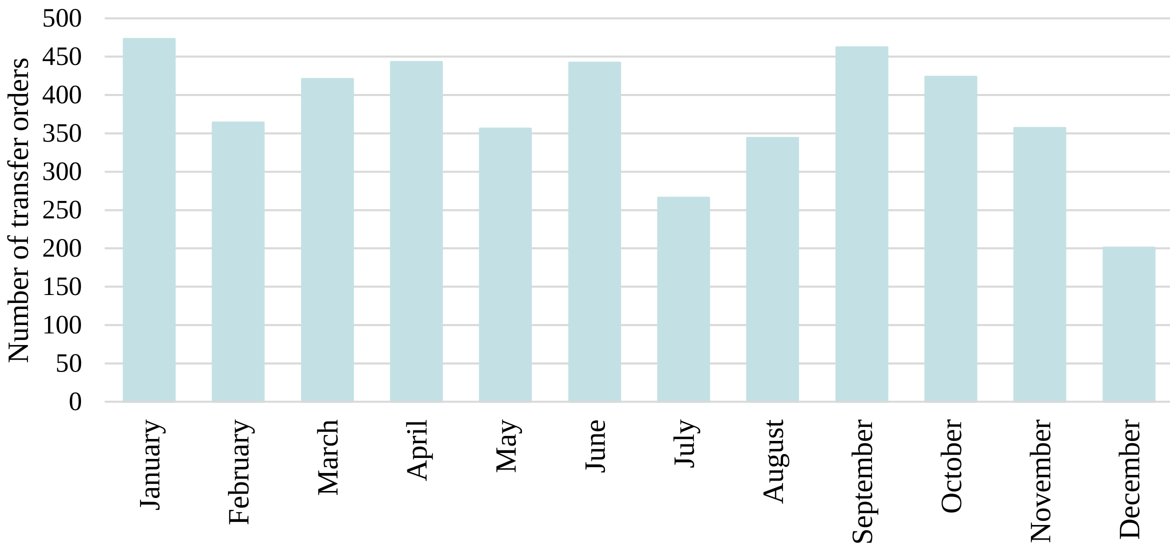


Figure 53: Color coding of all the layout maps.

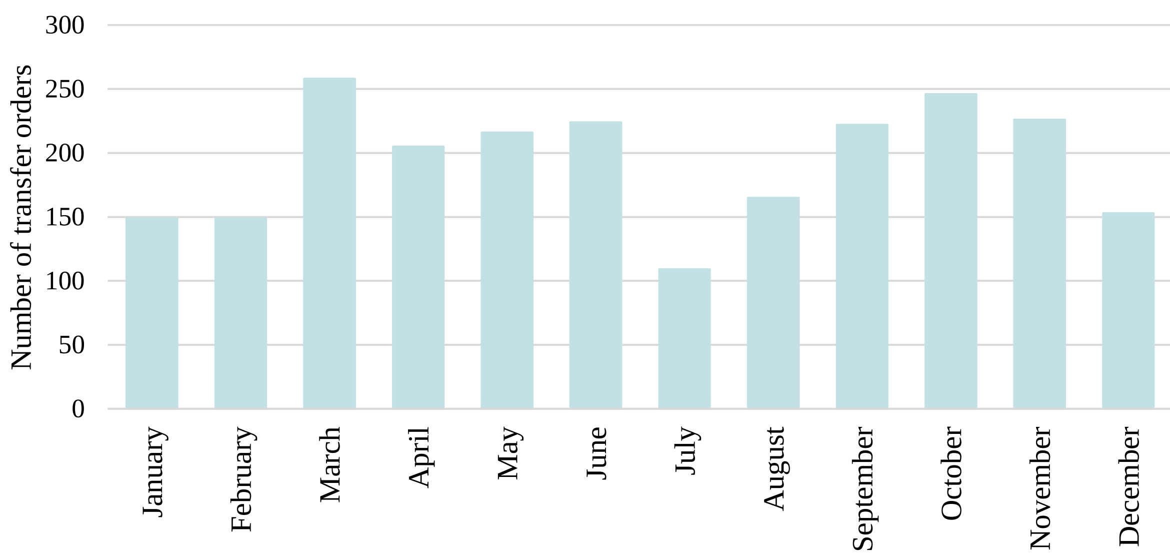
Appendix IV – Demand variety of material flows

The number of transfer orders for each month in the time-period 2019-03-01 to 2022-02-28 for the defined material flows (see table 15) are presented in figure 54, 55, 56, 57, 58, 59, and 60.



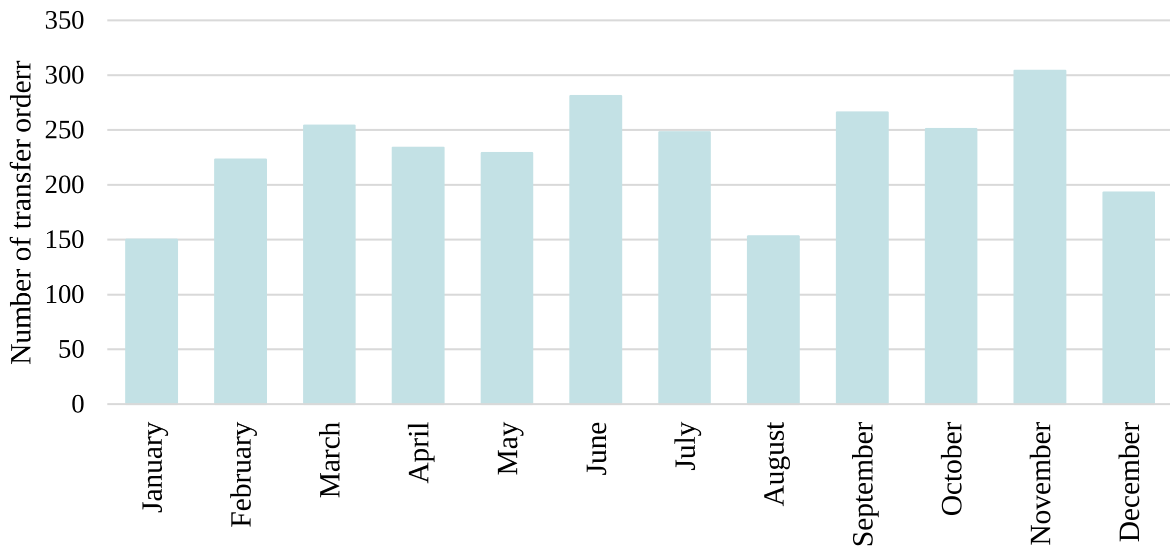
MPE	24.7	-4.1	11.0	16.8	-6.2	16.5	-29.9	-9.3	21.8	11.8	-5.9	-47.0
MAPE	24.7	4.1	11.0	16.8	6.2	16.5	29.9	9.3	21.8	11.8	5.9	47.0

Figure 54: Number of transfer orders for BPU – multi and the MPE and the MAPE for the different months.



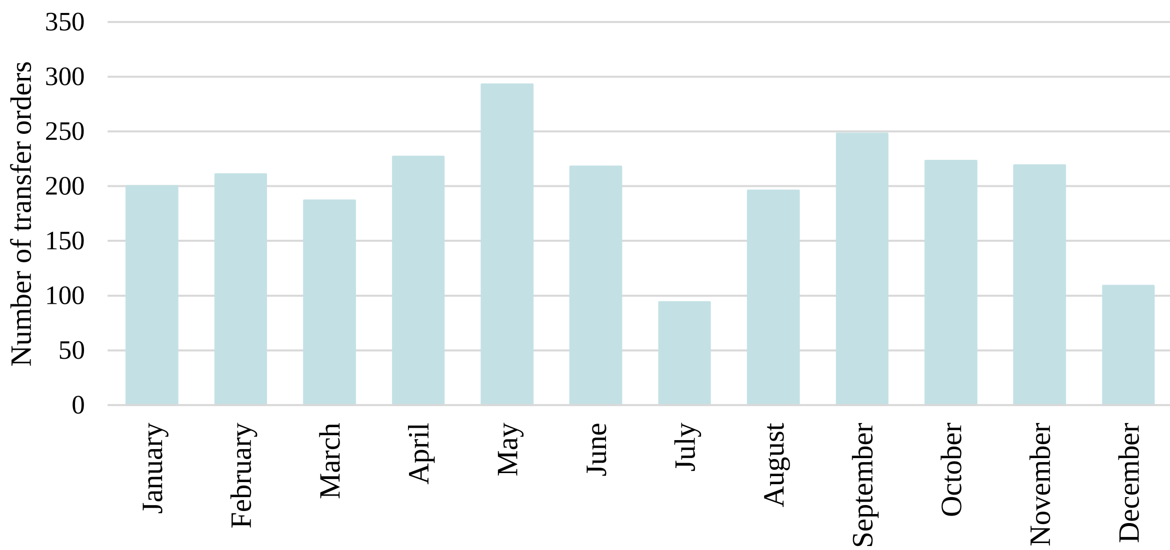
MPE	-23.0	-23.0	33.3	5.9	11.6	15.8	-43.7	-14.7	14.7	27.1	16.8	20.9
MAPE	23.0	23.0	33.3	5.9	11.6	15.8	43.7	14.7	14.7	27.1	16.8	20.9

Figure 55: Number of transfer orders for BPU – special and the MPE and the MAPE for the different months.



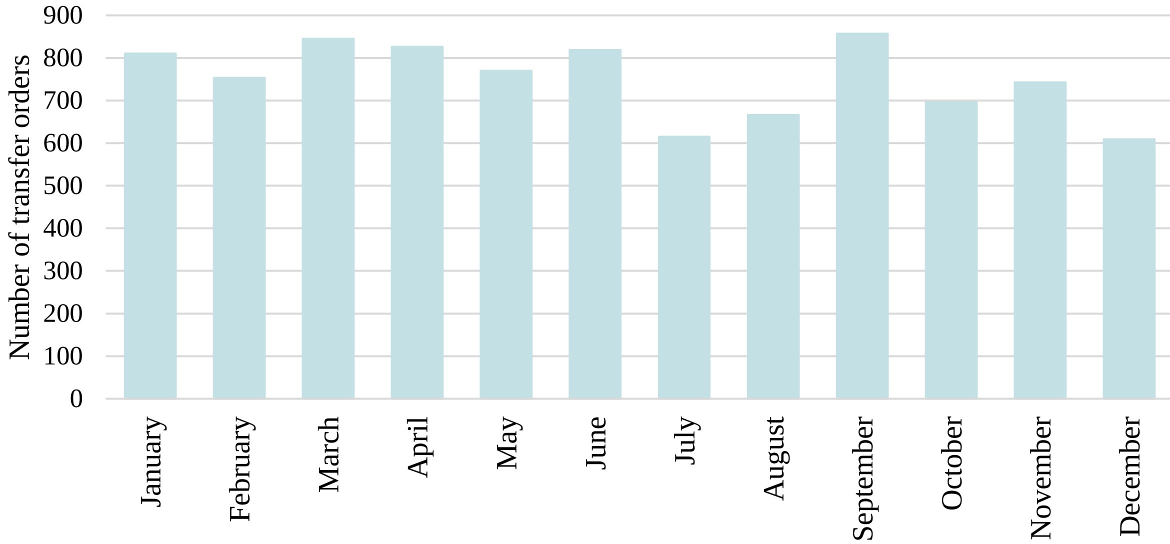
MPE	-35.4	-3.9	-9.4	0.8	-1.4	21.0	6.8	-34.1	14.6	8.1	30.9	16.9
MAPE	35.4	3.9	9.4	0.8	1.4	21.0	6.8	34.1	14.6	8.1	30.9	16.9

Figure 56: Number of transfer orders for BPU – test and the MPE and the MAPE for the different months.



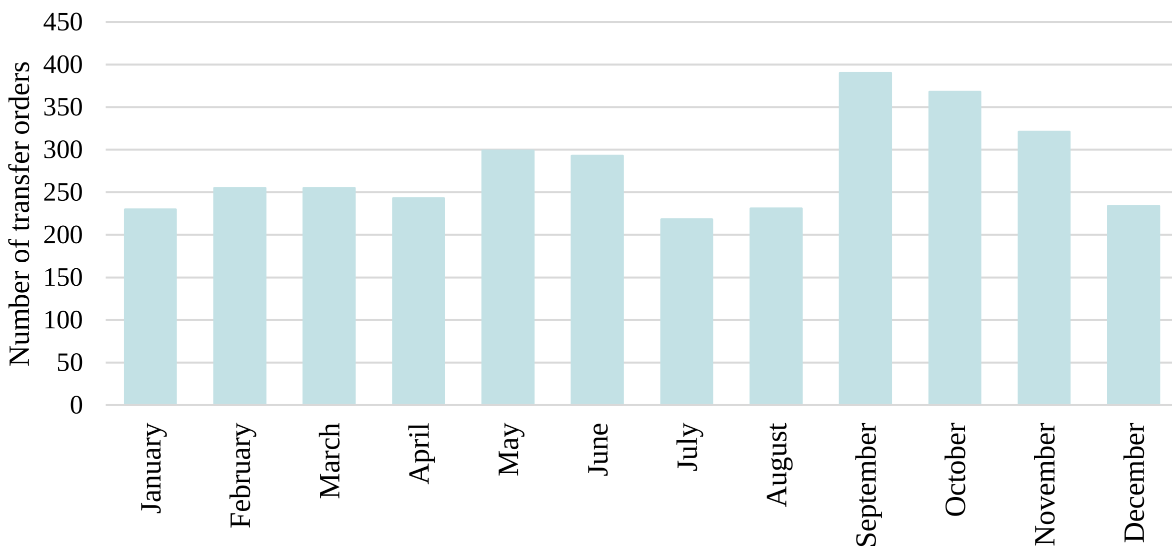
MPE	-1.0	4.4	-7.5	12.3	45.0	7.9	-53.3	-3.0	22.7	10.4	8.4	-46.1
MAPE	1.0	4.4	7.5	12.3	45.0	7.9	53.3	3.0	22.7	10.4	8.4	46.1

Figure 57: Number of transfer orders for BPU – manufacturing and the MPE and the MAPE for the different months.



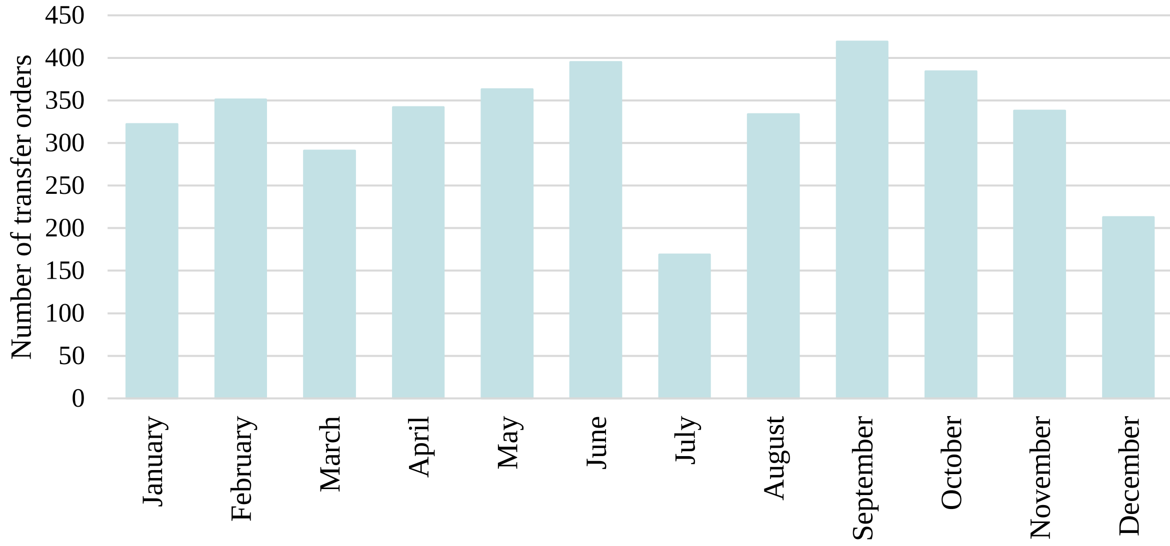
MPE	7.9	0.3	12.6	10.0	2.6	9.1	-18.1	-11.3	14.2	7.3	1.0	-18.9
MAPE	7.9	0.3	12.6	10.0	2.6	9.1	18.1	11.3	14.2	7.3	1.0	18.9

Figure 58: Number of transfer orders for HP and the MPE and the MAPE for the different months.



MPE	-17.3	-8.3	-8.3	-12.6	7.5	5.4	-21.6	-16.9	40.2	32.3	15.4	-15.9
MAPE	17.3	8.3	8.3	12.6	7.5	5.4	21.6	16.9	40.2	32.3	15.4	15.9

Figure 59: Number of transfer orders for HT – assembly and the MPE and the MAPE for the different months.



MPE	-1.5	7.4	-10.9	4.7	11.1	20.9	-48.3	2.2	28.2	17.5	3.4	-34.8
MAPE	1.5	7.4	10.9	4.7	11.1	20.9	48.3	2.2	28.2	17.5	3.4	34.8

Figure 60: Number of transfer orders for HT – MTS and the MPE and the MAPE for the different months.