Employing Theory of Constraints in Warehousing Operation: Case Study at Harald Pihl AB

Fabian Unghanse
mt08fu@student.lth.se

Department of Logistics
Lund University

Advisor: Hoda Davarzani

August 5, 2013

Printed in Sweden
M-huset, Lund, 2013

Abstract

Title :	Employing Theory of Constraints in Warehousing Operation: Case Study at Harald Pihl AB
Author:	Fabian Unghanse M08
Supervisions:	Hoda Davarzani, LTH Jonas Phil, CEO Harald Pihl AB
Background:	Theory of warehouse operation are a well explored area but it seems that warehouse manager have a hard time to understand what solutions to adapt to improve their warehouse. Theory of Constraints(ToC) are a young philosophy regarding improvements work that have been employed to many different business areas. Warehouse manager would need a method to evaluate what solutions to implement to the warehouse and there is no found papers where ToC is employed to facilitate this evaluation.
Purpose:	The purpose is to see if ToC can be employed for improvements work in a warehouse. At the same time the three research question should be answered to clarify what approaches and tools within ToC to use for different part of the improvements work.
Problem definition:	To know if ToC can be employed in a warehouse operation a case study was executed. The company in the case study have a warehouse that faces challenges in the near future due to increase sale and that the warehouse maximum capacity almost is reached, for how it operate today. The warehouse have low level of strategies. The warehouse have to get more effective and efficient to be able to maintain the service level in the future.
Method:	Warehouse operation have been studied at the university and a high level of knowledge in that field exist but low level of knowledge for ToC exist. The project will therefore start by studying ToC so it later can be successfully employed in the warehouse operation in the case study.

Conclusions: From the case study it is clear that ToC could be employed for improvements work for wear house operations. By following the approach provided by ToC the work could be carried out in an efficient way. It was identified which tools that was appropriate to use for different parts of the improvements work.

Keywords: ToC, TP, CRT, EC, FRT, PRT, TT, Harald Phil, Warehouse Operation, focusing steps.

Acknowledgement

This thesis is the final part of my time as a student and will result in a Master degree in Mechanical Engineering at Lund University. The project was carried out the spring of 2013. I came in contact with Harald Pihl AB at a pre-party and they needed someone to investigate their warehouse.

The opportunity to take on a project like this has been both fun and challenging and at the same time given a good insight how it is to work as warehouse consultant and how a real warehouse is operated in real life and that it is hard to change things within an organization.

I would like to thank everybody that have supported me through this thesis and my time at LTH. A special thanks to the following people.

Jonas Pihl	For making me feel like one in the team support throughout the project
Hode Davarzani	For good supervision and support
Jolina Haberkamm	For motivation and support
Staffan Trotzig	For assistans through the project
Alexander Karlsson	For support and making my time at LTH fun
Niclas Hanson	For support and making my time at LTH fun
Karin Unghanse	For supporting me in any situation
Leif Schiavone	For supporting me in any situation
The warehouse employees	For support and help
Carl Pihl	For introducing me to Harald Pihl

Table of Contents

List of Figures

List of Tables

List of abbreviations

AS/RS	Automatic Storage and Retrieval System
CLD	Casual Loop Diagram
CRT	Current Reality Tree
EC	Evaporating Cloud
FRT	Future Reality Tree
FS	Focusing Steps
HP	Harald Pihl AB
I	Inventory
JIT	Just-In-Time
LP	Linear Programming
MRP	Material Requirements Planning
MRP II	Manufacturing Resource Planning
OE	Operation Expense
OPT	Optimal Production Technology
PRT	Prerequisite Tree
T	Throughput
ToC	Theory of Constraints
TP	Undesirable Effect
TQM	Total Quality Management
TRIZ	Theory of Initiative Problem Solving
TT	Thinking Process
UDE	Undesirable Effect

Chapter 1
Introduction

The first chapter's intension is to introduce the project and provide an understanding for this master thesis. The introduction concludes a background of both the theory and the case company.

1.1 Background

Warehouse Operation is a well explored field and there are lots of theory and papers on it. Regardless warehouse managers have a hard time identifying what solutions to adapt to improve their warehouse. Theory of constraints(ToC) is a fairly new system based management philosophy for improvements work that has evolved since the early 1980s[6]. The thesis will show how to employ Theory of Constraints in a warehousing operational business that are looking for improvements. For the thesis to be valid the theoretical part will be backed-up by a case study for a company. The background for both the theory and the company follows.

1.1.1 Case Introduction

Harald Pihl AB(HP) is a family business with long history and today they have Europe's largest stock of Nickel Alloys and Titanium. Harald Pihl uses their stock to trade sheet, plate, strip, bar, wire, tube, pipe and welding material. They offer their customers fast deliveries and are rarely out of stock, these factors have led to an increase of sales the past years. Harald Pihl's office and warehouse is located just north of Stockholm and were built in 2006. When they moved in to their current head quarter it felt huge, they only used a corner of the warehouse and only just filled up half of their office spaces. Harald Pihl's intension was to rent the space they did not use. Today, seven years later the situation is another one. The annual increase in sales have led to that neither office space nor warehouse have been rented out instead Harald Pihl has filled it themselves.

Both CEO and management are happy about how the warehouse performance today. They say it is both fast and flexible. Harald Pihl has the fastest deliveries in the business, according to them, which verifies the statement that the warehouse is fast, in more technical terms they have short lead-times. The warehouse becomes flexible due to almost everything is done manually, that means sale persons can

ask the warehouse to prioritize a new order and abandon the first come first served policy. Normally orders get sorted after due date and get picked and packed in this order to guaranteeing the orders arrive to the customer in time. This kind of flexibility is very appreciated by the sale department.

Harald Pihl's fast deliveries are a major cause to the successful increase in sales. The costumers are promised, if an order is placed before noon it will ship the same afternoon. The warehouse's only strategy is to fulfill that promise and at the same time it is the desired service level. Service level is a measure for the work the management expects the warehouse to perform everyday. When Harald Pihl moved into the new head quarter they had two warehouse workers and because of the increase in sales today the warehouse employs five workers.

Harald Pihl has recently purchased a Danish competitor that does not have a warehouse, which will generate more work for the Swedish warehouse. Harald Pihl expects to continuously increase their sale and by that generate more work for the warehouse. The two factors stated above are raising a concern about their fast deliveries for the future. If the fast deliveries cannot be ensured it might led to a loss of costumers. Harald Pihl keeps a high level of stock in the warehouse due to that they have noticed that sales are proportional to inventory level. To keep a high level of stock is in general negative because it occupies space, goods get outdated before it get sold and the turn over rate decreases. The high stock level combined with the newly made investment, the Danish competitor, leave them in a spot where they have a lot of capital tied up, which means they cannot afford to lose costumers.

Harald Pihl has no strategy, on any levels, for the warehouse. The operational work is carried out as it pleases the warehouse personnel and are built on routines that have emerged over time. The focus in the warehouse, which can be seen as a strategy, is to ship orders to customers as fast as possible. The result of the focus is that the put-away process of arriving goods suffer and fall behind. This leads to new goods are lying around on the floor and prevent the picking and shipping work from being optimal.

1.1.2 Theory

In today's business environment competition between companies have moved from just price and profit to quality, lead times and service. The new competition environment have pushed the development for new approaches to become competitive. The new approaches have been introduced to the market and interest for them are growing fast and getting stronger on the market. In 1970s new approaches about how to redistribute resources to become more competitive started to grow and during the 1980s people become more and more interested in these new approaches. One person that saw an opportunity was Dr. Elyahu Goldratt. He had developed a management paradigm that he suggested to the market in form of a software that was called Optimized Production Timetables. He evaluated his work

and the result was a redesigned called Optimized Production philosophy Technology(OPT). As a result of marketing the philosophy and educating customer the novel The Goal was published, it introduced and explained every aspect of the theory. At this time OPT were meant to be used by manufacturer and the novel took place in a production plant. When the book was done Goldratt updated his timetable philosophy into a operational management philosophy [13]. The philosophy could be employed to more than just production plants and he called the new philosophy Theory of Constraints[15].

OPT were based on nine statements and from them ToC has evolved. [15]

- Balance flow not capacity.
- The level of utilization of a non-bottleneck is not determined by its own potential but by the some other constraint in the system.
- Utilization and activation of the resource are not synonymous.
- An hour lost at a bottleneck is an hour lost for the system.
- An hour saved at a non-bottleneck is just a mirage.
- Bottlenecks govern both throughput
- The transfer batch may not, and many time should not, be equal to the process batch.
- The process batch should be variable, not fixed.
- Schedules should be establish by looking at all constraints simultaneously. Lead times are the result of a schedule and cannot be predetermined.

Theory of Constraints main idea is to view an organization as a system and a system is not stronger than its weakest link according to ToC. The weakest link is identified as a constraint and to make the system stronger the system is reconstructed to exploit the constraint to the fullest. Theory of Constraints is a five Focusing Step(FS) approach and provides a tool box consisting of five Thinking Processes(TP). The approach and tools makes the ToC useful in numerous of different business environments. The success factors are to be accurate and have an open mind.

1.2 Problem Definition

Theory of Constraints has been applied and successfully implemented to numerous different fields from production plants to schools. An area that is not as explored in forms of articles and papers is to employ ToC in a warehouse environment and particular on operational level. This thesis aims to fill this gap in the literature.

Harald Pihl expects to continue grow the forthcoming years and due to that, they are concerned that if no change is made in the warehouse the service level cannot be maintained. In the past when concerns like this have occurred Harald

Pihl has hired another worker for the warehouse and the problem has gone away. Today's believe is, hiring another person is not the best way to go and instead they think the solution is to change how the warehouse resources are utilized. The management have discussed possible solutions, these are some of the ideas they thought of; the way the workers operate, the layout and placement of goods or bar-code system with software solutions that will facilitate the work. The company's goal is to make the warehouse more effective and efficient which should lead to maintaing the service level. For this work effective is defined as doing things the right way and efficient as doing the right thing at the right time.

The warehouse performs smoothly today and the management have no complains. During extra busy days the warehouse starts to fall behind and the service level is not maintained. That a few extra orders result in that the warehouse cannot keep the service level confirm the company's concern for the future growth. Harald Pihl understands that there are many activities that can be develop for the better at the same time they understand that it cannot be done all over night. This means the implementation of change have to be done properly and in the right order to have the maximum positive impact. However it is important for Harald Pihl that the service level is kept during the implementations due to that they cannot effort to lose sales. Harald Pihl's wish is to get a future progress plan for the warehouse.

To make the warehouse more effective and efficient this thesis work has to start at the foundation of the warehouse which is the operational work. The thesis goal is to come up with an implementation plan that will cover the future needs for as long as possible but due to the time constraint the focus will be on operational level. The operational level decisions and work that is carried out by the warehouse employees every day and can be made without being passed by the management. To facilitate the work and ensure value-adding solutions decisions about layout, infrastructure and design will be a part of the warehouse operation.

The theory of constraint will be used throughout the whole thesis from planing process to solution generating process.

1.3 Research Purpose and research questions

The purpose of this thesis is to contribute to the literature in warehousing. The contributions will be in warehouse management which is an area that has not been widely explored by ToC. To do this the thesis will undertake a case study on a company with a warehouse that has low level of operational strategy today and need a change.

The purpose is to solve the case problem and at the same time contribute to the warehouse literature by employing the method of ToC throughout the whole project from planing to resolving the future problems. The focus will be to employ

ToC to identify constraints and bottleneck in the warehouse. When a clear map of the warehouse operation is made ToC will be employed to find solutions that resolve the bottlenecks, with the result of a more effective and efficient warehouse. ToC has been mainly used in manufacturing environment as mention before and applying it to a warehousing environment is contributing to the literature. There are publications that show that ToC can be implemented to a wide area of different businesses such as: accounting, production and information sharing. Warehouse operation is somewhat missing. ToC has been successfully employed into a large number of various fields which makes an exciting project and hopefully a successful one as well.

To be able to employ ToC in an efficient way and make a contribution to the literature some of the well-known methods, approaches and tools of ToC will be employed. The employed steps and methods will illustrate how thinning process tools can be used to identify and solve warehouse operation problems. l.

For this project and thesis to have a purpose it will answer the following research questions:

How ToC can be employed in a warehouse operation to identify bottlenecks?
What tools and techniques should be used to solve/reduce the identified bottlenecks?‘
What future plan can be developed based on ToC?

1.4 Application of ToC in Logistics and and material handling

ToC has been employed to improve different types of logistics throughout time. Theory of Constraints started as a scheduling tool for manufactures and where in the beginning adapted by large producing companies in the USA. It was employed to increase the outcome of the different production plants and improve their production logistics. From there the ToC has developed and been adapted to other logistics problem such as inventory problems that Chou et al [1] shows in their case study in the aerospace industry. The development of ToC went from being a exclusive physical constraint solver to a more sophisticated management philosophy and by that it has been employed of many different logistics management as a single approach or combined with MRP or JIT for example. Rahman, 2002 [11] presented an articles on how to use ToC's Thinking Processes to develop strategies for a supply chain, these strategies can single show how ToC can be applied in for various logistics problems. Some of the problems he attacks are, high inventory management cost, long cycle time, low customer satisfaction and high distribution cost. These strategies are like all other found papers on strategic or tactical level, which leaves the a whole in the literature for ToC employed to solve operational level problems.

1.5 Method

This is a master thesis and it need to follow a clear method. The research approach that will be used is inductive, start with existing theory and then make real-life observation to form a new framework, and that will be the base for the whole project. The employed research method is explorative case study, the aim is to to understand why a phoneme arise and how it works. The research strategy will be a case study based on interviews and observations and to be able to employ ToC a good understanding of the theory is needed which leads to that a lot of literature is going to be read. To execute the case study ToC with all its method, approaches and tools will be employed and to contribute to the literature the employing will be analyzed to evaluate how the work proceeded and the result will be presented i nthe end.

1.6 Target Groups

This thesis has three main target groups.

The first one group consist by everybody that want to learn about ToC and especially how it can be employed in a warehouse environment. This group consist of a wide variety of people from students to consultants. It will be interesting for warehouse mangers in any types of company that are concern about their future and especially when the company has no or low level of strategies implemented.

The other group is warehouse managers that are looking for a way to change how their warehouse operate. It will be a great inspiration and foundation when trying to solve problems in operational level in a warehouse.

The third group is other researcher in this field that can read this work and use it as a starting point for future work within this area but either take another direction of their work or dig deeper into the area.

1.7 Structure of the report

For a report to add as much value as possible and make sense for the reader a good structure is crucial. This report will follow the following steps, first the methods and approaches used in the thesis is presented. Followed by a list of references that introduce and explain the theory of constraints and warehouse operational. To understand how ToC should be employed the case study is performed. Last conclusions of how it was to employ ToC in this environmental is given.

Chapter 2
Method

This chapter will describe and discuss the relevant methods and approaches for this thesis. The chosen method and approach will be stated and motivated.

2.1 Intro

To execute a good thesis and a successful project a good method is crucial. The method predetermines how a project is supposed to be carried out to achieve its goal. It helps the project members to restrict the work and how to approach the problems and its objectives. The method is the foundation for the project plan and provides an approach for the project team how the different steps of the work should be carried out, such as manage theory and collecting data. Further in the work it propose how to analyze and interpret the work as well as how to assure the quality of the work.

2.2 Research Approach

Reasoning process is an important part in the research approach for any project. There are two main approaches and one combination of the two that can be employed when executing a project like a thesis. These three approaches are Induction, Deduction and Abduction [10]. The three research approaches can be explain as a chain of event of how the project should be carried out. Kovacs [22] gave these explantations in his paper 2005.

Deduction

1. Theoretical framework (from prior literature).
2. Theoretical conclusions (hypotheses or proposition reached through logic).
3. Testing of the conclusions.
4. Final conclusions (corroborating or abandoning the theory; and accepting or disregard the hypothesis or proposition) .

Induction

1. Existing theoretical knowledge from prior research.
2. Real-life observations.
3. (Final) theoretical conclusions (framework).

Abduction

1. Prior theoretical knowledge.
2. Deviating real-life observations.
3. Theory matching, loop between step 2 and 3.
4. Theory suggestion (final conclusion of hypothesis or proposition).
5. Application of conclusion.

It is really hard to keep these three reasoning processes apart but Kovacs [22] article adductive reasoning in logistics research discusses and explains the different well. To clearer separate deductive and inductive it can be said that deductive follows a conscious direction from a general law to a specific case and inductive reason through moving from a specific case or a collection of observation to a general rule. Abductive separate itself from the other two through scanning theory, derives logical conclusions from the theory and presents them in form of hypotheses and propositions and after that test these in an empirical environment and first after that presents its conclusions. [22]

For the thesis
The thesis is aiming to employ a theory into a new area but for the case study to make sense the theory will be the base. This means the thesis will adapt induction approach. To be able to employ the theory, it needs to be understood when that is assured the theory can be used while by real-life observations identify problems in the system. By combing the observations and theory a new framework to use the theory in the new environment can be establish.

2.3 Research method

The method describes how the work will be executed throughout the project. There are four levels of methods and the selecting process is determined by the knowledge within in field of the project and what the aim of the outcome is. The levels in increasing knowledge order are, explorative, descriptive, explanative and problem solving[9]. The explorative approach is used when little knowledge of the problem is known, the aim is to understanding how a phenomena works or preforms. Descriptive approach is for projects where the authors have some knowledge in the field, the goal is to describe the phenomena but not explain why it occurs. Explanative approach is used for projects where the author have understanding and knowledge of the problem and aims to find and understand the relations to be able to explain the problem. Problem solving approach is used when the author have understanding of the problem and why it is there and the aim is to solve it.

For the thesis
The aim for the thesis is to understand how ToC can be employed in a warehouse operational environment but the goal with the case study is to explain who the different operational activities relate to each other and how they affect the end result. This leads to that the thesis is an explorative case study.

2.4 Data collection

Collecting data is an important process for projects and there are different types of data and ways to collect it. Data can be separated into two different types, primary and secondary data. The primary data is collected by the researcher specific for the project and can be carried out by interviews, surveys and observations. The secondary data is based on the purpose of the project and is public documents, descriptions and statistics.

2.4.1 Primary data

The primary data was collected in two ways, interviews and observations.

2.4.1.1 Interview

Interview is categorized as a primary data collector, it can be executed in different ways and structures. Normally an interview is one on one where the interviewer ask question within a specific field. Interviews can be structured and designed in three different ways; structured, semi-structured and open directed. The design determines how much questions that have been set up in advanced and how exact it is followed. Structured interviews are like an oral survey where the interviewer has prewritten questions and follows these exactly, this type of interview is usually used when there is a great number of interviews that should be executed. Semi-structured interviews have prewritten question as a base but the interviewer determines during the interview which question to ask and is free to ask following questions. Open-directed interviews let the person being interviewed speak free about the field and the interviewer makes sure that the interview is kept within the right area.[9]

For the thesis
The interviews made for the thesis were semi-structured with well written interview plan. The plan included questions were grouped for different areas and to make sure to cover all necessary parts of the areas back up and following up question were establish both in advance and during the interviews. The first interviews were one on one with managers for the company and for the warehouse. While in the solving state of the project group interviews with presentations were employed. The warehouse employees were interviewed by group interviews following open directed structure.

2.4.1.2 Observations

Observations can be executed in various ways, the two most common is either being present or by employing technical aids. Observations can be classified into four groups where the differences are the integration of the observer and to which level of knowledge the observed know they are getting observed. Table 2.1 presents the four different types of observations.

Table 2.1: Observation approaches [9]

	Knowledge of being observed	
Interaction	*High*	*Low*
High	observing participants	full participants
Low	participating observer	complete observer

An *observing participant* tries to be a part of the observed group and the group is well aware that they are being observed.
A *full participant* is part of the observed group but the group is not aware that they are being observed.
A *participating observer* follows the observed group but does not participate in the work. The group know they are being observed and the observer asks questions during the work and attempts to make the group think out loud about how they reason in different activities.
A *complete observer* tries to be totally invisible during the observations.
In the situations where the observer is visible there is always a risk that it effects the observed group.[9]

For the thesis
The first observations were carried out with a full participant approach and the observations were made at the same time the observer were working extra in the warehouse. Later in the project the employees got more and more knowledge that thy were getting observed and the observations took a participating observer approach.

2.4.2 Secondary data

Secondary data is public documentation and statistics that anyone can take part of and is collected to create a picture of the environment the project is taking place in. It can also be general information of companies that describe the culture and heuristics of the company at the same time show older change and how the company developed over the past.

For the thesis In the data collecting work for this thesis mostly primary data were collected, with some additional secondary data that was used to really

understand how the company was run. The primary data was collected to get understanding of what the company expects of their warehouse in the future and also to understand how the warehouse performs and execute tasks today. The primary data collected was a combination of the two ways explained. Observations were used to be able to establish a map over the system in this case the operational work in the warehouse. Interviews were made during the whole project; in the beginning they were the key to understand the structure and culture of the company and to understand what expectations the company had on the project. Observation were used as the primary data collecting activity when it comes to collecting data to be able to establish a map over the warehouse's flows and activities. Further in the project additional interviews held to collect information about the system and to confirm observed information. For example data regarding the material flow was collected by both interviews and observations to ensure that it was understood correctly. Interviews and observation plans can be viewed in the appendix. The first step when employing ToC is to draw a Current Reality Tree(CRT) and to get enough and accurate data for this observation is a great way to go. The exact data collections can be view in Table 2.2.

Table 2.2: How data was collected for the project

Data collection method	Total number of occasions	Focus of data collection
Interview Management	3	Information of the company and their expectations
Interview Warehouse manager	4	information about the warehouse
Interview Warehouse employees	4	Information about the warehouse
Presentations and discussions	2	Identification of constraints and how to solve them
Observation Warehouse	8	Material Flow, Activities, Order Flow, Resource utilization
Archival data	3	Company Culture and history

2.5 Analysis

The goal for most businesses are to make money now and in the future. To measure if a business or system is making money there exists a few

classical measurement such as Net Profit (NP), Cash Flow (CF), Return of Investment (ROI). These measurement are good when investigating a whole organization and identify that as a system but Goldratt argues that they are not suitable for subsystems. For subsystems, such as production plants or warehouses, new measurements are needed and ToC has introduced three measurements that is suitable for plants that works as subsystems. The three measurements are throughput (T), inventory (I) and Operation Expensive (OE). These measures are not new in operational management but makes it easier for the employees to understand and strive towards the goal[13].

According to ToC the biggest gain for a system is to increase the throughput followed by decreasing the inventory and reducing the operational expensive should come last. This approach separates ToC from traditional management who normally start with reducing OE followed by T and I [15].

Increasing the throughput should have the highest prioritize and the focus for the thesis was therefore to find causes that disable the warehouse to have higher throughput. By increasing the throughput more orders can be sent everyday.

This project want to employ ToC to make the operational work in a warehouse more effective and efficient and by that increase the throughput. To do this ToC and all its parts was followed starting with the approach which is called the five Focusing Steps, later updated to seven Focusing Steps. The approach starts with setting a goal and identifying the constraints and than progress with a continuous improvements work. To be able to execute the approach the provided tools were used. The tools for ToC is called Thinking Processes and consists of five tools, starting with creating a map of the current system and move the work forward all the way to an implementation map is created for a future improved system.

- **The Thinking Process**
- Current Reality Tree (CRT) - Identify's the constraints
- Evaporating Cloud (EC) - Solve the constraints
- Prerequisite Tree (FRT) - Introduces the solutions to the system
- Prerequisite Tree (PRT) - Identifies obstacles for the solutions
- Transition Tree (TT) - Action plan for the implementation

Figure 2.1 show how the tools are connected and gives a picture of how the approach looks. [13]

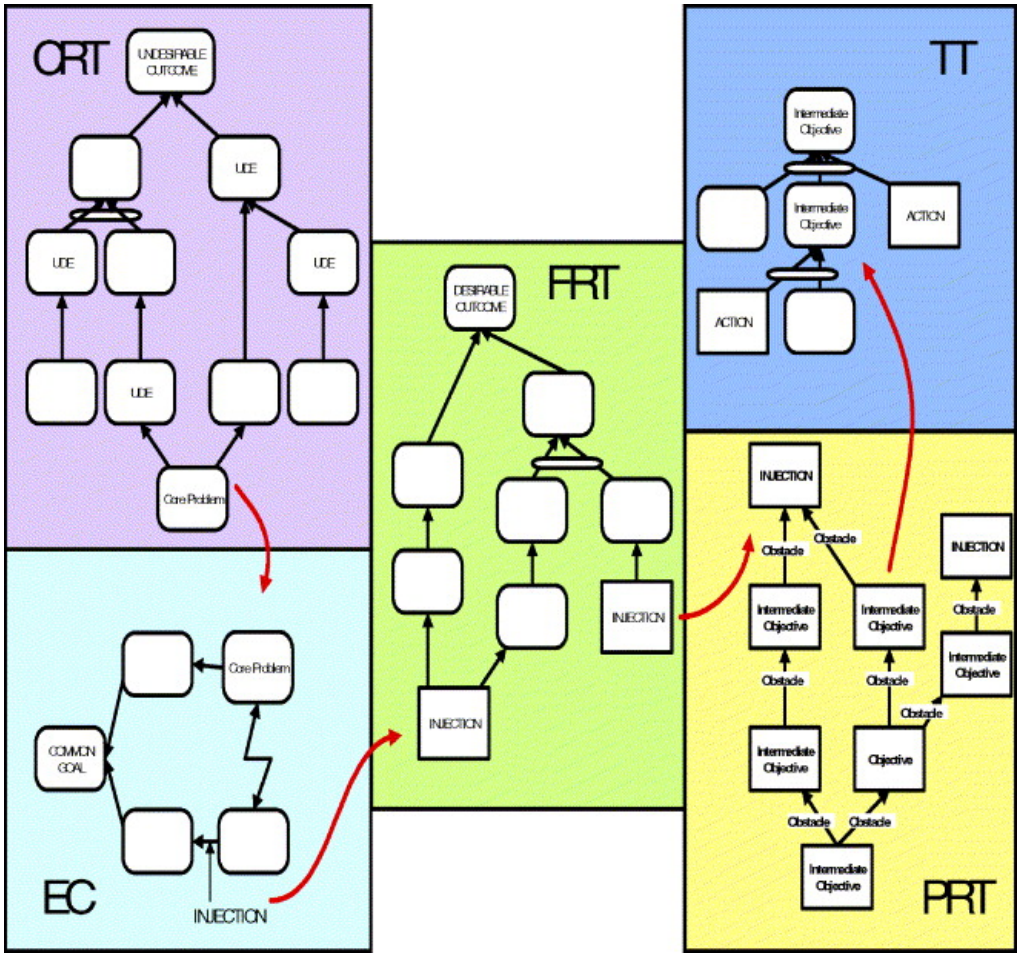

Figure 2.1: The ToC Thinking Process application tools [13]

2.6 Validity and reliability

To ensure quality and reliability for a project as a master thesis is essential. There are four establish tactics to employ for case studies [23] and they are presented in table 2.3 and explained after.

- **Constructive validity:** establish correct operational measures for the concepts being studied

Table 2.3: Case study tactics for four design tests [23]

Tests	Case Study Tactic	Phase of reference which tactic occurs
Construct validity	Use multiple sources Establish chain of evidence Have key informants review draft case study report	data collection data collection composition
Internal validity	Do pattern-matching Do explanation-building Address rival explanations Use logic models	data analysis data analysis data analysis data analysis
External validity	Use theory in single case studies Use replication logic in multiple-case studies	research design research design
Reliability	Use case study protocol develop case study database	data collection data collection

- **Internal validity** (for explanatory or casual studies only, and not for descriptive or exploratory studies): establish a casual relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships

- **External validity:** establish domain to which a study's findings can be generalized

- **Reliability:** demonstrating that the operations of a study, such as the data selection procedures, can be repeated with the same results

For this thesis

The thesis is valid and reliable because of many factors. For starters the information on ToC is retrieved form multiple sources in form of articles and papers from peer reviewed magazines as well as books on ToC and reports on books of ToC. The case study begin with collecting data in different ways and from multiple sources and the data collection can be made again. The research design and the way data was collected are developed to be able to reconstruct the study for the company in the case but also so ToC can be employed to a different companies in a similar environment. The solutions generated to the case are based on documented theory or discussions with management and warehouse manger.

2.7 Research process

This section will present the research process.

2.7.1 Study ToC

For the thesis to make sense and be accurate ToC had to be understood correctly and to ensure this ToC was studied. ToC was learnt by first reading about ToC in general to form a base. The general papers gave an overview of ToC and all its components. To make sure that the case study should run smoothly the different components of ToC was studied individual. The study were made by review theoretical literature of ToC and its parts and applications. There are a lot of papers for every part of ToC and to add more value to the learning experience smaller exercises were performed for each part.

2.7.2 The approach

Planning the project and establish a goal
When undertaking a project there is always a good start to stated the goal or desired outcome of the project. This simplify the defining and limitation work when planning the project. It limits the project not to get to big nor to small and narrow down what areas that the project should focus on, depending on how much time and resources that can be utilized for the project. For everyone involved in the project, both executers and stakeholders, to be able to see the results it is also crucial to agree about relevant performance measurements. If a project is started without defining these two key factors there is a risk that the result is unappreciated by the stakeholders and the whole project was a waste of time because it has to be redone. Luckily the two most recent added steps to Theory of Constraint's approach make sure that a goal is set up and that proper measurements are agreed upon.

To set up a goal for a system is a straight forward process where the outcome should be decided this does not mean it is an easy task, it is normal that different people involved in the project expects different outcomes. It is important to gather the opinions from everyone affected of the project and then form a goal that everyone believe is good. For this thesis project it was about making the warehouse more effective and efficient to be able to maintain the good service and low delivery times when the sales increase for the company. The management did a forecast over their sale's increase

for the future and provided a few milestones which basically where the forecasted sales per year the coming years. The management asked that the outcome would be an implementation map for the future to met this sales increase. The warehouse said they knew that the sales were going to continue to grow as it had for the past years but could not come up with any desired goals more than to ship all orders that are sold. Discussions about lead times, throughput and inventory levels were introduced to the warehouse employees to help them come up with additional goals, but that did not give any results. By combining the request from the management with the expectations from the university and the time horizon of the project a goal could be establish. The conclusion were that a recommendation and executing plan to make the warehouse more effective to meet the following years progression where a good goal. Discussion where held and everybody involved liked it and it was also said that the project would focusing on operational work and try to increase the throughput of the warehouse with the resources that exist when the projects started, this is aligned with the ToC. This is also the reason why just ToC was selected for the employment, the situation at the company fitted well with the criterions for ToC.

Establish measurements

When it came to designing performance measurements the management said that measuring the number of orders shipped per day and year where enough for them and the lack of ideas from the warehouse led to that the measurements where set to be a comparison between arrived orders from the sales department and shipped orders from the warehouse. Discussions about other measurements that could benefit the company were initiated but did not get anywhere. The benefits would have been in form of introducing a bonus system for the warehouse employees that would work as incentives for them to work hard.

Identifying the Undesirable Effects

The following step when employing Theory of Constraints is to identify the system's constraints which is a great approach to take when trying to change a system to the better. ToC tells us to find Undesirable Effects(UDE) of the system as a first step which differs from many other theories that are looking for the problem instantly. Undesirable Effects are activities that limits the system to have better outcome. By identifying effects and activities that do not add value and are unwanted in the system the executer knew where the change will arise and can easily use the imagination to see if that will influence other activities in a positive or negative way. After that the Undesirable Effects are identified the next step is to go backwards to find the root causes of this effects and by that identify the problem or con-

straint of the system. By employing other theories there are a great chance that the executer would say that the Undesirable Effect where the problem and try to fix that activity and not the problem that causes it. In many systems there are not one problem that causes the effect but a combination of problems. This gives the performer the opportunity to choose where to put the constraint and which problem to solve as long as it guaranties an improvement of the system as a whole. The last fact is very important to remember when working with ToC, it is the system that should improve and not single activities.

Observation approach to find constraints
From previous reading and general theory the classical Undesirable Effects in warehouses were known so at first these effects were looked after during observations. To just focusing on the classics were not an efficient observation plan. To be able to see more specific Undesirable Effects the classical ones were written down and additional observations were made. The approach to write down everything to clear the mind were provided by Scheinkopff's book[3] and is very effective to use to see the bigger picture or think outside the box. To be able to track what root problems and constraints that causes the Undesirable Effects ToC's tool Current Reality Tree was used, how the tools were employed and the results will be stated in the next section and just mention in this section.

Identifying core problems
In the warehouse the Undesirable Effects where caused by many different activities. This thesis were focusing on operational level and there were a few activities that were identified as constraints that were set on strategic level or by third party companies that could not at this moment be affected. Luckily the majority of the constraints that qualified to be core problems were made on operational level, and one major one on tactical level but to change that decision would only have positive effects and affect on operational level. The management gladly approved that the project investigated this area a well. To generate ideas to exploit and solve the constraints and core problem the Evaporating Cloud(EC) were employed.

Exploit the constraints
The following step is to decide how to exploit the constraints, core problems. The goal is to exploit it so the system get stronger. A system is not stronger than its weakest link and the Undesirable Effect and constraint are the weakest links of the system. By exploiting the constraint the system will natural become stronger, the better the constraints are exploit or solved the stronger the system can grow. The approach inform that the impor-

tance here is to realize that the priority is to exploit the constraint. This can mean that other activities might have to be changed to what appear to be less efficient than they are today, but the system will improve if this is executed right.

Redesign the system to subordinate everything to the core problem
By just exploiting and solving the constraints the system would increase but not to its fully potential. To ensure or at least get as close as possible to the fully potential the system need to be subordinated. Subordinate activity connects back to the earlier statement that non constraint activities might need to be changed and some time to the worse. It is hard to redesign a system as it is and the need to subordinate all activities that the owner is proud of is hard, but can be motivated by it is not activities that being redesign or matter. It is all about the system and as long as it improves it should be motivation enough to redesign the system.

To subordinate the warehouse to the solutions generated by the EC meant that a lot of operational work had to be changed. Most changes compost of breaking routines that the warehouse employees followed without thinking about if they were efficient or not. The redesigned system would be met by mixed feelings from the people affected of the project. The management and sale employees would like it but the warehouse employees were probably not going to like it and might take it as an attack on them. This is a classical problem when it comes to change processes in an organization but luckily ToC provides the Future Reality Tree(FRT). The FRT were first used to redesign the system to a desirable one that would increase the throughput of the system in the future. Secondly it was used to motivate and show the warehouse workers the positive effects of changing their operational work and break the routines. The second step worked thanks to that the tools of ToC has designed in a way that anybody understands them when they are finished.

Planning for the change
Even though everybody have agreed and passed the changes there are some crucial steps left until the new system is up and running. At this stage of a project it is easy to be blind by how well the future system will perform and the change work is started. This is not a good approach because when injection the change there is often more than one thing that have to be change and it is important to ensure that those changes do not effect other activities in the system. Before making an implementation the performer should investigate and search for possible obstacles that have to be overcome for the injections for change to take effect.

Depending on the scope of the change and the structure of the organization more or less obstacles can occur. In a warehouse on operational level the most likely obstacle to appear is that the employees do not adapt the new strategies because humans like routines and do not like change. If the new strategies are advanced the employees might not understand them or why they would be good and by that do not follow them. Other obstacles regarding redesigning infrastructure and design that can arise are that the new solutions intrude on space that is needed for the employees to drive their trucks, the performer might just think a truck is two meter wide and design after that while in reality SKUs in the warehouse that the truck transport is six meters wide. The performer might have a solution that utilize space better but instead he have doubled the travel distance per pick which will not improve the system. To find obstacles and ways to overcome them the Prerequisite Tree(PRT) were employed.

Action plan for implementation
The last step to execute before the new system is up and running is do develop an implementation plan, to let the changes get implemented smoothly to the system. To develop an effective implementation plan it is important to understand how much and fast the system can implement on the same time, because in most cases the organization cannot effort to close their system just to implement a new system. The person that undertakes the work of making the action plan have to realize what part of the change that is needed to be implemented first and what that implementation mean for the system. At the same time is it essential to see the big picture and make sure that not one implementation affects other parts of the system. If it does take this into consideration and state clearly in the plan how it will be handled as part of the implementation plan. If this is ignored the implementation might create more problems than it solve.

The company where the case study took place cannot afford to close their warehouse during the implementation due to number of reasons which makes this step crucial. The implementation plan have to provide information regarding time and resource consumptions as well as in what order the constraints should be changed in the warehouse. When employing the ToC at the warehouse the implementation plan told almost the similar action as the previous step due to various reason. The first reason is that the company has not agreed on what changes to implement and that the implementation needed cost analysis before put into work. The second is that no matter what solutions that get implemented it is important to make the employees in the warehouse to change the way they work and think. This

fact have affected the two last step a lot in the case study. ToC provide the tool Transition Tree(TT) to develop the implementation plan.

Chapter 3
Frame of references

This chapter intentions is to reveal the used frame of references both for Theory of Constraint and operational warehousing. The first part will be about ToC and the second on operational warehousing.

3.1 Theory of ToC

This section will be about ToC and will first provide an introduction and the history behind ToC. For the reader to appreciate the case study and learn about ToC the next part will in detail explain ToC and its approach and tools. In the end of the section example of what ToC has been used to earlier and how it can be used is provided.

3.1.1 History

The theory of constraint was introduced by Dr. Elyahu Goldratt, when he 1984 published his novel "The Goal". The Goal is a management-oriented book that has become a best-seller, it has been revisited and republished twice since 1984. The book is a fiction story about a manufacturing plant manager who turns a negative trend to a positive one. Over the time ToC has grown from the early OPT version to its full version it is today and the major improvements and adding of approaches and tools have been introduced by new books, here follow the whole history of ToC.

The root of Theory of Constraints started to grow when Goldratt's neighbors asked him to help them increase the output of their chicken farm. Goldratt formed a scheduling program for the chicken farm which tripled the output of the farm[13]. Goldratt revisited his algorithm and formed a software he called Optimized Production Timetable that evolved into the more known Optimized Production Technology (OPT). In a marketing purpose Goldratt wrote the book The Goal in which the theory behind OPT

was revealed and the theory became known as the Theory of Constraints, since than numerous of papers has been published about ToC.

Goldratt introduced his OPT software in the early 1980s and it was adopted by a numerous of large cooperation and then smaller one followed. In the beginning it was hard to say if OPT was good or not. At that time performance measurements measured activities and employees individual and when companies implemented OPT the result were that some stations were fully utilized and other gave the impression of being inefficient. Leading to employees deviated from the software to not look bad in the measurements. The result became unsynchronized flows in the company and the OPT gave the impression of not being value adding. In an attempt to save his work, Goldratt started to educate managers and workers that had implemented OPT. He also formed the ninth rule of OPT. To be able to educate more people efficient he wrote the book The Goal. The propose of The Goal was to illustrate how OPT, and later ToC, should be used in everyday work to get an effective and efficient system. The Focusing Steps was introduced in this book and were the first step toward the transaction from OPT to ToC. In a try to make ToC more understandable Goldratt introduced the Drum-Buffer-Rope (DBR) which shows how the whole system should be aligned and arranged after the constraint. A problem yet occurring was that employees got measured individual. Goldratt said that the classic performance measurement had to be replaced with new ones that measured the system. Goldratt continue saying all companies want to make money today and in the future even though the performance measurements should be focusing on throughput, inventory and operating expansive instead of profit and return of investment. First when management had made this switch the employees could work together towards one goal instead of individual goals which prevented the system to perform at its best. As time went by business management evolved to become more effective and with that the problems, or constraints became more complex. Goldratt saw the need for a new tool that could help manager to find suitable solutions for these complex problems and at the same time he could make the ToC more efficient. In 1994 he published the book It's not luck where he introduced the Thinking Process(TP) which were a map consisting of 4 cause-effect diagrams and one cloud. The TP provided a base for thinking that could identify and solve problems and how to implement that solutions to the system. The TP was the last added tool to ToC and completed the philosophy. From that applications, approaches and tools have been developed for ToC to be more efficient in special areas and fields.

3.1.2 Introduction

Theory of Constraints is basically used to accomplish a system's goal by identify its constraints and utilize them. That is how ToC can be explained in its simplest form, if ToC is investigated deeper it appears that ToC is a business strategy to improve any system of a business. The system is defined as the process that is being undertaken and can be anything from a production line to a whole company. ToC is based on that every system has these three features[1].

- Each system has a goal and a set of necessary conditions that must be satisfied to achieve its goal.
- Overall system performance is more than the sum of the performance of its components.
- Very few factors or constraints (often only one) limit a system's performance at any given time.

Constraints are defined as anything that prevent the system from achieving its goal[2]. ToC came with a clear top-down methodology called the five Focusing Steps. To execute the system-based philosophy the Thinking Processes are employed to facilitate the five Focusing Steps process. The idea is to use the TP to reorganize the system in a way that makes the system exploit its constraint(s)[3]. The TP are performed as a bottom-up approach. The Thinking Processes consist of five logic tools and from the tools the TP can be divided into five steps. Depending on the system all five tools are not always suitable to employ.

3.1.3 Focusing Steps

The five Focusing Step is an ongoing process for improvements work and is the approach when ToC is employed to change an organization. When an organization is changing there are often some internal resistance due to that people do not like change and will do almost anything before they shift paradigm. According to [4] the five Focusing Steps are a powerful tool to make people accept the paradigm shift. If the five FS is used correctly it can explain why changes need to be done and skeptical persons in the organization can except the change. The five Focusing Steps are a great approach for physical constraints but often physical constraints are connected with policy constraints and thats why Goldratt developed the Thinking Processes as a compliment. The Five Focusing Steps are the following[3].

1. Identify the system's constraint(s).

2. Decide how to exploit the system's constraint
3. Subordinate everything else to the decisions made in steps one and two.
4. Elevate the system's constraint(s).
5. Do not allow inertia to be the system's constraint. When a constraint has been broken, go back to step one.

The five Focusing Steps have the past years developed into a seven step approach [1] & [5]. The additional two step is supposed to be handled before moving into the original five FS. The two new steps are.

1. Set up the system's goal.
2. Determine the performance measures.

The following section will explain every step deeper.

3.1.3.1 Step 1. Set up the system's goal.

Every system need a goal to motivate and push the system and its employees to preform as good as possible. The goal is set by the management but it is crucial that everyone involved in the system understands the goal. If the goal is not understood there are many things that can go wrong.

3.1.3.2 Step 2. Determine the performance measure.

Performance measurements have become a popular topic for all types of companies lately. There are numerous of studies and researchers on the topic and it reveals both pros and cons. Before beginning to discuss what performance measurement to implement to the system there is important to understand what a performance measurement is. By the quote of Neely et al [7] "Performance measurement is a topic which is often discussed but rarely defined" it is understood that the definition is often forgot or not known, this leads to complications when they are implemented. Neely et al [7] suggest the definitions of performance measurement.

- *Performance measurement* can be defined as the process of quantifying the efficiency and effectiveness of action.
- *A performance measure* can be defined as a metric used to quantify the efficiency and/or effectiveness of an action.

- *A performance measurement system* can be defined as the set of metrics used to quantify both the efficiency and effectiveness of actions.

Even by these definitions it is a broad topic that requires both time and resources to be designed in an efficient way and bring value to the system. When the definition is understood the next step is to realize that performance measurement system can be reviewed from three different levels and it is supposed to be analyzed different. The three levels are according to Neely et al [7].

1. the individual performance measure
2. the set of performance measures - the performance measurement system as an entity
3. the relationship between the performance measurement system and the environment within which it operates

Analysis of the different levels give answers to various areas. The individual level answer question about what do we measure, what does it cost and how large is the benefit. The system level provides an analysis that shows if the right elements are measured, that the measures match the progress of the company and that the measure is implemented throughout the whole organization. The highest level supply a comprehension that the measurement is aligned with the company strategies, culture and reward system. [7].

When implementing performance measurements it is important to make sure that the measurement system is easy to understand for everyone involved in the system. Extra important is too make sure that the employees know what is measured so they can focusing their work to be as good and accurate as possible. The measurements need to be accurate, meaning that the measurements should be reachable but challenging to motivate the workers and keep the management satisfied by good results. At the same time the measurements need to be kept updated as the system progress, but when updates are made it is important that the result can be compared with older and forthcoming results. Without the ability to comparing the measures the measurements have no value, this attribute is the hardest to ensure.

The performance measurements design process is a tough process and to facilitate this process there have been numerous of papers trying to categorize the process. Mainly two dimension procedures and methods are defined as the 'hard' and 'soft' issues[8].

- **The procedures 'hard' issues** consist of three procedures.
  - *the needs led* is a top down procedure where customer's, business and stakeholder's needs are the base for developing the measurement. This procedure is designed to monitor the system's progress towards the needs.
  - *the audit led* is a bottom up procedure where the present performance is the base for the developing of the measurement. This procedure is designed to continues improve the system.
  - *the model led* is using a predetermine theoretical model of the system to motivate the development of the measurement.
- **The methods 'soft' issues** consist of two methods.
  - *the consultant led* is an approach were most of the work is outsourced to a small group of individuals, normally consultants. The work is often care it out with workshops that are spread out over time where the consultant goes from collecting data to analysis to present the result.
  - *the facilitator led* is an approach opposite to the consultant led meaning most of the work is undertaken by the management in facilitate workshops. In these workshops the facilitator's role is to induction information from the management, monitor debates and question decisions.

There are five big design processes that are well documented and applicable for different systems:

- Balance scorecard
- The performance model
- Getting the measure of your
- PMQ - the performance measurement questionnaire
- ECOGRAI [8]

3.1.3.3 Step 3. Identify the system's constraints

This step is crucial and will form the whole application of ToC. Worth to mention is that identifying the system's constraint also mean where to place it, because in the end it is about choosing what constraint to change. Important when identifying constraints is to first of all be sure that the

activity is a constraint and not just lacks because of other activities. When a constraint is proven, the constraint has to be questioned, depending on the activity the question differs. The idea of the questions are to find out what would happen to the outcome if the constraint was exploit. The answer should be positive for example increase in throughput, shorted lead-times or decrease in cost for the system. If the answer is the opposite it is a sign that the activity is not a constraint and a new activity needs to be identified as a constraint.[3]

3.1.3.4 Step 4. Decide how to exploit the system's constraint

The constraint is identified and now it is time to decide how to exploit it. The preferred way to start is by asking what the desired outcome of the constraint activity or resource is. The aim should be to maximize the outcome of the constraint to contribute to the systen and be able climb closer to the goal. The focus should be on how good outcome can be produced at the current state of resources not what outcome that could be produced with new or different resources. Meaning how do we get the most out of what we have.[3]

3.1.3.5 Step 5. Subordinate the system to the constraint

This step needs carful strategy and is the actual implementation. The concept is to align the system to the exploiting decision and make sure that every job throughout the system is executed in a way to make it possible for the constraint to be exploit[3]. The constraint activity has the highest priority which mean that all other activities will become subordinate to produce the best environment for the constraint to be exploit in.

3.1.3.6 Step 6. Elevate the system's constraint

In this step the constraint should be expand by increasing the capacity of the activity or resource. This will allow more outcome to be produced, the system to improve and achieve the goal. The different with this step compare to step 4 is at this point the resources are expanded and in step 4 as much as possible is pushed through the resources. An example to illustrate this would be a pipe with water where in step 4 the aim is to get has much water as possible through the pipe and in this step 6 the pipe is expanded to let more water through.[3]

3.1.3.7 Step 7. If, in the previous steps, a constraint has been lifted, go back to step 3. Do not let inertia become the system's constraint

The final step is to make sure that the policies and paradigm is aligned with the exploited and subordinated decisions. Now when the constraint is changed and by that the system is changed the policies and paradigm should be changed as well otherwise the system will not achieve as high outcome as possible and it will not accomplish the goal.

3.1.4 Thinking Process

The Thinking Process were developed as a methodology to carry out the ToC work and its goal is to embrace creative solutions by common sense, intuitive knowledge and logic[11]. The first step when employing the Thinking Process is to shift exclamation points to question marks by asking questions[3]. Challenging the system by questions are good and there are three essential questions for every manager to ask when applying TP[11].

- *What to change?* It is important to understand what to change and what effects that the change will bring. It is important to find the core problem if the system have more than one problem.
- *To what to change?* When the problem is identified and it is agreed upon what should be changed a solution most be formed.
- *How to cause the change?* When the solution is formed it is time to make up a plan for the change. The implementation plan should include and demonstrate how much time, resources and costs should be used for the change but also deal with how to make employees understand the change.

While working with TP there are important to understand what Sufficient Cause is because it works as a red threat throughout the whole TP. Sufficient cause thinking is a pattern of effect-cause-effect, meaning that something causes something else to exist. The cause thinking can be both passive and active [3]. Active cause thinking can generate good solutions while passive often is a waste of time. To understand the effect-cause-effect relations when the system consist of more than two causes a flow-chart map can be drawn. It is important that all the characteristics for each chart has been defined before the map is drawn because the map is recurring in all the Thinking Process tools. Understanding sufficient cause and flow-chart maps is essential for the Thinking Process. While working actively with cause-effect thinking there is important not to forget what the necessary conditions are. Necessary condition thinking is vital because without it

there is a risk of finding unfeasible solutions. Necessary condition thinking is a thinking approach that focus on requirements such as that one thing has to exist for the next thing to exist. A necessary condition is defined with terms like must, must not and need. The necessary conditions derived from polices, laws or rules that form boundaries or limits for the system. [3]

To answer the three questions the Thinking Process provides different tools. For the first question about what to change a tool called Current Reality Tree is used which is a logical tool to structure an image of the current situation[12]. For the second question where a solutions should be developed there are two tools called Future Reality Tree which is a strategic tools to realize major changes [12] the second tool is Evaporating Cloud which is a problem solving technique[3]. The last question have two tools called Prerequisite Tree and Transition Tree which both are good tools for finding and over come obstacles for the implementation work [11].

Rahman 1998 provided table 3.1 to easier explain what tool to use to answer each question. [15]

Table 3.1: Case study tactics for four design tests [23]

Generic questions	Purpose	TP tool(s)
What to change?	Identify core problems	Future Reality Tree
What to change to?	Develop simple, practical solutions	Evaporating Cloud, Future Reality Tree
How to cause the change?	Implement solutions	Prerequisite Tree, Transition Tree

The Thinking Process tools where developed to be used together but the independent use can be favorable and most definitely useful for specific cases. Full Thinking Process analysis papers are those who mention all five Thinking Processes and by employing it identification of the core problem, development of solutions and determine how to implement can be made. It is a very effective tool to use if there are resistance towards change in an organization. The reason is that it clearly shows a path from the current system to the changed system and can be constructed in a way that everyone can understand it, such as stakeholders and partners. From studying the papers it is understood that FTP is a good tool and versatility so it can be employed into many different department and settings, example given management polices, strategic planing, executing bank mergers and many

different change work in manufacturing [16].

- Current Reality Tree
- Evaporating Cloud
- Future Reality Tree
- Prerequisite Tree
- Transition Tree

3.1.4.1 Current Reality Tree

Current Reality Tree is the first tool to use in the Thinking Process. CRT is an effective tool and when used correctly easy to asset when searching for an answer to the question what to change? It is used to find the constraints of the system and that is also what need to be changed [3]. The CRT identifies cause-effect relationships in the system, it is done with a top-down approach by locate all Undesirable Effects(UDE) in the system [11]. CRT can be used to identify physical as well as policy constraints that causes the UDEs. The CRT reveals which or what constraints that causes the UDE to arose because it is not always that one UDE is caused by just one constraint. There are two major approaches to develop a CRT the following one by Rahman et al and Scheinkopf, which is used in the thesis.

1. Determine the scope of the analysis and provide the base to understand the system
2. Identify a list of UDEs it is suggested to list five to ten to start with.
3. Connect one UDE to another UDE using cause-effect thinking continue to all UDE is connected somehow, use arrows that states the cause-effect relations between the UDEs.
4. Read the map bottom to the top and make any necessary changes so it reflect the reality.
5. Make sure the tree reflects the reality and respond to the intuitions of the system being analyzed.
6. Feel free to add UDEs, that were not on the first UDE list, to complement the map to make a better picture of the system.
7. Apply the "so what test" and make someone else look at the map to make sure nothing is forgotten

8. Decide that the CRT is done and identify the core problem.

The second approach is called three-cloud approach, here is a mini guide to to develop the CRT from that approach.

1. Identify a list of UDEs
2. Generate three ECs from the list of UDEs
3. Construct a generic EC from the three ECs, thus identifying the likely core conflicts
4. Build a CRT that starts with the core conflicts, and harnesses the logic and pictorial representation of the generic EC

Studies of the literature show that there are papers given both general and specific instructions and distributions on how to design and develop the CRT, the special one are in different settings. On the other hand there is also a few papers that compare CRT to other root cause analysis tools. From the paper it can be said that the most normal reason for CRT to fail is because either that managers do not want to realize that there is a problem or that they believe that the work to develop the CRT is too complicated and time consuming. From the CRT the communication CRT has evolved which shows the core problem by highlight the relation between the UDE and the core conflicts [16].

3.1.4.2 Evaporating Cloud

The next step of TP is to answer the question to what to change? by finding a suitable solution to the constraints that has been identified with the CRT. Evaporating Cloud is an efficient model that is fast to apply and some argue that it can solve any problem as long as the problem can be realized as a conflict. Evaporating Cloud argues that every problem also can be seen as a conflict between two adverse arguments or activities. EC is the most frequent used TP tool. The solution search proceed to evaporate the conflict or dilemma and it can be executed in few different ways. The two main ways are to either examine the conflict or look at the assumption and find something that is invalid. Many authors argue about the benefits of using EC and that it can lead to a win-win solution due to that underlying invalid assumption usually is broken and that can open up for new and much more suitable solutions. It is important to remember that it is a far better chance to find a good solutions to the system by first conducting the CRT and then do the EC instead of jumping straight to the EC with a

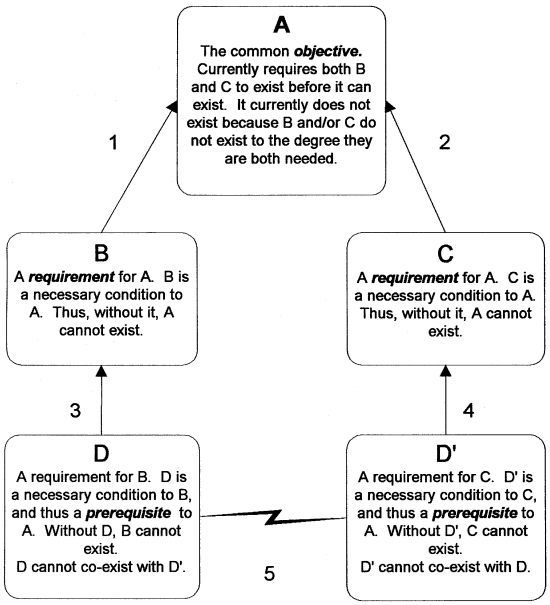

Figure 3.1: Evaporating Cloud [3]

believe of what the core problem is. [16]

Scheinkopf propose that the EC view a conflict as set of five relationship[3] See figure 3.1.
The model exists of five elements.

Entity is a single element.

Arrow indicate a relationship between two entities

Necessary condition is an entity that is required for another entity to exist.

Objective is an entity that cannot exist without nessecary condition(s), is found in the top of the model.

Assumption is the reason why an entity need a necessary condition, the reason for the relationships in the model.

1. Arrow #1 identifies entity B as a perceived necessary condition for entity A.
2. Arrow #2 also identifies entity C as a perceived necessary condition for entity A

3. Arrow #3 identifies entity D as a perceived necessary condition for entity B.

4. Arrow #4 identifies entity D' as a perceived necessary condition for C. (Please note that the notation D' is often interchanged with the notation E.)

5. Arrow #5 identifies entities D and D' as entities that are believed to be in conflict, perceived as unable to coexist in the current system.

As seen in figure 3.1 the entities D and D' is in conflict with each other and cannot co-exist. By following the process, that will follow, the conflict will be resolved. The result can either be a solution that creates a environment where the entities can co-exisit or if a solution like that cannot be found one of the entities have to win. The both entities leads to the same result but have different effect on the system on its way to the result. The solving process for Evaporating Cloud is the following[3].

1. *Articulate the problem*
   Begin with realizing that there are a problem and it is a problem that needs to be solved. The problem is a conflict where only one can win this can be hard to agree with, take a step back and view they whole problem. It is no idea to show empathy to either of the entities. To easier visualize the problem retell the problem as a story and do not forget to involve predicted effects and relations. This is just the first step and it is a long way until a solution should take form, instead draw the Evaporating Cloud and make sure all boxes are filled. It does not matter which box being filled first. When all boxes are filled it should be possible to read it like this

   - (Objective entity A) cannot exist if not (requirement entity B) and (requirement entity C) exist
   - (Requirement entity B) needs (prerequisite entity D)
   - (Requirement entity C) needs (prerequisite entity D')
   - (Entity D) cannot exist if (entity D') exist and verse versa

2. *For each arrow, uncover assumptions and identify potential solutions*
   The Evaporating Cloud model has been drawn, now it is time to investigate every arrow in the model. Underneath every arrow there is an assumption and it is because of these assumptions the problem has occurred. An assumption is the activity or reason for that one entity exist owing of another one. For arrow one, two, three and four the assumption is kind of easy to reveal. A good trick to find out

what the assumption is, is to read back this sentence and write down all assumptions.

- In order to achieve (objective), I must (necessary condition) because (assumption).

The assumption that is under arrow five is the major one and can be found by answering any of these questions.

- Why can't entities D and D' co-exist?
- Is there any overlap between them?
- Why aren't we allowed to have both D and D'?

The answer should be able to be read back like, the reason we cannot have both D and D' is (assumption). For each assumption to remain on the list they have to pass two question and the answer must be yes for the assumption to stay on the list.

- Is the assumption that is currently being made in the conflict's system (situation)?
- Is this assumption valid in the conflict's system (situation)?

3. *Chose an injection to implement*
At this point the only thing left on the list is the valid assumptions. It is now time to find new solutions and make the assumptions invalid. The new solutions are referred to as injections. The name comes from by injecting them the conflict is supposed to disappear. To find the best solutions it is recommended to brainstorm the injections. The key is to brainstorm as much ideas as possible, write down all ideas both good and silly once this will make it easier to generate more ideas. By injecting the injection the objective should occur without needing the necessary condition. If the solutions from the brainstorming is not satisfying one can use these two question to generate more ideas.

   - How can we achieve our objective without the necessary conditions attached to it?
   - What, if we implemented it, would enable us to render the key assumptions invalid or irrelevant?

   The injection for arrow number five should be formed so the entity D and D' can co-exist and do not conflict any more.
   The last step is to implement the injections, choose the best injection. It is ideal with a simple and practical solution instead of a complex and fancy one. It is important that the organization want to see the

injection implemented and that they can ensure that enough time and effort will be put into the implementing process. [3]

3.1.4.3 Future Reality Tree

To finish up the answer to what to change the FRT is employed. The Future Reality Tree is a future prediction tool, that at the same time teach its readers about the changes in the system. Most authors argue that the classical way of CRT, EC and last FRT is the best one and is employed in this project. It is a sufficient cause thinking diagram predicting the future which is quite hard but still almost all people are doing it every day, sometimes the prediction is right and sometimes it is off. The prediction often could have been better if more thoughts and resources had been put into the prediction. The FRT is build by four blocks according to Schienkopf [3].

1. Injections are entry points in the digram and are not present in the current reality. They work as a shot towards illness and are the start of the future change. As soon as the injection is implemented the predicted result should arise.
2. Entities that exist in the current system's reality. They are often entry points in the diagram.
3. Entities that do not exist until currently existing entities are combined with injections then they are predicted to exist.
4. Reinforcing loops is often used in the Future Reality Tree to create pattern to sustain and continue improve the system.

To execute this there are a three step process presented in [3]

1. Define the basis for the tree.
   (a) Identify an injection (idea).
   (b) List the objectives (pro's) of the injection.
   (c) List potential undesirable consequences (con's) of the injection.
2. Describe the effect - cause - effect relationships.
   (a) Using sufficient cause thinking, connect the injection to the objectives.
   (b) Using sufficient cause thinking, seek and block potential undesirable consequences of the injection.

3. Enhance the solution.
   (a) Predict additional effects
   (b) Add reinforcing loops.

On later days a new approach has evolved to develop the FRT. The new approach changes from tree to branch the new name is GEC-CRB-FRB-NBR. The CRB show the causal linkage between the action or policy to their effect in the current system. The FRB is a logical tool to study potential solution before implement it [16].

3.1.4.4 Prerequisite Tree

Everyday tones of people have dreams that they believe is to far away and employers get projects and tasks assigned to them that have goals that is out of the employe's comfort zone. There are two ways of comforting these situations, sadly the normal way is to reduce or ignore the goal or hope that somehow it will be achieved. The better is not to compromise and instead strive to the goal by setting the necessary milestones on the way there and make sure that in the end achieve the goal. The Prerequisite Tree is a tool that enables more people to achieve their goal by some thinking before striving towards the goal.

The Prerequisite Tree is a tool that helps the executer to identify and understand what stands between the current situation and the goal. The Prerequisite Tree process highlights obstacles and what need to be done to ensure that the goal is achieved. The Prerequisite Tree recalls the earlier introduced trees and is a diagram as well. The elements included in the Prerequisite Tree is two entities; objectives and intermediate objectives and between them obstacles. The objective is the desired result or goal but to achieve it an obstacle need to be overcome. It is done by an intermediate objective but it might has an obstacle before it so an additional intermediate objective is needed and so on. The obstacles are stated as entities that exist in the CRT. The PRT is a good approach to employ if the Future Reality Tree has multiple injections and the knowledge about which one to implement first is missing. The Prerequisite Tree should be employed when an action or implementation plan is created and to achieve the objectives will be difficult if it is clear what to do skip the PRT. [3]

The process to develop the Prerequisite Tree is the following

1. *Define the purpose for the Prerequisite Tree*
   The first step is to determine why the Prerequisite Tree is created it is important to have this clear from the beginning due to it simplifies

the creating process. When the purpose is establish introduce the objective or objectives. To determine the objective one can ask what is the desired outcome of the process, what will be accomplish or what is the purpose. The intermediate objectives from the Transition Tree, not described yet, is the intermediate objectives in the Prerequisite Tree. The objectives or goal of the PRT should be the injections for the Future Reality Tree. An usually made mistake is to not see the big picture and by that do not include all stakeholders which can lead to that the objectives get sub optimized. [3]

2. *List the obstacles to achieving each of the objectives and the intermediate objectives that will over come them*
   It does not matter if the obstacles or the intermediate objectives are listed first but the literature suggest that the list with obstacles are carried out first. The obstacles are reasons the objective cannot just be put in place and be used. To be able to use the objectives there are tasks that have to be executed, this is made by the intermediate objectives. Important to think about when listing obstacles are not list existing entities and not ones that might occur in the future. Often when an obstacle that might occur in the future is listed, it can be change to an actual obstacle that exist today by digging deeper into the obstacle. For example, "my boss will say no" is an obstacle that might occur in the future that could be replaced by "my boss has never given anyone that has worked here for less than two years a rise". It is always better to phrase the obstacle as something that exist instead of something that does not exist or is missing, for example "we don't have enough money" is better to put as "we only have 25 thousand dollars". If there are problems creating the list sufficient cause thinking can be employed.[3]

   For each obstacle on the list there is at least one intermediate objective that will make it possible to reach the objective. Now it is time to determine which objectives to use. To execute this step smoothly take the list of obstacles and next to each obstacle state an objective. The objective should either make the obstacle disappear or that the desired objective can be reach even though the obstacle still exists. For an intermediate objective to be successfully implemented there are a few criterion that need to be meet, like:

   - If (intermediate objective), then (obstacle) no longer prevents system from achieving [objective].
   - It is feasible.

- There are a motivation to implement the intermediate objective

It is normal to think that the intermediate objectives are not enough if that is the case examine every obstacle with necessary condition thinking to be sure that they all are covered by the intermediate objectives. [3]

3. *Map the implementation order of the intermediate objectives*
Now a list of all the obstacles that stand between the today's system and the objectives are establish it is time to decide in what order the implementations should be executed.
To do this the easiest way there is a logic seven step approach to use [3].

   - Identify two intermediate objectives that appear to have time dependency between them. Normally this is done by following you intuition, otherwise some thinking and mapping will tell which objectives that are time depend of each other
   - Diagram the relationship as a necessary condition relationship. The digram should be drawn with the earliest intermediate objective in the bottom with an arrow to the next one and the obstacle that is over come by that intermediate objective is showed by the arrow.
   - Scrutinize the relation digram using necessary condition thinking and make sure that the obstacles will be overcome by the intermediate objective and if not add another intermediate objective if necessary.
   - Select another intermediate objective from the list that appears to have a time dependency with any other intermediate objectives already placed in the diagram. Add the intermediate objective so its time dependency is right and scrutinize the relationship and make sure that the obstacles will be overcome.
   - Repeat the last step until all possible intermediated objectives from the list are linked.
   - Connect the cluster, any remaining entities and the objectives. The diagram should have one or more intermediate objectives at the top that will over come the main obstacle and by that ensure that the objective is fulfilled.
   - Make sure that every entry point, entity that does not have an arrow going in to it, is fairly easy to achieve. The entry point should be of the characteristics that when looked at a solution should easily come to mind.

3.1.4.5 Transition Tree

The Transition Tree is a sufficient cause digram employed to create action plans, for example an implementation plan. The digram have four different blocks in it[3].

A The injections are action. These are the things that have to be done to be able to execute the plan

B Entities that exist in the present system are always entities to the tree. The current situation should be taken into consideration when develop an action plan

C Entities that will exist in the future are the results of the combination of combining an existing entity and an action, can consist of more entities and actions depending on the situation

D The objective of the action plan is achieved by the conditions created by the implemented actions

The Transition Tree should be employed for developing an action plan first when the performer have some kind of understand of what outcome that should come from the implementation and have some ideas of what need to be done to get to that outcome. There is no point in employing the TT if it is clear exactly what need to be done to achieve the goal, than it is just waste of time. In other cases if the implementation seems really difficult and few ideas how to reach the goal, before employing TT go back and employ the PRT.

The develop process of a TT has four main steps and they will be presented here

1. *Establish the scope of the Transition Tree*
   First of all it is impossible to create a action plan if the goal is not well defined so the first thing to do is to state exactly why the action plan is created and what it is going to be used for. When it is decided that an action plan is needed because the goal cannot be achieved otherwise it is important to keep that goal in mind that will ensure the tree to strive towards the goal. The next thing to do is to define the objectives. This might look alike the goal but here the purpose is stated. Example the reason and goal for using TT can be to plan a meeting and than the objective is the expectancy of the meeting. Now when the goal and purpose of the TT is established it is time to go back

to reality and verbalize the starting points. This should be a quick step and one or two sentences is enough just to understand what the current situation is. If the goal of the meeting in the earlier example was to teach about ToC the starting point can be, the participates in the meeting have never heard of ToC. Now its time to find the first action that will bring the current situation closer to the goal. Important to remember is that action is strictly things the creator or creators do to affect the system, things that other do should be noted as effects. [3]

2. *Using sufficient cause thinking, link the action to an objective*
   At this point the tree only consists of an action and the objective(s), by following this step additional action and entities will be identified to connect the first action to all objectives. Start with trying to draw an arrow from the action directly to the objective and by using sufficient cause thinking evaluate if the objective will be reach by that action, it will not or if it do starting a TT were a waste of time. To get somewhere ask what the action actually causes that brings the tree closer to the objective. State the effect caused by the action as an entity and draw the arrow to it from the action. Next step is to be able to show how the process is progressing towards the goal, add the current situation and draw an arrow from that entity to the entity that was caused by the action. Now identify what action that will bring the situation in the new entity to or closer to the objective. Repeat this process until sufficient cause thinking agrees that an action actually leads to the objective.[3]

3. *Seek and block undesirable consequences*
   At this time the Transition Tree shows an action plan to get from the current situation the the desirable one. Now it is time to review the tree to make sure that what is stated in the tree actually will happen and keep an extra eye out for potential side effects that can happen and especially side effects that are not desirable for the system. By following the approach present now this step should go relatively smooth.[3]

   A Identify and list all potential Undesirable Effects that any of the entities, actions or causal relation give rise to, do not forget to think wide and consider the impact for stakeholders, owners, labour or family.

   B Select on effect and identify what causes that to rise, add the Undesirable Effect to the tree.

C Review the relationship and identify how the entity causes the Undesirable Effect, meaning which other entities or action are causing the effect to exist.

D Identify an action that could prevent the effect to exist. The simpler the solution the better the goal is to achieve the objectives not block Undesirable Effects in a fancy way.

E Insert the new action as a injection to block the effect, the new tree should only have desirable (or at least non-undesirable) entities in it.

F With some luck the action just taken blocks out more than just one Undesirable Effects and if that is true cross the others from the list.

G Repeat the process until the tree have no potential Undesirable Effects in it.

4. *Implement the plan!*
   The tree is done but the system will not get from the current situation to the objectives without the creator taking action and start with implementing the first injection. When the effect of that occur th next action can be implemented and so on until the objective is achieved. [3]

3.1.5 Previous work of ToC

This section will provide a resume of earlier work of ToC. Papers and articles of ToC has had many different orientations and focus so this section will present what types of papers have been published than present a few specialized ToC approaches that have connection to this thesis. Papers published on ToC has a wide area of focus. The publications are everything from general description of ToC to usage of a specific tool and case studies in different fields. To make sure that this was the case a pair of literature review papers of ToC was studied and it confirmed that there are a good spread of papers. This section will introduce and explain the different focus and purpose of papers that exist on ToC, due to time restriction most information is retrieved from the existing literature reviews.

3.1.5.1 Enhancement of ToC concept

Since Goldratt published his first article of ToC the subject has been the head subject of articles of numerous of well known journals and been the foundations to several books. Following is a list over the journals that have

had ToC published articles in it between 1980 and 1994:

- Computers & Industrial Engineering
- Engineering Cost & Production Economics
- European Journal of Operational Research
- Harvard Business Review
- Industrial Engineering
- Industrial Management
- Interfaces
- International Journal of Operation & Production Management
- International journal of Purchasing & Materials Management
- International Journal of Production Economics
- International Journal of Production Research
- Inventories and Production
- Management Accounting (UK)
- Management Accounting (US)
- Omega
- Production and Inventory Management
- Production & Operations Management
- Quality Progress

To get a better perspective of the publications they have been divided into three broad categories which are:

1. philosophy
2. applications
3. books

Based on the type of study these articles have been subcategorized to easier be explained for the reader. The subcategorizes are concept and enhancement of ToC concept, comparison with other production methods, applications in business areas and book reviews.

The majority of the articles published are focusing on the concept and principle of the ToC these articles aims to give an insight and understanding of the underlying concepts of ToC. Some of the articles in this subcategory goes deeper and explain and point of the advantage of ToC when it comes to increase the throughput, decrease the inventories and reduce the operational expenses. When OPT was introduced in the beginning of the 1980s it received a lot of criticism from different direction and some authors said that the production planning and scheduling could be implemented without the software that Goldratt sold. Many authors wrote articles that tried to enhance the ToC principle by solving theoretical problem settings. Other authors argued that ToC was a great planning theory an example is the comparison to TQM where TQM look at each process and optimize them individual when the ToC improve performances of the weakest link of the system and by that improvise the whole system as one. [15]

3.1.5.2 Comparison to other methods

In the beginning many articles compared ToC with other existing production methods like MRP, JIT and also linear programming (LP). Papers argue that OPT and ToC is an enhancement of the MRP II. Other authors explain the relations and benefits between the production methods differently. The argues state that the three methods is good complement to each other depending on the time horizon and focus of the planning. What most studies result in is that ToC is both more complete and outperform JIT and are more productive than MRP. Even though studies can show ToC benefits over the other methods in specific environment the general conclusion is that most company would benefit the most from a combination of the methods. The LP and ToC has a few key characteristics in common such as the law in TOC about one hour gained at the bottleneck is an hour gained for the system is close related to the shadow price in the LP method. [15]

3.1.5.3 Applications in business areas

In the early stage of the ToC there were a lack of papers who addresses ToC as an application in business areas. From surveys it was shown that

the main users of the method were the automotive industries and that ToC was mostly adapted by companies that apply the make-to-order production philosophy. Authors have done many studies in manufacturing environmental and have been able to show ToC benefits in reducing inventory, lead-time and improving the delivery performances. On the same time studies have been made where ToC has been implemented to different management departments such as purchasing, quality and information these studies show a decrease in paperwork backlog and also improvements in productivity. From the ToC an accounting concept has evolved that is called throughput accounting that can complement ABC (activity-based costing) when it comes to for short terms decisions. [15]

3.1.6 Thinking Process review

In recent years the interest of ToC's Thinking Process has arise and grown to be the most central tool of the ToC. There have published a lot of papers on the Thinking Process tools and the TP will be an essential part of this thesis which have led to that one section of Thinking Process literature review was developed. The articles that will be reviews in this section are published between 1994 and 2006 and are in total 114 papers to ease the work a lot of the information has been retrieved from Kim's article [16]. In this section three different types of literature reviews will be presented with focus on the TP. The different classifications of the review is:

- Classifications
- Focused on epistemology in TOC TPs
- Based on applications

3.1.6.1 Classifications

The first section of review is classical classification review and the papers talking about the Thinking Process can be group into four main classes theoretical/methodological, applications, epistemological and TP tool. [16]

Theoretical/methodological papers aim to explain the basics philosophy behind the TP and give an understanding of the theoretical foundation. The class can be divided in to three subclasses [16]

1. *Concept development* papers explain the basics disguise the principles of the trees and provides a background of the processes.

2. *Methodological comparison* papers compare the process with other methods and there are both wide comparison and specific ones.

3. *Enhancement/multi-methodology* papers aim to provide a deeper understanding of the process and how they can be used.

Applications papers within this class explain the use of the TP and highlight the expected benefits. In this class the papers can also be put into three subclasses. [16]

1. *TP applications related to the whole business system* papers describe how to implement the TP to an organization but also investigate the effects of the tools for an organizations performance measurement and change management.

2. *TP applications in specific areas* papers investigate and describe how the use of TP preform in different areas there have been papers in areas as manufacturing and production, human resources, supply chain management to mention a few.

3. *TP applications in the service sector* consists of papers focusing on applying TP to the service factor which is popular and these paper has got its own subclass.

Epistemological findings show that there are four types of epistemological papers published through 1994 to 2006 and these types are[16]:

- *Illustrative application of theory* are studies that explain and describe the basic principles of the TP.

- *Case study* is deep study of one or a number of companies that uses TP and the result is a detailed report.

- *Empirical research* is hypothesis test by collecting data from surveys or case studies.

- *Literature review* is papers that studies the existing literature of the ToC.

TP tools, in papers of this class the focus were to find out how popular it is to write about the TP individual compare to combinations of TP. It was found that nearly all papers on TP also explained the use of the TP. In these papers it was low number that explained all five Thinking Processes and a quite high number only explained one Thinking Process. The single most mention TP is the Evaporating Cloud and it is followed by the combination of EC and CRT together, they answer for 40% of the papers. [16]

3.1.6.2 Focused on epistemology in TOC's TP

In this section an deeper analysis of different epistemology is presented.

Methodological comparisons are all the papers comparing TP with other method and the comparisons are not only trying to show which is best but also show difference in nature, use and effectiveness. There are two other methods that TP is compared to most frequently and they are quality management and root cause analysis. Another method TP has been compared to is TQM where results show that TQM is a good approach to use on process level but that ToC is far more effective on system level. By using the TP companies can easier fulfill their goal. Numbers of authors argue that CRT is a great root cause finder and it has been compared to a lot of other root cause finding approaches such as cause effect diagrams and interrelationship digraphs. [16]

Enhancement of TP methodology and multi-methodology are papers trying to explain the use of combine TP with other tools and methods. One methods that several authors mean can benefit from being combined with TP is the theory of initiative problem solving, also known as its russian name TRIZ. At the same time TRIZ can make the removing process simpler for identified constraints. Authors have argued that ToC has a weakness when it comes to brainstorm ideas for technical problems but studies have shown that if TRIZ and ToC is combined the outcome is a mutual benefit in generating ideas to bot technical and non-technical problems. Another combination that have been proved valuable is the one between causal loop diagrams(CLD) and TP because CLD provide a good macro view while the TP shows a more detailed linkage in the micro environment. [16]

3.1.6.3 Applications of TP

The Thinking P rocess can be applied to different areas, and here they are divided into the whole business system, functional areas and in the service sector.

TP applications to the whole business system
The number one enemy of the ToC and its TP is the organizations performance measurements but if the measurement are redesigned to favor the work of the TP, it can bring much value to the business. To redesign the measurements the cause and effect thinking can be employed to identify the relationship between poor organizational measurements and local per-

formance measurements for example utilization or production cost. Studies also show there are various cases were the TP has failed because of old incentives and bonus systems. A few papers show that ToC can be employed just to overcome resistance of change within the whole business area.[16]

TP applications to specific areas
It is known that TP can be applied in any business where performances is constraint. There are studies on TP being used in SCM, marketing and sales, accounting and it has its largest usage in production and manufacturing. It has been argued that implementing TP can solve many of the common problems that production companies face today. To support this there have been papers published showing off case studies where the full Thinking Process or part of it has been implemented and the result has been good. Areas that have been studied are cooperate strategy, delivery performances and manufacturing performances to mention a few. Other authors have shown that the TP can resolve situation where a specific process is in conflict with the original and common goal, while other have shown cases where EC and CRT have been used for changing work in smaller departments. Concluding from the papers it does not seem to matter if the ToC is implemented top-down or bottom-up both methods have been studied and gave good results. SCM is an area where ToC and the TP are growing more and more every year. One author has showed that CRT not only can be used to find UDEs and root problems in the chain but also allocate causal relations and interdependence between actors in the chain. It has also been shown that the CRT can be a good tool to use for a SCM when they tries to decide if they should have a pull or push system. [16]

TP applications in service sector
TP have been employed by many different service sectors for quite some time now. The first service sector that used it were the healthcare after that education and teaching have followed. In the teaching area teacher has not only used the TP to identify constraint in the school but also used the TP to teach other things.[16]

3.2 Warehouse operation

The warehouse is an important component in any supply chain. Normally its basic role is to store and buffering material between supplier and customer for a company but a warehouse can do much more than just hold inventory and by using it right it can bring value to both the company and

the product. Value adding activities can be knitting, product customization and labeling, these activities are not operational decision for a warehouse and will not be further discussed. This section will present and discuss the literature for warehouse operation such as, receiving, put-away, storage, picking and shipping.[25]

Warehouses all around the world more or less have the same activities in them and the sane material flow through these activities. The basic activities in a warehouse is receiving, put-away, storage, picking and shipping. In the past before supply chains got to what they are today the warehouse main role where to hold inventory to make sure that the company could ship goods to their customers. For the past years an increase in supply chain integration have arise and combined with modern strategies like make-to-order and just-in-time delivers the warehouse role have drastically changed. Companies are trying to eliminate their need for the warehouse which start with moving from many small close to customer warehouses to one large distribution central warehouse. The changes have had late impact on the operational work in warehouses and humans are getting exchanged for robots and advanced automatically solutions such as automatic storage and retrieval system AS/RS. To compete with the AS/RS or at least bring value to the supply chain warehouse operational approaches and strategies have developed a lot the last years. A key factor to maintain a world-class warehouse is flexibility combined with that the operational work is carried out by as little transport and handling as possible [24].

Warehouses contribute a lot to the total cost of logistics for companies and with the classical approach of just storing goods at the warehouse it does not add value in the same way that other logistics activities. Never the less if the warehouse is used correct it can reduce other costs more than the cost it occur to. According to Lamberg [20] the following activities can be utilized by the warehouse and by that reduce costs and add value to the logistics process.

- Achieving transportation economies
- Achieving production economies
- Taking advantage of quality purchase discounts and forward buys
- Supporting the firm's customer service policies
- Meeting changing market conditions and uncertainties
- Overcoming the time and space differences that exist between producers and customers

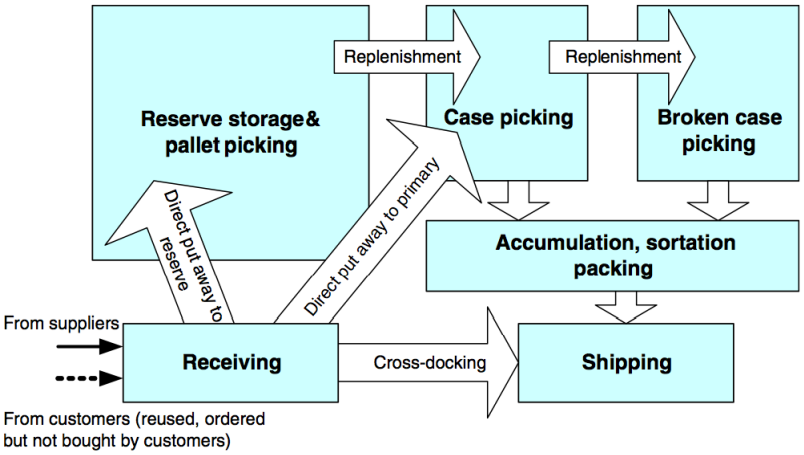

Figure 3.2: Material flow in warehouse [19]

- Accomplishing least total cost logistics commensurate with a desired level of customer service
- Supporting the just-in-time programs of suppliers and customers
- Providing customers with a mix of products instead of a single product on each order
- Providing temporary storage of material to be disposed or recycled
- Providing a buffer location for trans-shipments

Following will the five main actives be presented in form of a literature review of earlier work in the fields of warehouse operation. From the literature it is clear that every activity in the warehouse contributes to how well the warehouse works and it is important to execute every activity at its best to get a world class warehouse. Every activity consist of sub-activities and the first goal is to eliminate the activities and after that the sub-activities in the remaining activities.

3.2.1 Receiving and Shipping

Goods enter the warehouse through the receiving dock and later leave the warehouse from the shipping dock. The material entering the warehouse can take many different ways before it departure the warehouse on its way to the customer. Frazelle presents five different receiving approaches and they are presented in decreasing level of how good they are:

- Direct Shipping
  Direct shipping is when a company do not use their own warehouse and instead order from a vendor that ships the order straight to the customer. This minimize the chance of errors and delays from the warehouse. It also prevent all the non value adding actives in the warehouse for that order. This approach is propitiate for build orders and make to order goods for example.[24]

- Cross-docking
  Cross-docking is when the material is received, unpacked and then sent directly yo the shipping area. This approach skips the large and most costly activities in the warehouse and aim to minimize material handling. If cross docking is applied it is important to establish suitable strategies so the traditional actives such as inspection, put-away storage and picking can be eliminated. Even more important is to have control over the material flow iin the warehouse and match arrived goods with outgoing goods. Suitable goods for cross docking are backorders, special orders and normal order flow if the arriving and departure time can be matched. A great design for cross docking warehouses are to have the receiving and shipping area next to each other to minimize transport.[24]

- Receiving Scheduling
  Smaller warehouses might not have one dedicated receiving and one shipping area installed in the warehouse and instead these areas are intact the same or for warehouses that cannot match their in and out going goods cross-docking cannot be achieved. A propitiate approach then is receiving schedule, the idea is to schedule the arrivals to minimize the time spent on receiving. Labour could take care of arrival goods for a while and than know that he or she can undisturbed undertake an other activity.[24].

- Prereceiving
  The two most time and space intensive actives in the receiving process are the staging where the material is identified and their location is decided. With today's technologies warehouses can ask the vendor to send the product specifications before they ship it so the warehouse can plan for the receiving and by that eliminate expensive activities. [24].

A warehouse should try to use direct and cross-docking as much as possible and if that is not possible the aim should be to have a combination of approaches. A combination could be beneficial for the warehouse

in total but also for each approach [17]. In receiving and shipping it is important to plan and schedule the arrival of carrier after the resources in this departments. The literature provides ideas how to approach arriving and departing trucks by truck to dock and different types of doors such as strip and stack for the two activities respectively. However, there are a few papers on how to apply and use cross docking warehouses. [17]

3.2.2 Put-Away

The put away process is the picking process in reverse and most picking strategies or approaches work for the put-away process as well [24]. To contribute for a world-class warehouse four different put-away strategies can be used they are called Direct, Directed, Batched and sequenced and Interleaving.

- Direct put-away
  This strategy should be adapt if cross docking cannot be applied. The aim is to eliminate all activities that prevent arrived goods to be put-away directly. This can be made be not have and accept any receiving staging and it results in less material handling. [24]

- Directed Put-Away
  Directed mean that the worker that put away goods get direction about where to place the goods to ensure that the material get placed in a suitable location. If the worker do not get direction they tend to place the goods at the easiest position such as closest empty position. [24]

- Batched and sequenced put-away
  Batched and sequenced put away means that more than one material is put away at the same time. for example goods that are located in the same zone can be put-away at the same time. [24]

- Interleaving Put-Away
  This strategy tries to minimize the dead-heading. Dead-heading is when a worker transports himself or herself without caring any goods, for example on the way back from a put-away. The idea is to combined the put-away and picking process so the worker can first put-away a SKU and than on the way back can pick a new SKU that should be shipped. [24]

From literature it seems that put-away process is a sub process and the way it is executed often is depended on strategies regarding the other

activities such as receiving, storage and picking. To design the best possible put-away process the focus should be on minimizing material handling and double handling.

3.2.3 Storage

. Storage is the major warehouse function, and the form of the warehouse can be decided by following three questions, how much inventory to keep in the warehouse? how frequently and at what time should the replenishment take place? where should every SKUs be stored? The two first question are determined mostly based on the demand and sales which decides the size of the warehouse. This factor is hard to affect in other ways than estimate for optimal levels and replenishment times for all SKUs. The last question is the one to focus on and it can be answered in many different ways and if the right approach is taken the warehouse can save a lot of resources and cut lead times [17]. The storage normally answer for 52 % of the used space in the warehouse [25].

The storage approach and picking strategy is closely related and to achieve a maximum performance in the warehouse it is important to carefully think about these strategies and approaches before implementing them. Then five major storage approaches are random storage, closest open location storage, dedicated storage, full turnover storage and class based storage. For random storage every incoming SKU is placed in a random free location, which generate a high space utilization but a increased travel distance. Closest open location storage is one the employees put the new SKU in the first available location he or she can find, this leads to, if the warehouse has that capacity, that the racks closest to the depot are full and the farer from the depot the racks are more and more empty. Random and closest open location have more or less the same effects. Dedicated storage is when every SKU always get stored at the same location, this approach have the worst space utilization but in advantages the workers remember where different goods are stored and the picking goes faster. Dedicated storage can be preferred when a warehouse holds SKUs that differ a lot in weight, store heavy goods low and light high. Full turnover rate storage identify the SKUs that are most frequently picked and locate it at the most convenient location, this decreases the travel distance but for many items the demand shifts a lot over time and to keep the full turn over rate optimal the location need to be changed often. [19]

To determine which type of storage policy to employ is the first step the second is to actually determine which SJU that should be placed where.

This is a known problem that is called storage location assignment problem (SLAP) and talks about how to assign arriving goods to their locations in the warehouse. The idea is to do this in away that reduces material handling and transport costs within the warehouse and there are a few different types of solutions to the SLAP. The three most common strategies are based on the type of information that can be established before the goods arrive. The first SLAP solution is based on item information. The information in this case regards the arrival and departure of the SKU and by knowing that one location can be detected to more than one type of SKU as long as the are not occupying that location at the same time. The information can also be used by applying the duration of stay (DOS) which state that the SKU that stays the shortest in the warehouse should be located closest to the door due to that this location will be visited most and by locate it close to the door or packing station the transportation will be minimized. The next information base that can be used is Product Information. It is more common to knew this information because it is the physical shape of the SKU and when that is known assignment can be done into different types of racks such as pallets or bins. This information can also be about the usage rate or turn over in the warehouse. Most common is to store the new SKU in the nearest empty location to reduce transportation cost in put away process. The last information base for SLAP is no information, with no information the put away approach have to be design simple. There are a few known approaches and it is really hard to tell if any of them are better than the other. They are Closest-Open-Location (COL), Farthest-Open-Location (FOL), Random (RAN), and Longest-Open-Location (LOL). The first two measure the distance to the receiving station and the last one measure the time a location have been empty. In summary the most common base is product information and a popular strategy is the Cube-Per-Order-Index (COI), that is a older version of the full turnover storage, this policy take into consideration not only the popularity or how frequent a SKU is picked but also the space it occupies. The COI scale is sorted in increasing ratio and the SKU with the lowest COI can be located in the best locations. [17]

By using any of the different types of information from SLAP the warehouse can classify their goods after a criterion preferable into three classes and than the locations in the warehouse is classified to match the classes of SKU. E.G. classify SKU after weight and the heaviest goods are in one class medium in on and light in one than every rack can b classified to facilitate the picking for the employees both in practical and ergonomically. This approach is called class based storage [19].

One approach to adapt is to store a SKU in more than one location in the warehouse. In which departments to store the SKU is depending on the design of the warehouse.When a decision is made about where the SKU should be located the next problem is do determine what quantities to store in the different places. The reason for multi-location of a SKU can be that the warehouse have different departments for different customers or because of grouping SKUs that often is purchased together. By locating SKU in more than one place makes it possible for more than one worker to pick the same SKU to different orders at the same time, if not batch picking is put in work. [17]

Another approach is to develop an forward area that provides reserved location for SKUs that are frequently sold. This strategy is also called fast picking area and the idea is to keep a smaller quantity of the SKU in the forward area to provide easy and fast picking of the items located their. The FPA is often likened as a warehouse within the warehouse[21]. A forward picking area(FPA) reduces the picking costs at the expense of additional material handling due to that the FPA needs to be replenished and it requires more space because the need for a bulk area to hold the remain quantity of the SKU that is picked from the FPA. To reduce transport Bozer [18] introduce an approach where racks where split into an upper bulk area and a lower picking area, this reduced material handling and transport between bulk area and forward picking area during the replenishment process and results in lower costs. The main challenging when implementing a FPA is to decide about the replenishment strategy and their are two different strategies which one of them is used by almost every warehouse that have implemented FPA. They are called equal time (EQT) and equal space EQS) strategy. When EQT is employed all the stock get replenish at the same time and the space allocated in the FPA should match the demand of the SKU. While employing EQS all SKUs get the same space in the FPA and are replenish separately. However, the optimal solution is to try the middle between EQS and EQT as shown in the figure.

3.2.4 Picking

Order picking is identified as the most expensive activity in a warehouse in form of; time consumption and resources utilization resulting in the most labour intensive process in a warehouse[19]. It is said that 50 per cent of the warehouse cost are labour and that half of that is account for the order pickers [25]. There are different known strategies to managing order picking in a warehouse operation, the most common ones are, single-order picking,

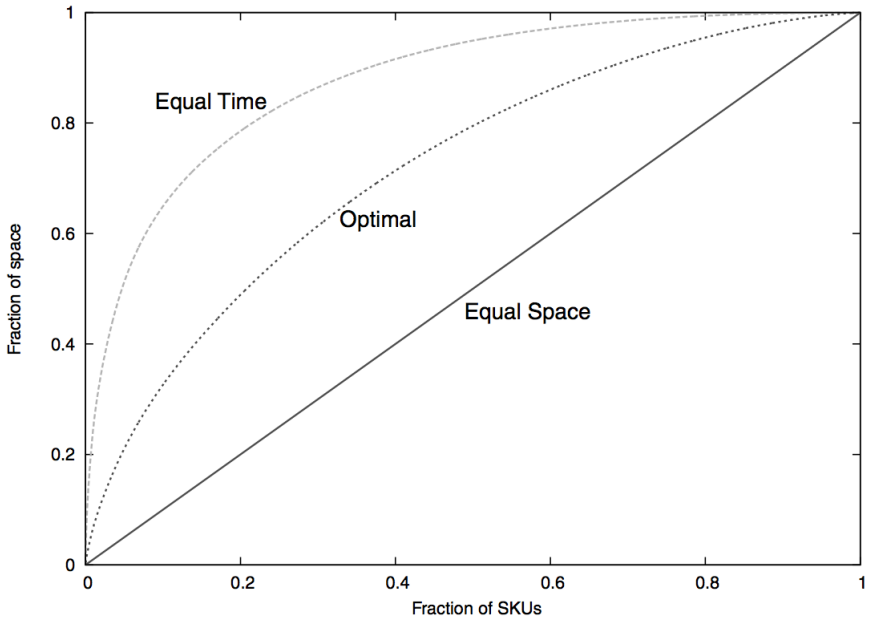

Figure 3.3: EQS vs. EQT [21]

batching with sort-while-pick, batching with sort-after-pick, sequential zone picking with single order, sequential zone picking with batching, concurrent zone picking without batching in the zones, and concurrent zone picking with batching in the zones. Each of these picking methods do consist of some or all of the following steps; batching, routing and sequencing and sorting. [17]. With these strategies the picking process can be shortened and letting companies accept later orders with faster deliveries, giving the warehouse less time to pick on. Another trend is that companies move from many small warehouses to one large distribution center. When company change to large distribution centers they often also implement value adding activities to these centers to cut costs and be more competitive[19].

Batching's basic principle is that if a few set of orders is shipped at the same time and by that an order picker should pick all these order at the same time to reduce transportation. Batch picking can be carried out differently one idea is to have a number of orders assigned to one picker and schedule his picking so there is time to pack all the picked orders. Another idea is to divide the warehouse into zones and let one picker be responsible for one zone. When picking all the items that is located in their zones to the different orders and than the orders are put together and packed after,

in this case a schedule that makes all pickers finish at the same time is required. The main idea of batching is to minimize transportation and by letting the pickers cooperate and share orders the chance of revisited a location is reduced [19]. Transportation is responsible for the majority of work while picking and at the same time do not add value to the product. From the papers it is understood that it is hard do develop an optimal bathing algorithm and that the best one that exist focusing in reducing the order picking time because it is believed to bring most value to warehouses. It would be interesting with studies that tests batching algorithms based on other criterion such as lead time and tardiness. When introducing batch picking in a warehouse it is important to remember that it is easier to batch pick if the warehouse is designed for it and to do this batch picking and a solution to SLAP can be combined, preferable with the product information. [17]

Sequencing and routing in a warehouse is done to find the best sequence and route while picking an order or putting away newly arrived goods. As transportation is the major activity while picking and is close connected to the material handling cost which the goal is to minimize a good sequencing and routing approach can save both time and money for the warehouse. To understand it the Traveling Salesman Problem (TSP) can be used to illustrate. TSP shows that with a given number of location to visit there is a lot of travel distance to save if the location are visited in an optimal order. A set back is that no routing algorithm is optimal for more than one warehouse due to differences in layout [19]. In a warehouse the TSP is special because of limitations as aisle design such as width and accessibility. There are four common approaches which are multi-parallel-aisle system, man-on-board AS/RS, unit-load AS/RS and carousel. The multi-parallel-aisle system is used in classic warehouse without automation and the pickers are routed in the warehouse but it is important to state the limitations before designing the sequence and routing algorithm. If the warehouse have aisles that only can be entered from one side is it important to make sure that not one picker get trapped in the aisle while another is picking, or with double entering aisle make sure that not two pickers enter the same aisle at the same time if they are routed to pass throughout the whole aisle. The automation systems do not bring any value to the case study so it is not further discussed. By combining good sequencing and routing with batch picking a warehouse can reduce the travel time and material handling costs and increase the throughput. Routing and sequencing are the most studied problems in warehouse operational papers and it is shown that with multi located SKUs the routing becomes more complex but larger savings can be made. [17]

Sorting is an activity that every warehouse perform in one way or another. Sorting is done in larger extension in warehouses that have batch picking and in those cases the sorting can either be done while picking or after picking at the pack station. When the sorting is done is normally determined by the type of SKUs that are being picked, small SKUs that are picked to a wagon can be sorted while picked while larger SKUs might be to have to sort while picked so they have to be sorted after. If a warehouse have really large SKUs that have to be picked separately the sorting process is taking place while the worker is away to pick the additional goods for the order and in those cases it is important to have a large packing station to make it possible for more than one picker at the time can stash their ongoing orders there. There is possible to design automatic sorting systems especially if the picking process is automatic.

3.2.5 Equipment

There are some equipment that can be found in almost every warehouse. The equipments are racks, trucks and automatic systems, all three of these are found in different types of warehouses and for different purposes.

In addition to the equipment there are some standard tools that is common in most warehouses and these are the different unit loads. The most common is the wooden pallet [25]. The wooden pallet comes in many different sizes but there are a few ones that have standardized size such as the europallet. The pallet is a convenient sized load to move goods on it is easy to pick up with the forklift and can carry a lot of weight. Material is often shipped on pallets to ease the movement of the material for the transporter and the customers. On the pallet almost anything can be stored, from whole unopened cartons to a mix of smaller boxes and unpacked materials. Pallets should be combined with racks that are build for storage pallets.

3.2.5.1 Racks

Racks are used in storage to enable a better space utilization. Racks have multiple levels with shelves which makes it possible to store multiple item on the same floor space but on top of each other. Racks are the most common way to store goods but some warehouses do not have them because of different reason the larges one is that the material that being handled do not need racks. If no racks is used the storage is called block stacking and it means that the SKU are placed on the floor or on a pallet and than more

SKUs are placed on top of the first SKU. A rule is to not store SKUs higher than six times the wide of the shortest side of the pallet in the bottom, so for a pallet with the sides 1,2 m and 1 m the stack should not be higher than 6 m [25].

There are a lot of different types of racks on the market and due to what the warehouse handles different types are suitable. There are also multiple policies that could be applied to these different racks. Often the rack is designed after the policy and they together create a system.

The most simple system is the drive in and drive through system which is pretty similar to the stacking but here the goods are stored on shelves in racks. This system does not support FIFO, first in first out, because of its design. The racks are design so that the truck can drive into the racks and leave the SKU and than back out again and when the next SKU enters the rack it will be placed so it blocks the previous stored SKUs. When picking the driver pick the closet SKU, resulting in that a Drive in and drive through system is most suitable for material with a large quantity. Drive in is one the aisles are only open on one side and drive though is when it is open on both sides. [25]

Double multiple deep rack is a smaller drive in or through rack where in a double deep can host two pallets behind each other on every floor. The racks can either be design so that picking and packing are done from different sides and the FIFO policy can be used or that picking and packing is done on the same side and than FILO, first in last out, policy is used. [25]

Narrow aisle racks are the most common ones and are multiple racks placed two and two with there back towards each other, creating a aisle between the fronts. The aisle should be as narrow s possible but at the same time enable picking with truck. This racks are normally single deep other wise the aisle cannot be as narrow as possible. This system is often used for AS/RS, automatic storage and retrieval system. [25]

All mention system above are for pallets there are also rack system for smaller SKU such as shelves, bins and flow racks. These system are for smaller goods which the case company has none of and therefore are not discussed deeper.

3.2.5.2 Trucks

All most every warehouse has at least one truck in form of a forklift. The forklift is used to transport, put-away and pick goods in the warehouse. There are countless with brands on forklift and there are also a lot of different models of forklifts. There are ones the employee sits down in and there are them they stand in. The fork can be in front or on the side of the truck to fit in aisles and some have counter weight in the back so they can retrieve heavy goods from heights with out falling over. [25]

3.2.5.3 Automatic system

In recent years more and more warehouses have installed and employed automatic solutions for different activities in the warehouse. The most common one is to have some type of automatic storage and retrieval system and its task is to put-away and pick goods. The most efficient system is to let the AS/RS to put-away one SKU and on the way back pick another one. To employ AS/RS the SKU have to be stored on standardized pallets or bins. The AS/RS benefit is the speed and the disadvantage is the flexibility. [25]

Conveyor belts are another popular installation that can transport goods automatic through the warehouse and minimze the transport in a warehouse. The conveyors can be customized for the warehouse to transport goods from receiving area to storage and from storage to packing area. Conveyor belt combined with AS/RS can enable a totally automatic warehouse from receiving to shipping. [25]

For small goods there are a few different automatic solutions such as mini load that area a storage area that workers cannot go into and instead the worker tells the system what is needed and it will come to the picking area the mini load is a developed carrousel where the storage position rotate. [25]

Chapter 4
Case Study

This chapter will show how the Current Reality Tree employed in a warehouse operational environment and what results that were achieved. The case study follows the presented approach and uses all the provided tools.

Harald Pihl AB is uncertain if their warehouse will be able to deliver the same result in the future as they do today due to the increase in sales. Harald Pihl AB has no strategy for the warehouse and the workers have a free roll when it comes to planning and execute their work. The idea is that all orders that arrives before noon should ship the same afternoon. The warehouse fulfill this today but the management of Harald Pihl feels that they have to start investigate the warehouse for possible improvements and develop their warehouse to increase the throughput and maintain the service level. At this moment Harald Pihl has two projects running that both aims to make the warehouse more effective and efficient. The first project is this thesis work and the second one is that Harald Pihl is implementing a barcoding system.

Barcoding means that every Stock keeping unit (SKU) in the warehouse will be market with a barcode that holds information about the SKU. All workers will get a handheld device that is connected to the data system and can scan the barcodes to provide the system with information. The system provides the device with information about the queue of orders that should be picked, the location and inventory of the goods. The barcoding system will reduce the work in front of the computers and by that decrease the dead-heading back to the computers. The idea of implementing barcodes came from that Harald Pihl have begin to sell material to the aircraft industry. To be granted to sell material to the aircraft industry the company has to keep track of the material flow in detail and it seemed as the easiest and most efficient thing to do both to keep track and for the warehouse was to implement barcodes. The barcodes will create opportunities for this thesis

and will enable more complex solutions. Opportunities will come in form of automatic updated picking list, batch picking can easy be employed, information about inventory levels and goods information can easier be accessed.

The mission for the case is to make the warehouse more effective and efficient by employing ToC. For the case study to give the admired result the presented method have been followed combined with employing the Theory of Constraints. Both the scientific method and the theory have been followed in every step in the analysis.

ToC has evolved over time and from the beginning it contained of the five or seven focusing steps which is the over all approach that will be used for the case. To be able to fulfill the different steps in the method there is a lot of work that need to be done before moving on to the next step.

4.1 Case Study Process

Here follows a quick summary of the tools provided by ToC and how they were used throughout the case study.

The first tooll is the Current Reality Tree which is a map over the existing system. Its task is to find the root problem that causes the Undesirable Effects but it also work excellent as a mapping tool. When the observations where made to get an understanding of the system the CRT was the starting point which provided a rich base when planning for the observations.

When the observations where made and all data needed to understand the different flows and working routines in the warehouse were collected. One CRT for each flow and activity were establish. Some activities appeared in all or some of the different CRTs and by these activities all trees were connected. By connecting all trees some problems that appeared to be root problems disappeared because it was clear that something else caused that problem and the number of root problems decreased until it were a reasonable number. This root causes where later investigated to get the understanding of which that actually were core problems and which that were not. From the tree it was possible to establish what problem that had the highest impact of the Undesirable Effects. The problems with the highest impact were defined as core problems and were the ones to be exploit and solved throughout the case study.

To determine how to exploit and solve the constraints the Evaporating Cloud was employed which is a powerful problem solving tool in any situation, as long as the problem can be viewed as a conflict between two arguments that both strives towards the same result. In the case study the cloud were constructed as the following. The conflicting action where between one constraint and the opposite to the constraint and they both strived to a desirable effect, an effect that the future system want to have. As the warehouse system is today the constraint and the opposite cannot co-exist. The Evaporating Cloud have one middle step, one for each argument, between the conflict and the desirable effect. When the cloud were developed different solution were brainstormed to find the ones with potential to satisfy both argument to coexist and at the same time achieve the desirable effect. A number of solution that could work were identified but by deeper analysis it were cleared that for each cloud there were only one solution that really solved the problem and could be backed up theoretically. The Evaporating Cloud were a good tool to employ and were used to totally different activities as well throughout the thesis work, such as planning.

Theory of Constraints aim to develop a new stronger system and when solutions to solve the current constraints is establish it is time to develop a Future Reality Tree to visualize how the system should look and work when the work is finished. The Future Reality Tree were develop for the warehouse while basing it on the CRT and the solutions developed from the EC. By introducing the solutions in the FRT and analyze it the solutions could be evaluated if they would work and bring value to the system. There were two main benefits of creating the FRT, except to evaluate the solution and get a picture of the future. The first one were that it provided knowledge about what would happen by implementing the changes. The second one were that FRT could be understood by anyone. Both these benefits were valuable while discussing the changes to prevent resistance.

From the resistance, questions occurred about how the changes would be implemented and if they would not affect activities and flows that were not supposed to be affected. To show them how the changes only would bring benefits the Prerequisite Tree were establish where potential obstacles where stated and how these obstacles were overcome in an appropriate way. By the PRT it was possible to prove that breaking the employees routines were not an attack on how they operated today but an upgrade from a good system to more effective and efficient system by providing them with the chances to learn about these things through workshops and seminars. The Prerequisite Tree straighten out all question marks that had occurred when the new solutions and system were presented. Most obstacles were identi-

fied as the employees not willing to change as this process were identified to be more complex than the physical changes in the warehouse.

When management and employees had accepted the changes and were looking forward to be apart of the future system the last question arose, how do we get from the current system to the future system. When updating the system by employing ToC the core problems are changed and this means that a lot of actives will be affected. To facilitate and ensure a smooth change process the Transition Tree were employed. The TT is a tool used when developing implementation plans it is a sufficient cause digram that take a bottom-up approach and reveals all the action that need to be undertaken to get to the future system. It is important to follow the steps of the process and that the goal of the TT is decided in advanced. By employing the TT both the management and employees understood what they needed to do and that the new system could not be implemented just by one part. The employees have to install the new physical equipment and the management need to provide the employees with seminars to change the routines to effective strategies. This proves that TT can be used both for hard and soft implementations in a warehouse.

4.2 System's goal

The first focusing step is to set the system's goal which is the starting point of employing ToC. To be able to set a goal for the system the management where interviewed and their expectations of the warehouse were the foundation for the goal. From the interviews it was understood that the reason for the past years success and increase in sales came from Harald Pihl's fast deliveries. Harald Pihl keeps a high level of stock which enables the fast deliveries. The high level of stock do not only support the fast deliveries but also prevent stock outs and loss of costumers, costumers seem to purchase from the retailer that have the desired goods and it is hard to build relationships with customers. From the interviews the conclusion that Harald Pihl probably kept to much in stock and that their restock policies needed to be changed were establish. Thus, further discussion with the management revealed that Harald Pihl was happy with their inventory level and purchasing strategy. The motivation is that high stock level attract costumers to purchase from HP and it supports the fast deliveries. The management kept talking about increase the level of effectiveness and efficiency of the warehouse. Effective and efficient were defined as good and high performance and to make the warehouse more effective and efficient means increase the

performances and get a higher throughput. From discussions about Harald Pihl's future and predictions for forthcoming demand a goal could be agreed upon. The set goal is to still fulfill the delivery policy, orders that arrive before noon should ship the same afternoon, when the number of order per year increases to 7,500 which is an increase with 25% from today. To get an understand of how Harald Pihl's warehouse performed and executed the operational work at the moment an activity profile were made. The activity profile had a few major purposes such as, confirming the problem that the management had mention at the interviews, give a picture of how the different activities were carried out in the warehouse and identify in which areas the main problem where. The activity profile cover all the main activities in the warehouse and each activity is revealed in table 4.1 to 4.5.

The goal is also referred to as the service level. The set goal is specific but there are different ways to satisfy it. To narrow down the potential ways of satisfying the goal and limit the thesis a sub-goal was defined. This sub-goal occur during the activity profiling and is that the company do not have a warehouse strategies and if they really want to improve their warehouse it is best to start from the foundation. This led to that the sub-goal is to perform all improvement work on the operational level. When the goal were formed with the sub-goal the management and warehouse employees were called to a meeting. During the meeting information about the thesis were given and discussed. Explanations about the different levels were held to make everyone understand what would happen and why. From the meeting management and employees understood the benefits of starting with the operational work and not try to implement advanced solutions. Advanced solutions would not contribute with their full potential because the workers would become constraint and limit the solutions. To start the change in the operational work the labour would get a higher utilization and become more efficient. The fact that it is possible to get a higher utilization of the labour does not mean that the workers are lazy today, but by introducing some strategies the operational work gets facilitated and the warehouse would become more effective and efficient.

4.3 Performances measures

To be able to fulfill the goal there is important to have correct performance measurements and measures. In this case the goal is to meet the demand when it rises. To keep control if the goal is satisfied outgoing order can just be compared to orders sent from the sales department to the warehouse, the

Table 4.1: Activity Profile Receiving

Receiving		
Activity	Comment	Good/Bad
Unloading the truck	The goods are just put aside on the floor. Most deliveries are made during the mornings but the put-away work starts first at the afternoon which means goods are piled up on the floor.	+ Fast unloading and picking work can be carried away. -The goods are left a long time on the floor and the more goods left on the floor the more space it use and the risk for double handling increase due to that the accessibility decrease.
Weighing	Smooth and the delivery guy helps with this activity.	The placement of scales - Goods get forgotten on the scale.

Table 4.2: Activity Profile Put-Away

Put-away		
Activity	Comment	Good/Bad
Add to system	Identify the goods from the specification but also check the goods.	+Assure the right delivery. -A lot of non value adding work and can be hard do execute when more than one material is received in the same box.
Find location	Find the location for the material through the data base and make sure there is enough space to fit the new goods there.	+Good data base that provide essential information for the put-away. -A lotos transport and dead-heading.
Put-away	Rack B is replenish with just material by hand, no boxes, the rest of the racks are storing boxes so the put-away process asks a truck.	+ Easy to find the locations and to see if the goods actually fits. - Ergonomically demanding for the workers and due to the shared location double handling often occur.
Relocate goods	Have to check the data base.	+Easy. -Time consuming and dead-heading.

Table 4.3: Activity Profile Storage

Storage		
Activity	Comment	Good/Bad
Space	A lot of inventory position to store goods at. Shared location which leads to that goods rotate where it is stored.	+Shared Location and a lot of locations. -No strategy for where to locate new goods.
Storage departments	There are four different kind of storage in the warehouse	+Different storage types - The layout is probe by not optimal
Narrow aisle racks	Large and strong racks where heavy goods or large quantities of a material can be stored. Truck is needed to operate in these racks.	+Many positions and a crane for sheets. -Products are miss placed and no standardized boxes to store goods in.
Trays, rack B	Many trays, hand picking is employed here and the trays are host for multiple materials.	+Easy hand picking and a saw close b. -Shared location causes double handling and some material is poorly located and that makes it ergonomically demanding.

Table 4.4: Activity Profile Picking

Picking		
Activity	Comment	Good/Bad
Order sorting	Print pick list	Okay strategy.
Picking	Identify position and quantity that should be picked from the picking list. Confirm right goods by heat-number and weight.	+Making sure the right goods are picked. -A lot of dead-heading back to the computer when problems occur.

Table 4.5: Activity Profile Packaging

Packaging		
Activity	Comment	Good/Bad
Protect the goods	Every package is customized for the order.	Good pack station and location of packaging goods. -Need more pack benches in the packing station.
Measuring and Weighting	Every goods need to be measured and weight before and after packaging.	+Good place meant of scales. -Not value adding activities.
Laboring	Every SKU that is being sent has to have a visible heat number.	+Facilitate the control of sending the right material. -Extra work while packing
Placement of packed goods waiting to be shipped	No dedicated place for outgoing goods instead they are placed were they fit. Picking and packing are mostly done in the morning and the delivery trucks pick up the orders in the afternoon.	Pack station is close to the shipping dock. -Messy and unorganized around the outgoing goods.

throughput, which in the end will result in that the throughput will need to increase. To increase the throughput the future identified constraints have to be exploited as much as possible. In additional to just measure shipped orders every constraint should be measured individual.

4.4 System's constraints and Current Reality Tree

In this step the real change work starts. The first thing that has to be done is to answer the question what to change? To ensure the right answer, that will bring most value to the system it is important to be careful and make all the necessary background work. It is easy to look at the system and say this does not work let's change it. However that is not the right approach and by following the method provided by ToC the right answer should appear clearly after a few steps work.

From the Table 3.1 it is clear that the CRT should be used to answer the question what to change? To be able to ensure a correct Current Reality Tree data is needed. The collected data will be the foundation for the list of Undesirable Effects(UDE). Undesirable Effect is an activity or an effect that occur in the system and that somewhat limits the system or do not bring any value to the system, the goal is to block or remove these effects. Earlier interviews had talked about what the management where unhappy with in the warehouse, the answers from the interviews where revisited. An analysis focusing on Undesirable Effects where conducted to find out and understand what the management where unhappy with. The main point the management had were that the warehouse is disordered and messy, meaning that goods are stored on the floor, this occurred from that storing arrived goods are not priority.

In order to form an own picture and be able to identify Undesirable Effects of the warehouse an observation plan were establish, see appendix. The observation plan consisted of points to check out in every activity in the warehouse as well as how to follow material flows and employees routines. The observation took placed during a few days and were carried out by following workers, orders and material flows. From the observation an understanding of the system (warehouse) could be created. During the observations an understanding about Undesirable Effects, behaviors and activities in the warehouse were establish. By linking activities and behaviors with the identified effects the true Undesirable Effects could be identified and stated. The following list shows the Undesirable Effects.

Undesirable Effects

Double Handling

Every order, in or out, demands a lot of resources

Resources are not ready to be used

Arrived goods are placed inappropriate

The Undesirable Effects are the starting point for developing the CRT and from that the constraints can be identified and the core problems can be revealed. One CRT per each effect were developed. The constraints are the boxes with round corners that only causes effects and are not caused by other entities. The Undesirable Effect are the boxes with round corner that only occur and do not causes any thing. The squares are entities that are caused by and causes other activities. The CRTs can be viewed in Figure 4.1, 4.2, 4.3, 4.4.

From the CRT it is clear what the core problems are and what effects that occur from them. To determine which of the possible core problems that causes the most Undesirable Effects the following table is generated and it shows the problems impact on the effects.

Table 4.6: Identifying core problems

UDE / Entity	Double handling	Order demands a lot of resources	Resources are not ready to be used	Arrived goods are placed poorly	Packed orders take up a lot of space	Impact
Shared location	X	X				40%
Workers Prioritize Picking			X	X	X	60 %
Infrastructure & Design	X	X	X	X	X	100%
Order sorting algorithm	X	X	X			60 %
Measuring and weighing	X	X	X	X	X	100&
Heavy goods	X	X	X			60 %

- Shared location: more than one SKU is stored in one tray. A tray being one location on one shelf in the rack. In rack B the trays are narrow and deep while in the large rack they are wide and not so deep.
- Workers prioritize picking: every time a worker has a choice to choose what to do he prioritize picking order in front off put away goods for example.

- Infrastructure & Design: how space is utilized, where resources are placed and how the racks are organized and used.
- Order sorting algorithm: the way the warehouse sort the orders that should be picked during the day. Today they sort the orders after due date and first come first served.
- Measuring and weighting: all goods have to go through these two activities before and after it gets packed, to ensure that the right material are picked and to be able to book transport.
- Heavy goods: the warehouse deal with heavy goods and for the employees to be able to pick, transport and put away goods they need to use a forklift.

Table 4.6 shows how large impact the entity has on each UDE. According to Scheinkopf [3] any constraint that causes more than 80 % of the UDEs should be regarded as a core problem. The table shows that two entities are a part of causing all the UDEs. The two entities are Infrastructure & Design and Measuring and Weighing. Measuring and weighing are essential activities in the warehouse both to make sure the right material is picked and when booking transport the exact length and weight are needed. This activity will be ignored as a core problem but the behavior around weighing and measuring should attempt to be improved by changing other activities. Measuring and weighing are strategic level decisions and by ignoring them for now Infrastructure & Design becomes the core problem. Infrastructure & Design is a broad area for a warehouse but the focus for the case will be to find changes that can affect the operational work in a positive way and improve the throughput. The change of Infrastructure & Design should result in that the UDEs disappears. Order sorting stands for 60% of the UDEs which is under 80% but it is believed that by improving the order sorting process combined with the barcoding system the operational work can be facilitated, so order sorting will be classified as a core problem. Order sorting classifies as a core problem due to that the way that the orders being sorted determines in which order they should be picked which is the main activity when the employes plan their working day.

By employing CRT the question What to Change? has been answered. The answers is equal with the determined constraints that are the Infrastructure & Design and the order sortation. These two constraints will have the focus for the rest of the analysis and by exploiting and changing them the aim is to improve the throughput in the warehouse enough to maintain the over all goal from the management.

4.5 Overcoming the constraints with Evaporating Cloud

In this step the idea is to come up with solutions that will maximize the outcome from the constraints and by that answer the question To what to change? From the Table 3.1 it follows that there are two tools that can be used to answer the question Evaporating Cloud and Future Reality Tree. It is appropriate to use the Evaporating Clouds to begin with.

In this case we have two constraints, Infrastructure & Design and Order sorting. The Infrastructure & Design constraint is as mention a huge one and can be attacked from many different angles. Important to remember is that the Infrastructure & Design constraint should be changed so that the UDEs disappear this will narrow down the possible changes and will guarantee that the outcome increase, as said before An hour saved at a non-bottleneck is just a mirage [15]. To come up with solutions or ways to exploit and change the constraint the Evaporating Cloud is used.

Lets start with the conflict about prioritize activities in the warehouse. This conflict arises from the high number of orders that need to be shipped everyday and at the same time everyone want to maintain a clean and organized warehouse. The two prioritizes that exists in this conflict are that the workers prioritize picking vs prioritize a clean and organized warehouse by storing new arrivals in racks and not leave it on the floor. If workers prioritize picking they can make many picks and ship all the orders but at the same time every pick takes longer time due to that new arrivals are placed randomly and at poor positions in the warehouse. It starts to pile up goods on the floor and the workers have to move around the goods to be able to pick orders. On the other hand if the workers always prioritize storing new goods the warehouse would would not be able to maintain the service level because they do not have time to pick. The positive is that every pick would go faster and the risk of double handling is decreased. The goal is to have a high number of picks and a short picking time per pick and this would be done if the workers picked as much as possible and at the same time kept the warehouse clean. A solution to this would be to invest in a new rack that could function as a storing rack for arriving goods, due to that when a delivery arrive one worker already has to help the delivery guy unload the truck and sign the paper. If the worker instead of placing the goods on the floor put it in the rack it would not take much extra time and the warehouse floor would be kept free. Figure 4.5 visualizes the conflict.

The next conflict is the one regarding the B rack. The area and rack that is called B is a smaller rack that is six meter deep. This rack holds smaller

goods and are sorted into trays that are 25 cm wide. The idea is that the rack should be able to hold a whole batch of material unpacked from its original box to facilitate picking of these SKUs. Today the rack is overfilled and in many trays there are materials sharing the space. The one big benefit is easy picking but the shared locations have caused many drawbacks such as goods get damaged when picked item slides out. When putting away goods heavy material have to be stored under lighter ones or bars under pipes to not damage the goods. This leads to, in worst case, that before a new batch can be put away the batch in the tray first have to be picked out because it have to be on top and than the new batch can be put in followed of the old batch on top. One batch can weight a several hundred kilos and consist of many six meter long tubes, this double handling is exhausting. There is either no good area to put the out picked batch of material because six meter form the rack is the load and unload dock for trucks. From experience the replenishment process it was realized that the process was a great waste of time and added no value, almost removed value due to the risk of damaging goods. Next to the B rack there is an old saw that work fine for cutting all material stored in the B rack, the material from B never goes into the larger saws. Figures 4.6, 4.7, 4.8 shows how the b rack look and two example of the disorder that occur because of the shared location policy.

The conflict is between keeping the rack as it is and keep all goods of the material there or redesign the rack to smaller compartments in rack B to create more positions but less space to store. If the B rack is kept as it is today the workers will know that all material are stored together and they can pick both large and small orders from rack B, and at the same time not intrude on the space in the other racks. If rack B was redesigned it would generate more positions in rack B. The worker would only be allowed to pick smaller quantities from B and pick larger quantities from the box stored in the larger racks. By that transports could be reduced and dead-heading be eliminated. This approach will take up space in the larger racks. Easy and low resource picking combined with fitting all goods in the warehouse is the goal for this conflict and that could be done by turning the B rack into a forward picking area (FPA). To change the B rack into a FPA and introducing a few policies regarding the FPA would facilitate the picking process to be more effective and efficient. The policies would be that the worker only picked smaller batcher of material from the FPA tentatively not larger batches than they can carry back to the packing station by hand. Larger batches will consume a bit more resources but hopefully the time spent on retrieving the back up box is the same as walking back an forth to the B rack and the packing station. The next policy is generated by that the FPA would apply equal time strategy, that affects the replenishment of

goods. With help of the new barcoding system, more advanced information about the inventory can be accessed and by that the need for replenishment can be provided by the hand held devices. The idea is to have one set time when the replenishment is made and at that time the system will tell the works what positions that need replenish and what amount. Of course the system needs to keep track of the levels between replenishments to avoid that the rack stock out. Figure 4.9 visualizes the conflict.

The next conflict is about the sortation of the incoming order that should be picked. The two conflicting arguments are sorting orders fast after due date versus advanced order sorting by consider resources that need to be used, batching orders and due date. If the orders are sorted fast just after due date the workers get maximum time to pick orders, this can lead to long queues to the saws for goods that need to be cut. The orders could be sorted after how much resources they employ and by that the utilization of resources, as the saw, could improve and unexpected waiting time in form of queues would disappear. The outcome from this conflict should be to spend as little time as possible on sorting orders and to utilize the resources at an as high as possible degree that would result in a maximum picking pace. This could be done by employing an algorithm for sorting the orders. To develop this algorithm the operation time in the saw need to be establish and when they are known it would be easy to employ a queue system. The algorithm could later be implemented as a side system that could be run in the hand held devices or by introduce a few simple rules for hand sorting the orders. Figure 4.10 visualize how this conflict were solved.

Another conflict is the one that results in that resources are not ready to be used. From the observations it was established that the resources that was effected by this were the scale and the pack benches. Almost every time a worker were suppose to weigh material there were already goods on the scale. Most of the time the goods left on the scale were packed orders that were waiting to be shipped. This results in that the worker that wants to use the scale has to move the goods from the scale. It is a risk the employee places it poorly due to that it is someone else's order. This could result in that the order get forgotten when the carrier arrives to pick up all orders. The conflict here is believed to occur from laziness but can be seen as the following. To have a strategy for outgoing goods versus no strategy and all outgoing orders are treated as it pleases the worker and that order. With a strategy all orders would be treated the same and end up in a dedicated area in the warehouse the bad thing is that all orders are different in size and going with different third party logistics companies. Without a strategy the workers can leave the order where he finds a suitable place for it. The

negative is that after the worker has weight the package he leaves it on the scale and moves to the computer to book transport and then he forgets the package on the scale and move on to the next order. Which make the scale unusable for the next worker. The goal for the conflict is to have an area to place outgoing goods and minimize the risk of misplacing the goods, resulting in that the scales and packing bench is kept free from finished orders. This could be done by introduce a strategy or policy that says; all outgoing orders should be placed in dedicated area. This area could be one shelf in the new rack that were talked about in previously conflict or by introduce an additional rack close to the pack bench, preferable where the packaging sheets are stored today. Figure 4.11 shows the EC used in this conflict.

From the Evaporating Clouds four conflicts have been solved. The solutions exploits the constraints and are believed to increase the throughput if they are implemented. The four solutions are dedicated areas for arriving and departing orders in one or more new rack(s), redesign rack B to a FPA with bulk storage in the large racks and introduce a new order sorting algorithm that focusing on utilize the resources. This is four independent solutions, to illustrate how the whole system will look in the future the next tool to help answer the question To what to change will start now. The next tool is the Future Reality Tree and it reveals how the system will be look when all solutions are implemented.

4.6 Visualize the change by Future Reality Tree

The aim for the FRT is to reveal how the system should work when the constraints have been exploited and the changes are implemented. The FRT is an excellent tool to use to over come residence to the change, thanks to that it is easy for anyone to understand the positive outcome from the change. The idea is to develop a reality tree with the base of the four changes that were identified from the ECs and by that remove the Undesirable Effects. The CRTs that were establish earlier was a bit messy and even hard to understand due to that they did not have a clear start or ending because the warehouse was in bad shape and had no strategies. The FRT will be design as it represent one working day even though the arrival of orders is continues happing during the day. Thus, as the system will be in the future it has two main entry points and one end.

The system start by orders arrive and that they get sorted by the new algorithm that make sure that the resources get utilized. On a normal day

there are five workers in the warehouse, the idea is that two workers are responsible for one saw each. They load the saw with the first order that should be cut and during the time the martial is processed the worker can collect the rest of the material that should be cut in that saw and queue them. By queuing all the material the set-up time between the cuttings are kept to a minimal. One worker is responsible for the water jet cutting machine so his job is to get that going as fast as possible. When the saws are working the employees are suppose to start picking the rest of the first order and make sure that when the cutting process is done it will go fast to pack the order. If there is time before the cutting is done the worker will continue picking the next order. By doing this the labors are more efficient utilized. Of course he goes on picking orders until the all materials are cut in the saw. The saw machine should be working all the time until there are no more goods to cut for the day, which means that setting up the saw is priority number one. With two workers on the saws and one on the water jet leaves two people to pick the smaller orders, mainly picking from the new FPA. If there is an order with small goods in small batches everything should be picked from the FPA, if there is a large batch of items from the same material the picking should be made form the bulk box that can be placed next to the packing station. Ones the order is packed for any of the workers he is supposed to book the transport and put the order in the dedicated area, this will prevent workers from leaving orders on the scale. The dedicated area is divided after transport companies.

During the day new goods arrive and the policy with the new system is that one of the workers, that are not responsible for the saws, can receive the goods and have to place it in the new rack and mark it with its specification. When the goods are placed in the rack he can return to the work he was doing. In the end of the day when all orders have been pack and there is no more new arrivals the workers have three main activities to do. The first one is to make sure that the FPA holds enough material so it would not stock out the following day. The second is to make sure that the arriving goods rack gets empty and all goods goes into their real location. The last thing that should be done if possible is to set up the queue for the saws for tomorrow. This will increase the utilization of the saws the following day and decrease the transport the worker need to do the following day so he can pack even more orders or use himself to more valuable work than transporting. Figure 4.12 shows the FRT.

Now when the Future Reality Tree is developed a picture of the future system is visible. All involved, manager, stakeholders and employees can get an understanding of what will happen in the future and see why some

changes are necessary today. Now the question How to cause the change? arises in everyones head. Thats why the next tool was developed, the tool is called Prerequisite Tree. The Prerequisite Tree will show and explain what work is need to be executed to be able to implement the new solution and by that occur the new system to start working.

4.7 Constraint elevation: Prerequisite Tree

The Prerequisite Tree aims to reveal for the company how to go from today's system to the one develop with the Future Reality Tree and provide the first part of the answer to the question How to cause the change? It is done by identify obstacles that can arise when trying to implement the solutions, the new entry points in the FRT. This section will provide one description per solution in form of onePrerequisite Tree each.

4.7.1 Introducing Forward Picking Area

The first change is the hardest one to implement because it consist of both a physical and strategy change and it is to turn rack B into a FPA. A FPA can be viewed as a warehouse within the warehouse, with one pick area where smaller quantities of the material is stored for easy picking and one bulk area where the rest of the batch of the materials are stored [21]. The idea of a FPA came from that the management and the warehouse employees liked the idea of rack B because it is easy to pick from it but after years with no strategy have ended up in that the trays are shared by more than one material which complicates the picking and put away process. Today the warehouse store whole batches in these trays making many of the overfilled with goods, complicating the picking and put away process even more. Figure 4.7 and 4.8 shows how rack B look today. A FPA combined with splitting the trays in suitable sizes will simplify the picking and put-away process again. For the new system to perform as the Future Reality Tree desires rack B has to be redesign to have more positions. The easiest way to do this is it start with the compartments that exist today and chop these up in smaller ones. Today compartments are suppose to hold the entire batch of a material and the FPA is only suppose to hold a part of the batch while the rest are stored in the bulk area. The change of where and how to store provides an opportunity to switch todays compartments to new smaller ones, suggestively half the size of the size that is used today. The next challenge is to find space to put the bulk area. When these physical changes are solved the employees in the warehouse need to understand the

idea of a FPA and by that shift their routine's while picking orders.

Lets start with creating more positions. The first issue that come to mind when looking at rack B, see figure 4.7 and 4.8, is that the goods being stored there various in shape, size and weight a lot, from heavy rectangular copper bars to thin light nickel tubes. Just by looking it is understood that if all compartments are reduced to half the size larger goods will not be able to be stored in large enough quantities which leave us with that not all compartments can be reduced in size. By trying to pick the different SKUs in the rack it is obvious that heavier goods have to be placed low because it will be impossible to pick it if its located high. To over come this obstacle the rack will have to be divided into different section and then the material have to be analyzed by an ABC approach. The first step is to classify the rack into different classes and to make it easy they will be called A, B, C and D. Not to confuse rack B with shelf class B. The classification of shelves is based on two criterion how frequent positions are visited and ergonomics, to facilitate for the employees while lifting, picking and putting away goods.

Table 4.7: Classification of shelves

Shelf	Class	SKU
1-2	B	Heavy and large goods
3-5	A	Medium heavy and popular
6	D	Most popular light heavy
7-9	C	Light and un-popular medium heavy

When the shelfs are classified the SKUs need to be classified and then by combining these two classifications the design of the shelfs in the different classes can be made. Class A should consist of the materials that Harald Pihl AB sell the most of because these positions will be visit the most. By placing these in the most convenient area of the rack it will reduce the picking time overall. ABC-analysis claims that the 20% most popular goods should answer for 80 % of all picks also known as the Pareto principle or 80/20 rule [26]. By reducing the picking time for this class the total picking time will decrease. Within this class the heavier goods should be store low

and the lighter goods should be stored above, for ergonomic reasons. If there is possible to identify which goods that most frequently is required to be cut, they should be stored close to the saw on the racks left hand side to reduce transport from the FPA to the saw. When all goods that should be in this class are identified an analysis of each goods need to be execute to determine if the material will need a whole compartment or if half the size will be enough. This will depend on how much of the goods that need to be stored in the FPA to cover the demand from one replenish time to the next one and see if it fits into a whole or half size tray.

Class B should consist of the FPA's heaviest and largest goods. It will be stored on the bottom shelfs to facilitate the picks for the employees. These goods are in general so large that they will need a whole compartment. To insure themselves against running out of trays for large goods all compartments in class B should be kept at the size they are today. In this class the goods that tend to be sold in smaller sizes should be stored on the rack's left side to minimize the travel time to the saw.

The class C will be placed on the three highest levels in the rack and are suitable for light goods mostly. To pick from here the worker needs stairs which generates some difficulties when picking from here. This is why this area is for light goods, the worker can pick a number of tubes or bars and then carry it down the stairs and to the pack station. The medium heavy goods that did not fit into the popular area will be stored here as well. It will occur situations when the worker need to travel up and down the stairs a few times to collect an order but these materials are not sold often and will not affect the average picking time in a negative way. Even here it is favorable to place the goods that get cuts the most to the left seen from the racks view.

Class D will consist of the most popular light materials due to that shelf can be reach without stairs but it will be impossible to pick heavier goods than the lightest ones from there. Again the goods that is sold in smaller pieces should be stored on the left close to the saw.

The redesign of rack B is now finished and now space for the bulks are needed to be find. Today all SKUs in rack B are stored in trays that are 50 cm wide and one tray often holds two different SKUs, by reducing them to half the size the two SKUs should fit into two trays that are 25 cm wide. Which present a opportunity to store the bulks in the existing 25 cm boxes that are used to store material in the larger racks with. The hard work is to find space in the larger racks to fit all these boxes. The best way would

be to build a new rack to store all the bulk in and this could be possible at two places in the warehouse. The two locations are either where the pallet racks are today or where the six meter metal sheets are located today. Today pallets can be stored over rack B and by adding a few pallet racks in the end of the aisles of the larger racks. If instead the sheets where moved to make place for a new rack, the sheets could be stored in the titanium sheets rack or, if possible, fit them into the new rack that is suppose to hold the new arrived goods. Both these solutions would be great but would bring a lot of work in form of analysis and planing at the same time ask for some investments.

Another solution that would work is to do an inventory of all the larger racks and go through all goods. While doing this the goods should be sorted so the racks becomes more organized and the goods are stored in smaller boxes to exploit the hight instead of the depth of the racks. After cleaning the racks free space should appear and to exploit this space there are two approaches. The first one is to store bulk goods behind goods that only are stored in the larger racks. The second is to divide the racks into different zones and have some bulk zones and areas where the large and heavy goods are stored. There are pros and cons with both these approaches. If the racks are divided into zones the bulk goods can be stored as they are stored in the FPA. Then, when it is time for replenishment the worker could get all bulk boxes at the same time and drive with the truck to the FPA and easily replenish the FPA. The negative effect would be that if there is three different SKUs on one every shelf it will bring a lot of double handling it could be decreased by classify every rack into three positions. A, B and C where A would be furthest out, B in the middle and C at the far end and than classify all SKUs after how often they get pick and place the most frequently picked goods in A and so on. By placing all bulk boxes in the end of the racks it would minimize the need for double handling when picking the large goods but it would mean that for every replenish a double handling would occur.

The third obstacles to over come to implement the FPA successfully is to change the routines of the workers when it comes to picking. Today they pick all small goods from rack B even if that means they need to walk back and forth between the rack and the packing station ten times or get an truck and put the order batch on the forks of the truck and by that occupy it for some time. The new strategy is to go to the FPA when the quantity of a material in an order are not heavier than it can be carried by hand from the rack to the packing station. If the weight is greater than what a man can carry the worker should get a truck and retrieve the bulk box drive next

to the packing station pick the quantity the order requires and put back the bulk box. This strategy will reduce the total transport and eliminate dead-heading in the warehouse. A strategy regarding replenishment is also needed and the most efficient solution would be to replenish the FPA every friday afternoon when it normally is less to do in the warehouse and one or two workers can take the time to replenish. What goods that need to be replenish should be easy to identify by the barcoding system and the handheld device. Figure 4.12 shows the PRT for this solution.

4.7.2 Introducing an order sorting algorithm

The next solution to implement is the new way of sorting order for in which order to pick them. The idea of the algorithm is to provide the workers with a schedule that will facilitate their work and at the same time increase the utilization of the resources. The resources that has focus for the algorithm are the two large saws. For the picking work to become as effective as possible the saws should start working the first thing in the morning to ensure that there are enough time for all goods to be cut before they are supposed to be shipped. Then they can rest later in the days to provide an opportunity for the workers to start cutting tomorrows goods already today. An advanced algorithm should in addition to the schedule provide a timesheet when the different sawing jobs are done. This feature would facilitate the work in the warehouse by letting the workers know when the rest of the order need to be on the pack bench. With a timetable the workers would also know how much spare time they have to do other activities such as storing arrived goods and overall provide an easier environment to plan the day. To build this algorithm and include it to the system a few obstacles need to be overcome.

The first and most essential obstacle is to determine the cutting speed of the saw and if the saw cut all different material in the same speed. When this information is collected the speed just need to be divided by the radius of the material to get to know how long a cutting job will take. The next step is to determine and agree upon an appropriate queuing system. To do this there are two main approaches. One being start with the shortest job where the order only contains that piece of goods. The second being the opposite start with the longest and largest order. There is known algorithm for both these approaches. The algorithm should be combined with a policy for when jobs are not going to meet their due time. The normal approach for this is to move the first job that do not meet its due time to the last position of the queue to prevent more jobs to become late and if

there are more jobs being late move them to the far back of the queue. If it is important to get out that order it should be moved forward but leads in most cases to that additional jobs after will not meet the due time. The due time is the same time as when the transporter arrive which is late in the afternoon. According to the warehouse manager the sawing process is not a limitation in the warehouse but believe that in a near future it will become a tough bottleneck and by introducing the algorithm now it will give an opportunity for try and error approach to find the most suitable solution. The overall idea with introducing a schedule for the saw jobs are to provide the workers with time and deadlines to pick the remaining goods of the orders and pick orders that do not have any cutting requirements in them.

When the algorithm is implemented and running it should provide the workers with enough time in the afternoon to pick all material that should be pick the following day and queue it up for the saw. The following day the first arriving worker can just start the saws and then start with the normal work. This fact makes the second approach more appealing thus the first job in the morning will take long time and the worker will have time to pick the remaining goods of the order and check email and other information that might been added since yesterday. Also, all large order would be packed first so if something happens during the day the worker only have smaller orders to pick if it gets stressful in the afternoon.

The algorithm will only add value if the workers change their routines and follows the new schedule and that everybody is in agreement with the new way of planing the day. By introducing clear roles in the warehouse the work should run smoother and with less interruptions. The role could be responsibility for the saws, water jet responsible, one role for the the green saw, equal with picking goods from the FPA that needs to be cut, and let one worker have a free roll.

Another additional feature that would facilitate the picking work is to add a function that checked if any orders during the day consists of the same SKU. This would let the workers only visit one inventory position once every day and would decrease the double handling. This sort of picking is called batch picking and is proven effective. To implement this future the algorithm need to go through all order for the day and match the material to each other. An even more advanced solution would be, at least for the FPA, to check if material from different orders are stored close together and are in small quantities the worker could collect all these material in the same picking line and then sort them to their different orders at the

pack station. This is another type of batch picking that is effective. The batch picking process will require a larger packing station to easier keep the orders separated, and in the next implementation one of the side effects are a larger packing station so batch picking is spot on. Figure 4.13 shows this solutions PRT.

4.7.3 Installation of new rack(s) for incoming and outgoing goods

This solution arise from that the management is unhappy with how messy the warehouse is due to that there are goods stored on the floor all around the warehouse. From observations it is clear that this issue leads to double handling which is an Undesirable Effect. From the observations it were quite clear why this were a problem the warehouse prioritized picking and had no dedicated area for arriving goods or outgoing orders. The warehouse do have a small rack central in the warehouse next to the packing station that is holding all packaging material. This rack is small and weak today but it is a great spot for an unloading rack. The solution here requires that the weak rack gets replaced by a new rack that is twice as wide, much higher and stronger.

The new rack is not hard to install it is just to change it but for it to make sense and add value to the system it is important to plan how to utilize the rack. The new rack need to be divided into different areas to meet the expectations of the rack. The rack should at least hold packaging material and arriving goods and maybe as well large outgoing goods. When packing the worker pick their packaging material by hand and to store this material in the bottom would be natural. To reduce the walking distance for retrieving the material all packaging material should be located so it can be grab from the knuckle of the rack. Today the packaging material fits into three shelfs today the warehouse have choose to have the plastic sheets for packaging on the floor next to the scale. That space could be used in a more efficient way so to clear it the sheets will be moved into the bottom shelf in the new rack. This results in that nine out of twelve meters on the bottom shelf and six out of twelve meters on shelf number two and three would be occupied by packaging material. Depending on how high every shelf need to be the rack could hold between six and nine shelfs which means there will be plenty of space to store other material in the rack.

The remaining space in the rack should primary go to store arriving goods when the warehouse do not have time to store it at its actually position, as a temporary storage. At the same time outgoing goods, or at least

long ones, that are waiting for its delivery have no good space to be stored at the moment. The new rack offers a lot of space and the most efficient way to use it would be to store arrived goods on the last, furthest from where the trucks drive in, six meters. Almost no arriving goods are longer than six meter. The remaining shelfs over the packaging material could host space for the outgoing goods. When moving the packaging sheets to the new rack a three meter long floor space is revealed. This space would be great to use for an additional rack. This rack should be three meter wide and strong with 150 cm depth. Here it would be possible to store all outgoing parcels, which have to be less than three meters long. This brings the possibility to store only over three meters orders in the large new rack.

The average parcel is small and can be carried by hands and the delivery guys retrieve them by them self which means the parcel needs to be stored on low level for easy be accessibility. Harald Pihl uses two standard delivery companies for parcels which makes it natural to make two dedicated areas in the rack for their orders. The best idea is to put two one and a half meter wide boxes on the floor where parcels going with the standard companies can be put. Over the boxes it should be a shelf designed as a bench where the odd orders can be placed. If this rack is built high the remaining space could be used to store titanium sheets due to that the existing rack for that is on its way to get overfilled.

By introducing these new racks the result should be a cleaner warehouse that will result in less double handling while picking and increased throughput. The second result should be that resources, such as scale and pack benches, should be kept free from goods, if the workers follow the strategy to store these goods at their dedicated areas.

Figure 4.14 show the PRT for this solution.

Now the Prerequisite Trees are finished and if they are followed all possible obstacles should be overcome. The next step is to create a implementation plan which will be based on this section in more detail will state what need to be done.

4.8 Action Plan: Transition Tree

The only thing left before the new system can be put into action is to come up with action plans for the implementations and by that give the second

part of the answer to the question How to cause the change? To do this the fifth and last tool of the Thinking Process will be employed, this tool is called the Transition Tree. The action plan will combine situation from the Current Reality Tree with action that need to be done to get to the Future Reality Tree and the action will be based on the objectives from the Prerequisite Tree. The implementation work for the three solutions are individual and therefore each of them will get their own transitition tree.

4.8.1 Introducing Forward Picking Area

In the current system rack B consist of nine levels and on each level there are 36 positions, these positions today hold a whole batch of a SKU and by that the routine for the workers are to pick from rack B no matter how large quantity that is requested by the order. Exceptions from this is that sometime the purchaser buy extremely large orders of a material and by that it does not fit into one position in rack B and the warehouse is forced to keep the remaining part of the batch in the larger racks.

In the future rack B should work as a FPA for the warehouse and have increased number of positions. A new strategy regarding the picking process should be establish and introduced that says that only quantities that can be carried by hand from one visit should be picked from the FPA if the order is larger than that the worker should pick from the bulk area. Following section will explain how the warehouse should implement to move from the situation today to the future desirable situation.

The first thing to do is to find a way to be able to reduce the size of todays trays which today are 25 cm wide and in the FPA they should be half that size in average. That will bring two effects; one the rack will get more positions which means more different SKUs can fit into the FPA and no goods need to share one tray as it is today. Two it will be natural to store less than whole batches in rack B and that is the idea with a FPA, to have the right amount stored for easy picking and then store the bulk somewhere else. The FPA are going to hold many different types of goods and the greatest different between them are their radius this means if all trays are split in half the amount of material that fit will for some SKUs be overwhelming and for other it will be to little for the demand between two replenishments. Therefore different types of trays are needed and for the thinnest SKUs the warehouse can use paper tubes with a suitable radius this will offer the opportunity to store three or four different SKUs in on of todays trays but still be separated from each other so the picking work can run smoothly. For most SKUs in the FPA half the size of todays compart-

ments will provide a good amount of space to store the right amount. To split the trays in middle seems easy enough but it has to be done proper so it can ensure quality in the rack. The best idea is to replace todays metal boxes that todays trays are and put in metal boxes that are half the size at the same time it would be preferable if the hight of the walls on the boxes where increased. This feature will prevent goods to fall over to the neighbor's tray and allow more goods to be stored in the trays when a situation calls for that. For those large goods being stored in the FPA the trays can be the same size as today to lower the amount of work with redesigning rack B.

The next phase is to change the picking policy which means breaking the routine of today. To make a FPA as efficient as possible is to only visit it once per order which in Harald Pihl's environment means that the worker should only pick from there if he can carry the whole quantity of one SKU of the order by hand. From observations it is clear that most picks from the existing B rack are small and can be carried by hand. It was observed that it sometimes happened that the worker picked up a forklift drove it to the rack and then picked out the desired quantity put that on the forks and drove to the scale and then to the packing station. Other times it was observed that a worker pick as much as he could carried it to the scale and then went back to the tray to pick more, some orders required the worker to visit the same tray more than five times. The future system want the workers to pick up a forklift but drive to the bulk area pick the bulk box and then drive to the scale and packing station. This strategy will both decrease transport and dead heading as well as decreasing handling of goods per pick. This change is hard to implement in a warehouse due to that people like to do what the are used to do and in this case it might seems as it is more job to pick up a box from the bulk area. To get the change working the best thing to do is to make the workers understand the benefits of the new system. That can be done in a few different ways, combing a few of these is the best way to go. For Harald Pihl's warehouse the change work should start with a seminar where the theory first is explained and examples are shown from other cases where this have work both in environments that are similar to Harald Pihl's and totally different to prove the positive effects. Another important fact to communicate is that picking normally answer for 50 % of the activities in a warehouse and that transport represent 55 % of the picking process and that transport never bring any value to the warehouse. When the warehouse team understand this, mappings can be executed. Mapping means that travel distances and picking times are measured when employing first the old routines and later the new strategy. This will show the improvements and hopefully make the workers understand that the new system is actually more effective and efficient.

The last step is on paper pretty easy but in reality quite hard and it is where to put the bulk area. There are two different ways to find and allocated space for the bulk area in the warehouse. One of the suggestions can be implemented in two different ways. The first one is to clean and organize the larger racks so that all goods are stored in standard boxes this should create free space in the racks. Then all bulk boxes are stored behind goods that are only stored at the larger racks due to that the bulk boxes are going to be visit rarely for picking and when it is time to replenish. The second one is to spare a part of the warehouse to be a bulk area. If the same approach of cleaning, organize and standardized are taken the free space can be allocated in one rack and that could be the bulk area. Another approach is to redesign some part of the warehouse and put in a new strong bulk racks. There are two areas in the warehouse that are suitable for this, the first location is where the pallet rack is and the second is where the six meter metal sheets are located today. The warehouse manager says that they rarely uses the six meter metal sheets and that he would like to remove them from the warehouse. Based on that the they should move the sheets and install a new rack there creating two new aisles where one should work as the bulk area. Figure 4.15 reveals the TT for this implementation.

4.8.2 Introduction of an order sorting algorithm

This solution will not affect any physical work in the warehouse while being designed but when it is done and implemented it should change and update a few routines in the warehouse. The desirable effect of this solution is to facilitate the work in the warehouse and make it easier to plan their day. Today the orders are only sorted after due date, the time and date they are suppose to be shipped, in addition that the manager in the warehouse tries to identify which orders that will employ most resources or will take extra time to put together. The problem is that Harald Pihl offers their customer to order before noon and then the order will be shipped the same afternoon which results in that orders that need to be packed the same day arrive all morning. This makes it hard to update the order picking list and later arrived orders are usually put in the end of today's picking list leading to that orders that requires a lot of work are not identified and makes the end of the day really stressful. This result in that other activities such as storing new goods suffers and falls behind. It is easy that the manager falls into routines and miss to sort orders in a way that would facilitate the picking process such as batch picking.

The future system should employ an automatic order sorting algorithm connected to the new system, that will be introduced with the hand held devices. The algorithm's job is to sort orders after the time they will require in the saw, if they need to be cut, it will identify if the same SKU is going to be send with different orders and if during a picking line the worker could pick up material for another order. With other words creating a new queue system for the saws and introduce batch picking in the warehouse. For this to happen a few things have to be made and what exactly will be explained in the following section.

Firstly an approach need to be agreed upon and there are two different to choose between. The first one pushes through as many orders as possible from the start of the day meaning the picking list would tell the workers to start with small orders that will go fast to pick, cut and pack. Orders fitting that description contains of one small SKU that goes fast to cut. The other one is the opposite and accelerate the number of orders being packed per time unit throughout the day. Meaning start with orders that contains of many SKUs and have one or more SKUs that requires long time in the saw. This approach provides the worker with time to either pick other material that should be cut after and put them in a queue to the saw or pick the rest of the order and other orders during the time the material getting cut. Customers not always require that their order get sent the same day as they do the order and this makes up for an opportunity for the algorithm to tell workers which orders that should be processed during the night and that they could build the queue the day before. This would let the worker that arrive first to the warehouse in the morning to just start the saw without needing to look at any orders or pick any goods. One feature that both approaches should employ is that the first job that want meet its due time will be moved last in the picking list to not delay other jobs.

When one approach is agreed upon the actual work start to write a program that can execute the desirable activities. According to Harald Pihl's IT manager and their programer it is easy to retrieve information from their system where the orders are put together. The company are as known implementing a barcode system and hand held devices and to make that change effective the programmer are writing a new side program that will execute various tasks. The algorithm could be a part of the side program or be its own side program and with help of the programmer it would not be to hard to implement it. Resulting in that the picking list would be feed to the hand held devices and could be updated during the day automatically. The management has informed that the side program that the programmer is building today will contain a feature that will look into all orders to find if

the same material is required in more than one order to let the workers only visit one position once every day. This feature would be great to implement to the order sorting algorithm to enable batch picking.

The employees in the warehouse are used to sort the orders themselves, resulting in that they could look if the saws are free and pick an order that need to be cut but sometimes it results in that a worker choose a easy picked order and misses the opportunity to load the saw for example. Today they only pick one order at the time, exception is made when the saw is processing a long job and it is natural to pick other orders during the time. When introducing the new order sorting system it is important to inform the employees. They should understand why the new system is used and what they need to change in their work, it will be more to keep track on when picking more than one order at the time even though the barcoding system will facilitate this a lot. To inform and make the workers understand a smaller seminar can be held where they are first informed and then the changes are discussed. Figure 4.16 shows the implementation plan.

4.8.3 Installation of new rack(s) for incoming and outgoing goods

The implementation of this solution will require both physical work as well as change of strategy. Today arriving goods are put aside when it arrive due to that workers prioritize picking and that the storing process is time consuming. Unfortunately there is no determined area to put aside the arriving goods so they get placed where the employee finds the space which many times are good for the moment but pretty soon the SKU is in the way for someone else and leads to double handling and longer picking times. A similar problem is caused by that the areas that are used to store outgoing goods are bad and that the workers leave packed goods on the scales and pack benches.

In the future the warehouse will have dedicated areas for both arriving goods and outgoing orders in form of racks. These racks are two new racks that will be put where the warehouse today store packaging material. The package material storing is utilizing the space very bad and with the new racks numerous of new positions will be generated for the warehouse.

To get the new racks in place is a pretty straight forward process now when measures are done. The first step is to throw out the old rack that stands next to the packing station, move the trash containers that is situated next to the rack and install the new twelve meter strong rack and

supply it with as many levels as possible. For the second one the packaging material that are placed there today is moved into the big new rack and a three meter strong rack can be placed there.

For the warehouse to reduce there double handling and picking time and by that increase the throughput the employees need to understand the importance to use the new racks for arriving goods and and outgoing orders which is easiest passed to them through a seminar. The seminar should explain the how large the negative effect on the throughput is because of double handling but also how much more efficient it will be when both workers and delivery guys know exactly where all goods should be and are stored. As a decoy they can use the space that is over to what ever they want or otherwise an analysis will be made to investigate if that space can be used for bulk boxes. Figure 4.17 is the TT for this implementation.

4.9 Continuous improvements

When Harald Pihl has gone through all steps of the improvements work and everything is set up and implemented it is time to continue to improve. Harald Pihl believes and hopes that the increase in sales will continue and the improvements made will not be enough after a while. For the warehouse to be able to maintain the service level while the sales continue to increase further improvements are needed in the future, here is few things that is believed should be made in the future.

The first step is to make an ABC-analysis of first the stock in the FPA to make the picking there as smooth as possible. While doing the ABC-analysis the company should continue with making it for the whole warehouse which would lead to that all SKUs can be positioned for the picking time to decrease and the throughput increase.

The purchase department of Harald Pihl have low strategy of when it comes to ordering new goods. The department have set up a few reorder points but often the order size and when to purchase is determine by the price. Alloys shift prices after availability and demand so sometime the purchaser by large order just because the price is low but the results are tied up capital and that it takes up valuable space. The second argument is going to be particular bad in the future when the number and amount of each SKU increase due to higher sales. To prevent this optimal reorder points and order sizes should be put in place.

Today Harald Pihl offer their customers the possibility to get their goods shipped the same day as the buy it. Fast deliveries is clearly a factor in their success in growing but the question is if it is the key factor. During a day new order arrives that have to be picked and shipped the same day causing the work to be interrupted and hard to plan, and even when the order sorting algorithm is in place it will create problems for the employees. Harald Pihl should evaluate by survey their customers if they really need these fast deliveries as standard. If not they should change this policy so that the warehouse operational work can be planned better and than offer an express delivery service. This would lead to that the operational work could be carried out more effective and efficient and at the same time bring in more money due to the more expensive express orders.

In the near future it is believed that the resources and in particular the saws will be a constraint again and before that happens an evaluation of the old existing machines should be done and at the same time an investigation of the possibility to purchase additional resources or change old and slow machines to new machines. This is not an operational level decision but it will facilitate and improve the picking work to increase the throughput.

These propositions are aligned with the approach of ToC that says that a company should start with increasing the throughput followed by decreasing the inventory and last affect their operational expensive.

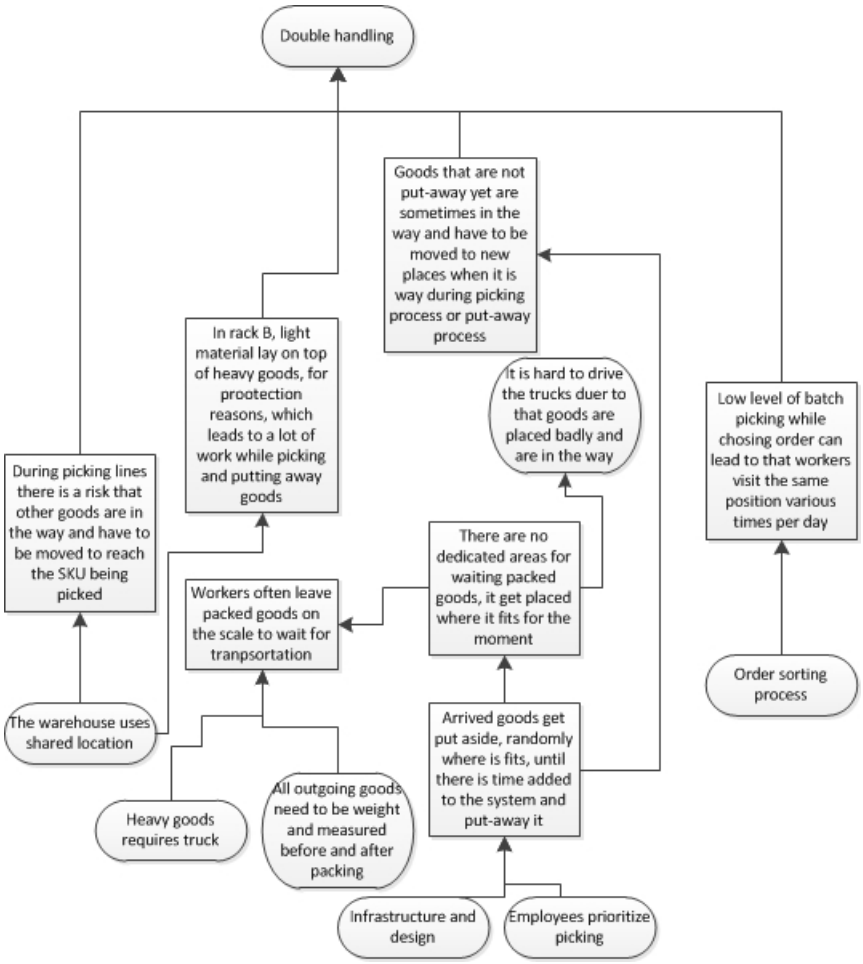

Figure 4.1: CRT for Double handling

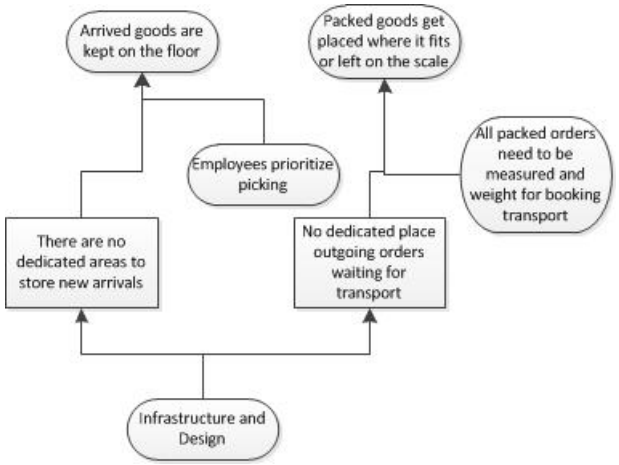

Figure 4.2: CRT for Incoming and Outgoing goods

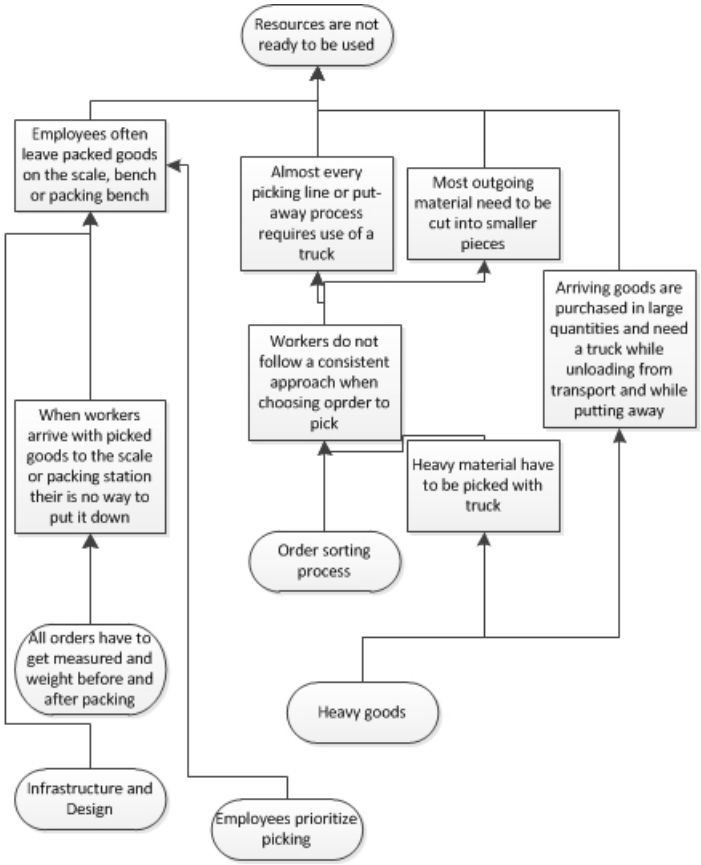

Figure 4.3: CRT for Resources not ready

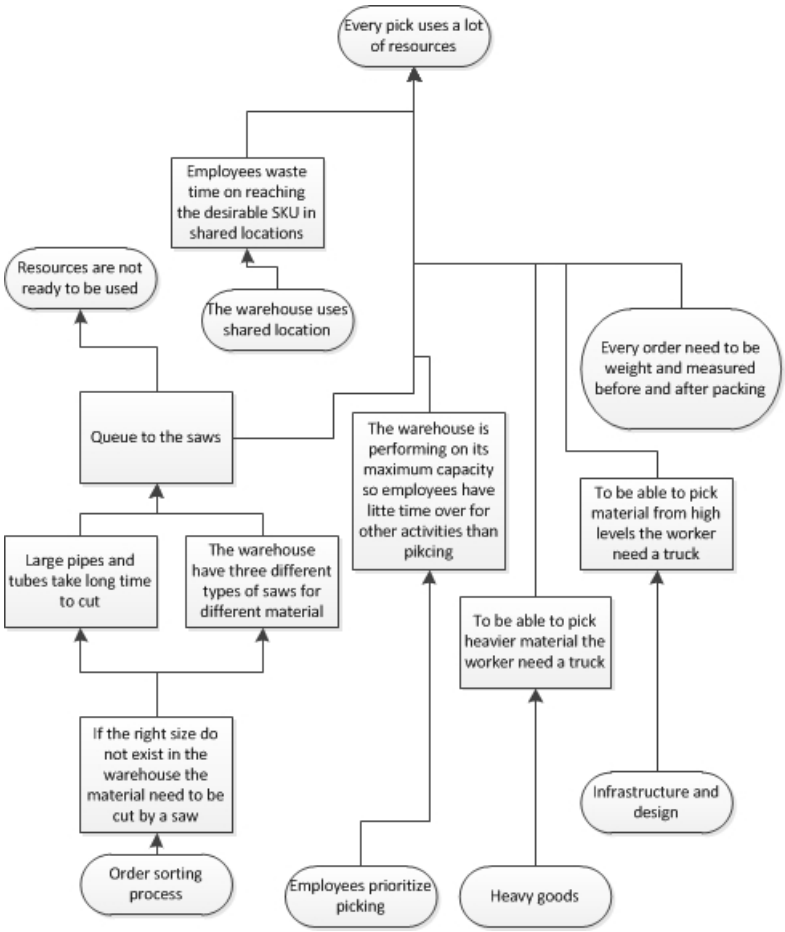

Figure 4.4: CRT for every pick requires a to of resources

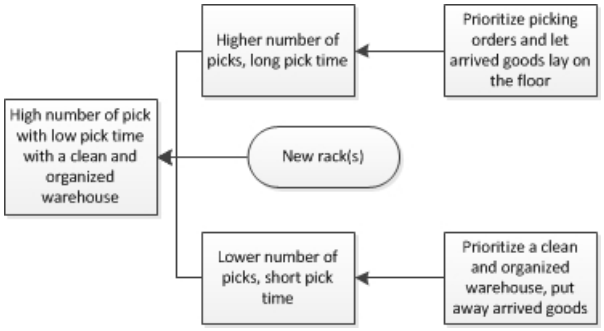

Figure 4.5: EC for new rack

Figure 4.6: B rack

Figure 4.7: An example of how it looks in rack B

Figure 4.8: An example of how it looks in rack B

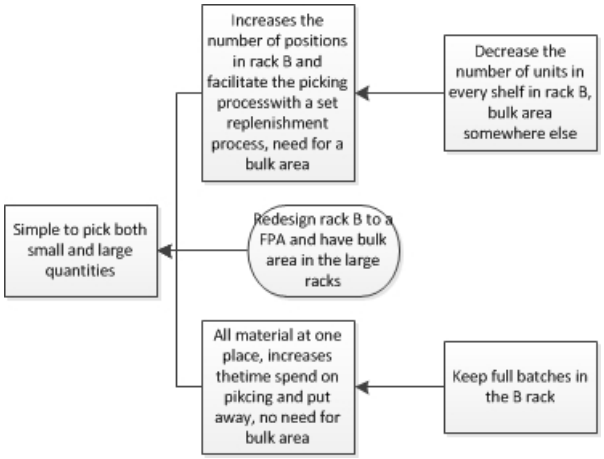

Figure 4.9: EC for FPA

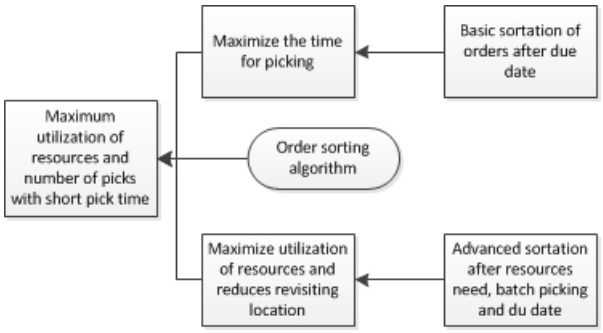

Figure 4.10: EC for order sorting algorithm

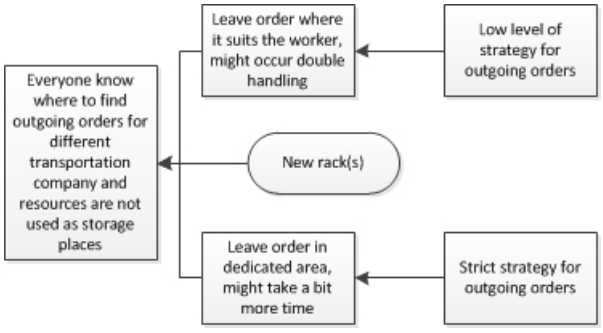

Figure 4.11: EC for new racks

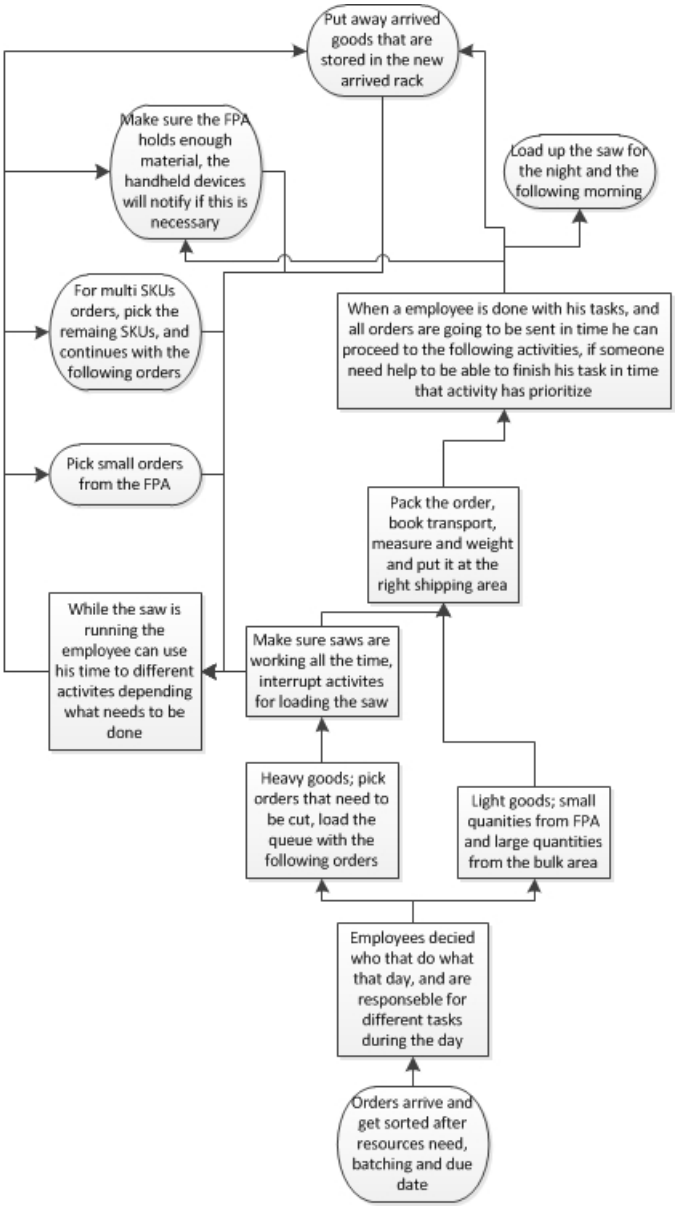

Figure 4.12: Future Reality Tree

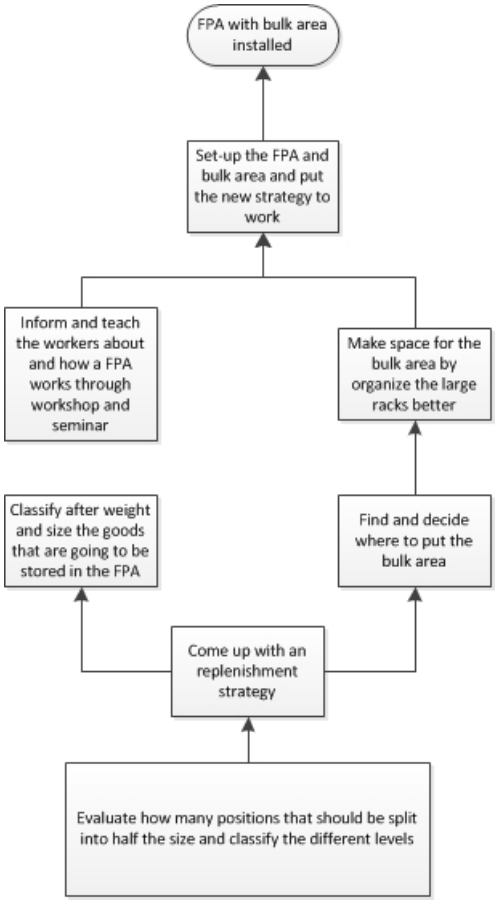

Figure 4.13: PRT for FPA

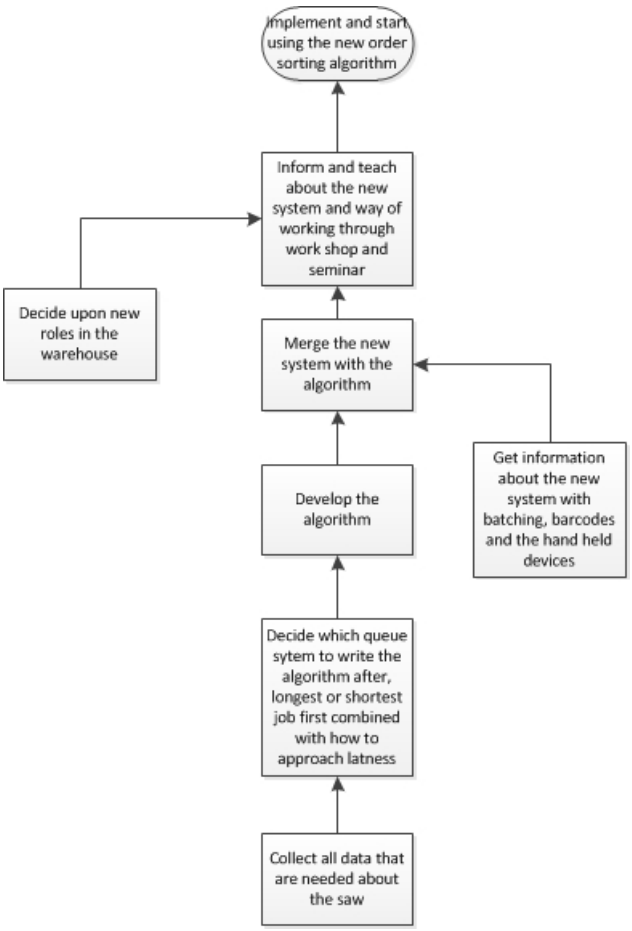

Figure 4.14: PRT for Order sorting algorithm

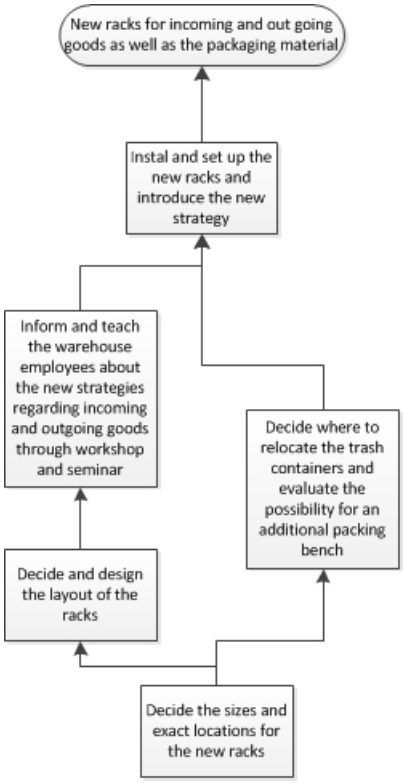

Figure 4.15: PRT for new Racks

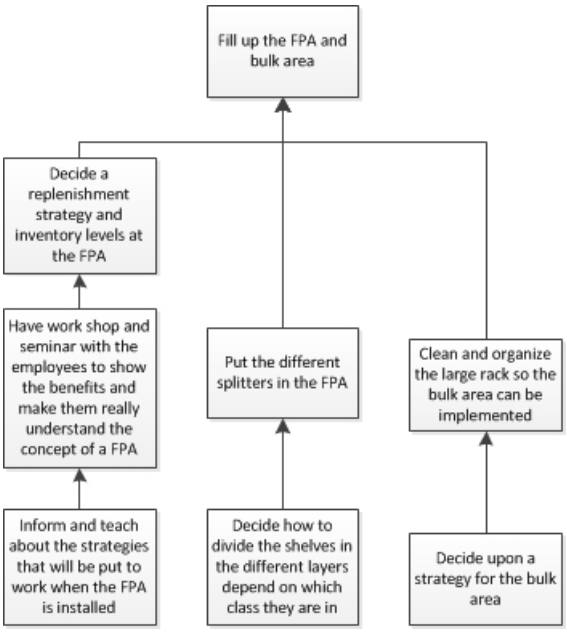

Figure 4.16: TT for FPA

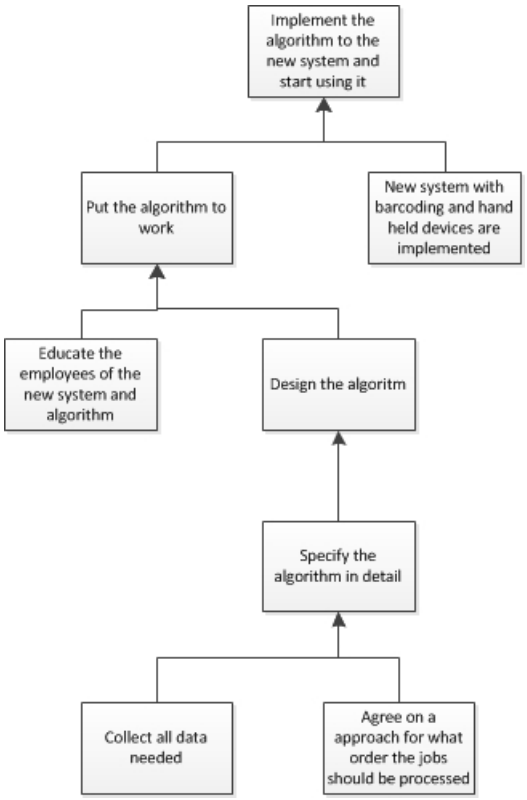

Figure 4.17: TT for order sorting algorithm

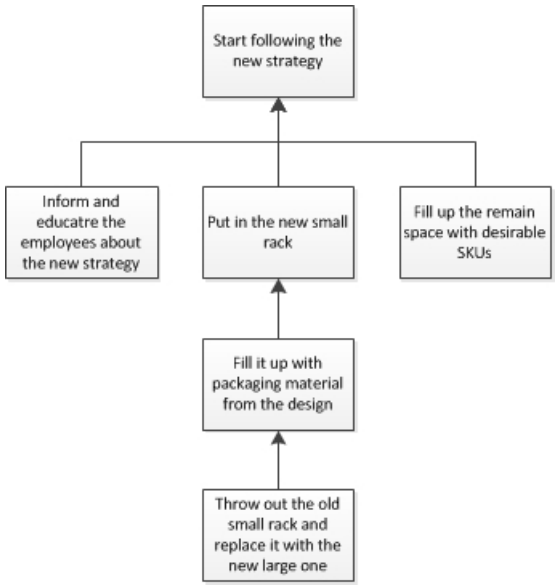

Figure 4.18: TT for new Racks

Chapter 5
Conclusion

This chapter will present the conclusions of studying and learning process of ToC and reveal the results of employing Theory of Constraints in a warehouse operation. It will also give answers the request questions and present the result from the case study. In the end this chapter will summarize the contributions and give suggestion for future work.

5.1 Summary

In this section the conclusions about underlaying theory that was used in the thesis will be presented followed by the conclusion of the approach and last the results will be presented.

5.1.1 Underlaying Theory

This master thesis is based in two areas of theory the environment that the project is performed, warehouse operation theory and the Theory of Constraints that were tested if it was possible to employ in the warehouse operational environment.

Warehouse operational theory is an old and widely explored area and it is based on four simple tasks receiving, storage, picking and shipping. These four activities were from the start all a warehouse did and the main purpose where to store material, finish goods or spare parts. Since a time ago after that production had been optimized and costs had been cut as much as possible the focus on how to save money and get more profit moved from production to storage. The warehouse got a more central role in companies and strategies how to get an effective, efficient and qualitative warehouse started to develop. Pretty fast researchers and managers came to the conclusion that it was hard to optimize warehouses without including suppliers and later also customers. All this have led to a huge development of strategies and approaches that can be undertaken for warehouses for both increase

performance in the warehouse and also integration of other parts of the supply chain such as, suppliers, customers and production plants.

With all these strategies and approaches that are available today and proven that they work every warehouse should be state of the art and world class. Unfortunately companies still struggle with their warehouses in form of that they cost to much and does not add enough value to the finished product. One reason for this is that today managers start to look and read about at different strategies and get lost when they should choose which strategy to implement and the result of this is often that they do not do anything or the implementation is done halfheartedly and causes more problem than it solved. It seems like what managers need to be able to determine what to do to improve their warehouse is a tool that could help them realize which strategies to choose and which to ignore.

Theory of Constraints is a management philosophy that should be employed for improvement work. It can be employed for improvement work in almost any business area and can handle both physical problems as well as policy problems. ToC was from the beginning a timetable software that improved the outcome for production plants and have form there developed to be a more sophisticated theory that can be used for much more than just planing production. The fact that ToC view the undertaken problem as a system and than focusing on to improve the system and not only solve the problem make it suitable for more business areas than just production. Another reason for ToC to be a good fit for almost any problem or improvement work comes from its development, the major development steps that ToC has taken is firstly the introduction of the focusing steps. The focusing steps are a straight forward approach that makes sure that the system improves. The second were the introduction of the Thinking Process, which consists of five Thinking Processes that are used as tools for identifying the core problems, solving them and than make an implementation plan for the changes.

The purpose with the thesis were to see if ToC could be employed to improve the operational work in a warehouse. Using ToC approach and tools to find which out of all strategies that exist in warehouse operational theory to implement to the improve the warehouse.

5.1.2 Research Approach

This section will provide conclusion about studying and employing the ToC was as well as how the approach and tools worked.

5.1.2.1 Study ToC

From studying ToC it was possible to conduct a guide to use ToC for new users that provides background, basics, approach and tools of Theory of Constraints. Even though the guide is narrowed down to provide the essential part that is needed to be understood to be able to follow the proceeding work in the case study. With the additional information given in the chapter frame of references it is believed that an over all picture of ToC is given. The goal for the guide and the frame of reference chapter was to conduct it so that a reader felt that he or she understood it and also could try it out on problems and with help of the case study warehouse manager should be able to employ it to improve the operational work.

5.1.2.2 Employing ToC

The result of employing ToC to create a more effective and efficient warehouse on an operational level were over the expectations. By following the ToC the work run smooth from planning to executing to writing. Many times ToC turned ordinary exercises into fun activities due to that ToC continuously pushes the person using it to challenge his or her thinking and decisions. The challenging appeared in every part both approach and tools by that the decision made in one step is closely connected to the next step and if the wrong decision were made it will show directly. Just as ToC views everything as a system ToC itself is a system that cannot proceed with out every link being right, or at least not perform at its best. ToC state that the system that is being undertaken should be view from far away and that it is important to see the bigger picture and this fact is not to be forgotten because any time the project got stuck a step back was taken to look at the whole system and the solution appeared easy.

5.1.2.3 Approach

ToC's approach was really good and conventional to use when it was learnt. The approach was employed to all part of this thesis to really get familiar with it, starting with planing the project to develop observation and interview plans to execute the case study. The approach made sure that

the goal of the project or subproject were known at all time and that all actions made on the way strived to get closer to the goal. The approach do not let the performer move forward until the actually step is executed in a correct and accurate way to ensure that at all time the work is proceeded by improvements for the whole project and not just that step. There are many approaches that can be employed for projects what make ToC's approach special is that a constraint is identified and after that the system is subordinated to the constraint. Instead of directly try to fix the problem the smaller changes is made to exploit the constraint as much as possible to first improve the the system and than improve the link of the system. Other approacher may try to solve or remove problems with out letting the performer think about the consequences for the system.

By thinking of constraint as the future problem or challenge the approach can be employed. For example when constructing a interview guide you set up a goal in form of what information you want to get out of the interview. Than ask how you will retrieve this information in the interview, design questions that are believed to gather the information but also think about a back-up strategy if the person being interviewed is avoiding important information or do not understand the questions. By moving forward in the interview an understanding of the importance of follow-up question for more than just one situation is developed which prepare the the interviewer in a broad way and makes him o her ready for any situation. As seen with minor change and thinking out side the box and realize that a constraint can be what ever the performer want it to be the approach can be used everywhere.

5.1.2.4 Tools

ToC's tools were great assets for this project, both for planning and executing the thesis as well as the case study. Scheinkopf's [3] book was of great support when learning about the tools she has detailed explanations with various example for every tool and for each step in the creating process. The Thinking Process with its tools were employed from the start of the project both to plan the project and to get familiar with the tools. During the planning work the EC was used the most frequent and the goal was to employ it every time a problem arose. The FRT gave a good picture of the goal for the thesis and project and the Transition Tree were establish throughout the project, which could have been done entirely from the beginning to easier set up milestones and deadlines.

In the warehouse operational environment all tools were used. From observing the UDEs and the guidelines for creating a CRT lay a good foundation for observation plan. After the observations were done it was smooth to put together the CRT and even if it was hard the first day of using the CRT it did not take long before sufficient cause and necessary condition thinking were adapted and the trees came together and constraints revealed themselves. To make sure the CRT had pointed out the right constraints an additional observation were made and it confirmed the CRT. The Evaporating Cloud did solve the problems smoothly due to it forces its user to see the problem from two direction. For warehouse operations improvements work it seems as the conflict always are between the current situation and a situation that are more preferable where routines and underlying strategies have to change because both side have the same goal. The current situation is how things are performed today and due to that the study took place at operational level the hardest changes were to change how people work. To come up with solutions that do not only look at personal attacks for the employees some extra thoughts were needed to come up with suitable solutions. To proceed the FRT was created reviewed and presented to the company and they liked the solutions and how the system would work in the future. The FRT was the easiest process to execute and it might was that because by implementing the solutions the system gets, in theory, exactly like it is desired. The two following tools are harder than the FRT due to it is by them the current system can get to the desirable future system. The TT can be employed straight away if it is believed that the future system can be reached not to complicated if the feeling is that it will take a lot of work and it is complex to see how to get from the current to the future the PRT should be employed. In the case study both tools were employed to show how to use them even if they look a bit the same because the implementation were not that complex and exact details about the implementation were not available from the company. In the PRT the focus were to find why solutions would not work and than come up with ideas that overcame this obstacles then for the TT the focus is to ensure that the new solution do not causes something undesirable to happen.

Over all, by employing the ToC with its Thinking Process and the tools the analysis, solution and implementation plan were set together fast and smooth and the fact that everything is visualized all the time makes it easy to include all necessary elements to every new tree.

5.1.3 Result

The thesis has three research questions and they will be answered in this section.

How ToC can be employed in a warehouse operation to identify bottlenecks?
From the literature it is quite clear that the best way to use ToC in any environment is to follow the focusing step. When employing ToC to a warehouse operation no excuses not to follow the step should be done because as many other theories one of the first step is to identify what the problem is and in ToC case the problems are constraints. To identify constraints can sound pretty trivial but in reality it takes some time to identify them. By using the first Thinking Process tool, Current Reality Tree, the identification is facilitated and the last key to be a able to identifying the true constraints is that the performer have high level of knowledge of the system that is investigated. CRT tells its performer to list all Undesirable Effects in the system and the best thing to do is to collect enough data from interviews and observations to make sure that the right effects are found. When the UDEs are found the next step is to identify what actually causes these effects. To do this observations combined with creating the CRT are a good way to take. Especially in this part but overall when using ToC it is important to remember to view the bigger picture and have the system in mind and not single activities.

What tools and and techniques should be used to solve/reduce the identified bottlenecks?
By following the focusing steps of ToC the steps after identifying the constraints are about how to attack this constraints to improve the system, as mention it is not about solving problems it is about improving the system. First the approach tells its user to find a way to exploit the constraints as much as possible which in other words can be told as solve the problems. This is where a lot of managers get stuck if they do not use an improvements method or theory due to that they might have identified a problem in the warehouse and when they start to read about suitable solutions the get overwhelmed by all the different strategies and it is hard to tell which one to choose. By employing ToC and for this step the tool Evaporating Cloud the problem can be solved logical and the performer get a chance to challenge different solutions that from the start might have given the impression of solving the problem. By challenging the solutions the chanceses to find the right one increases.

In a system there is often more than one problem that causes the bottleneck and is not unusual that more than one constraint have to be solved or exploit at the same time this can cause problems in different ways. The first one is that the performer do not know how the different solutions will affect the system and what the outcome will be and the second is that change is often met with residence. Both these problem will be solved by continue follow the approach. The next step is to subordinate all activities to the solved constraints, to create the best possible environments for the former constraints to perform in. To realize how to subordinate the system the third tool Future Reality Tree should be used. It guides its user to create a map over the future system, how it will look and perform in the future. The tree will help the performer to understand how the different solutions will affect the system and each other. A finished FRT can be understood by almost anyone and due to that it is a powerful tool to use to overcome residence to change in an organization.

What future plan can be develop based on ToC?
To find bottlenecks and solve them are hard tasks but an even harder task is to implement these solutions. The next step in the approach are to elevate the constraints and make sure that the implementation can be done efficient. It is important to think before beginning with the implementation work. It is not hard to get blinded by the generated solutions but by employing the forth tool of the Thinking Process and it is called Prerequisite Tree. Its main mission is to identify obstacles that could arise by implementing the solutions. The obstacles can be booth hard or soft, hard meaning physical and soft meaning policies or existing strategies. The tree also give the performer the chance to come up with ways to overcome these obstacles to ensure a smooth implementation. The PRT is not an action plan to implement but more a pre-action plan to make sure that the solutions will improve the system and not just create new problems.

To implement new solutions to a system are expensive and can be problematic. To reduce the chance of of failures it is important to think about how to execute the implementation both how and in what order it should be done then realize how much resources and time that will need to be spent on the implementation. The last step that might not be as obvious at this point of the process is to make sure that the implementations do not causes new Undesirable Effect to rise. The Thinking Process last tool is called Transition Tree and is suppose to be employed when it is time to come up with a action plan for the implementations. Its general strength is that it pushes the performer to challenge the implementation to make sure that if there will be new UDEs they will be found. When the UDEs are identified the

TT tells its performer to come up with ways to block these effects to arise. When the implementations are done the focusing step says that it is time to go back to the beginning and start over all again for continues improvement.

The research question have been answered by employing the ToC to a case study at Harald Pihl AB who have a warehouse. The warehouse have had low level of strategies and for the recent years their inventory and throughput have increased a lot due to that the company have increased their market share and sale. Harald Pihl AB was in need of some improvements in the warehouse and thats why this thesis project was called upon. By using ToC the warehouse bottleneck and constraints were identified, they were:

- Infrastructure and Design
- How orders were sorted for picking

By employing all the tools an future action plan were creating for three changes in the warehouse that will enable that the warehouse maintain the service level, ship all orders that have arrived before noon the same day, when the number of orders per year increase to 7500. The first solution to implement is to install two new racks for packaging material, incoming and outgoing goods and with that change strategy regarding the handle of incoming and outgoing goods. The second step is to redesign rack B and turn it into a Forward Picking Area and the last step is to write a more advanced order sorting algorithm that will facilitate planing the day and increase the utilization of resources. The case study ends with recommendations of what should be investigated after these implementation have been done.

5.2 Contributions

The aim of the thesis were to contribute to the warehouse operational theory by trying to find a method to improve the operational work in a warehouse. The method tried for this were the theory of constraints. The test was carried out by providing first a guide of how to use all different aspects of ToC and than employing it to a warehouse operation through a case study. The case study revealed that ToC was a good method to employ for improvements work in a warehouse operation. The thesis takes a trip through ToC's approach called the focusing steps and through that constraints were identified solutions generated and an advanced implementation plan were establish. From the approach of ToC it is clear that after all steps have been executed the performer is suppose to go back and start all over again to find

new constraints and solve them. By looping the focusing steps continuous improvement work can be done. The case study company had low level of strategies which provided an open environment where almost anything could be changed without creating conflicts with other existing strategies.

The solutions generated in the case study contribute to the literature on how a warehouse operation can with minor investments and existing resources can redesign activities, strategies and physical layout to improve the outcome of the warehouse. The conclusion here is that it is not always necessary to implement advanced and expensive solutions just because literature says it will increase the outcome radically. In some situations for example if a company have a lot of capital tied up and cannot make larges investment, the warehouse manger can find simpler but not because of that less effective and efficient solutions to implement and improve the operational work in the warehouse.

The contribution to ToC is that this thesis have confirmed and proved that Theory of Constraints was a philosophy that can be used in a wide range of business areas. The project shows that by adding two new steps to the five focusing steps, the steps being set up system's goal and introduce new performance measurements. The project is defined from the beginning and the performer new in every step what the goal is and how it going to be measured at the same time stakeholders, the board and management know what to expect and how they can measure if their expectations are met.

5.3 Future Research

The future researches presented here are based on this thesis and what would be good to continuous explore. The reason why ToC is employed for this thesis were to see if improvements work could be facilitated both by identification of problem and the solution selection process from existing solutions that are presented in literature with theory and strategies. For future work it would be interesting to compare ToC against similar methods and philosophies, from this thesis it is clear that it is a powerful method to use but without comparison it is impossible to tell how good it is. Another interesting field would be to use ToC for improvements work in a warehouse with high level of strategies and advanced solutions that would tell how powerful ToC is and show that it can be used in more advanced environments. A third approach would be to go multiple loops in the focusing steps to see if the approach for continues improvements works. These three

future research proposal should be good foundation for master thesis within logistics or warehousing.

5.4 Limitations

There are two main limitations in this project the first one is the environment the project were carried out in. ToC was employed to a warehouse operation to see if the philosophy could facilitate the improvements work. The case study is only performed at one company with low level of strategies. The low level of strategies resulted in that all constraints were physical problems and not strategies that needed to be changed. For the case ToC worked good and it should facilitate the improvements work for other warehouse operations but the process might differ due to that every warehouse is unique in with their strategies, the goods they store and the resources they have.

The second limitation is the way Theory of Constraints was used. First of all, ToC was learnt about especially for this project and without former experience there might be risk that ToC has not been used in the most efficient way or even in an incorrect way at some point. Another limitations of how ToC was used is that only one loop in the focusing steps was performed for the overall project which leads to that this thesis cannot say anything about continues improvements.

References

[1] Chou, Y-C., Lu, C-H. & Tang Y-Y., (2012), 'Identifying inventory problems in the aerospace industry using the theory of constraints', *International Journal of Production Research*, Vol. 50, No. 16, 4686-4698.

[2] Spector, Y, 2011. Theory of constraint methodology where the constraint is the business model, *International Journal of Production Research*, Vol. 49, No. 11, 3387Ð3394.

[3] Scheinkopf, L., (1999), '*Thinking for a change: Putting the TOC Thinking Processes to use*', Boca Raton, FL: APICS, St. Lucie Press.

[4] Goldratt, E.M. and Cox, J., (1984), '*The goal: A process of ongoing improvement*', Great Barrington, MA: North River Press.

[5] Ronen, B. & Spector, Y. (1992), 'Managing system constraints: a cost/utilization approach', *International Journal of Production Research*, Vol. 30, No. 9, 2045-2061.

[6] Reid, R., (2007), 'Applying the TOC five-step focusing process in the service sector: A banking subsystem', *Managing Service Quality*, Vol. 17 Iss: 2, pp.209 - 234.

[7] Neely, A., Gregory, M., Platts, K., (2005), 'Performance measurement system design: A literature review and research agenda', *International Journal of Operations & Production Management*, Vol. 25 Iss: 12 pp. 1228 - 1263.

[8] Bourne, M., Mills, J., Neely, A., Platts, K., (2003), 'Implementing performance measurement systems: a literature review', *International Journal of Business Performance Management*, Vol. 5, No. 1, 1-24

[9] Höst, M., Regnell, B., Runesson, P., (2006), *Att genomföra examensarbete* Studentieratur AB, Lund.

[10] Kudo, Y., Murai, T., Akama, S., (2009), 'A granularity-based framework of deduction, induction, and abduction', *International Journal of Approximate Reasoning*, Vol. 50, No. 8, PP. 1215-1226

[11] Rahman, S., (2002), 'The theory of constraints' Thinking Process approach to developing strategies in supply chains', *International Journal of Physical Distribution & Logistics Management* Vol. 32 Issue 10, PP. 809-828

[12] Wiliam Dettmer, H., (1997), '*Goldratt's Theory of Constraints: A Systems Approach to Continuous Improvement*', ASQC Quality Press, Milwaukee, WI.

[13] Watson, K.J., Blackstone, J.H., Gardiner, S.C., (2006), 'The evolution of a management philosophy: The theory of constrains', *Journal of Operations Management* Vol 25, PP. 387-402

[14] Bernardi de Souza, F., (2010), 'Theory of Constrains contributions to outbound logistics', *Management Research Review* Vol. 33, No. 7, PP. 663-700

[15] Rahman, S., (1998), 'Theory of constraints: A review of philosophy and its applications', *International Journal of Operations & Production Management* Vol. 18, No. 4, PP. 336-355

[16] Kim, S., (2008), 'The theory of constraints Thinking Process: retrospect and prospect', *nternational Journal of Operations & Production Management* Vol. 28, No. 2, pp. 155-184

[17] Gu, J., Goetschalckx, M., McGinnis, L.F., (2007), 'Research on warehouse operation: A comprehensive review', *European Journal of Operational Research* Vol. 177, PP. 1-21

[18] Bozer, Y.A., (1985), '*Optimizing throughput performance in designing order picking systems*', PhD thesis, Department of Industrial and Systems Engineering, Georgia Institute of Technology.

[19] de Koster, R., Le-Duc, T., Roodbergen, K.J., (2007), 'Design and control of warehouse order picking: A literature review', *European Journal of Operational Research* , Vol. 182, PP. 481-501

[20] Lambert, D.M., Stock, J.R., Ellram, L.M. (Eds.), 1998, Fundamentals of Logistics Management. McGraw-Hill, Singapore.

[21] Bartholdi, J.J., Hackman, S.T., (2008), '*Allocating space in a forward pick area of a distribution center for small parts*', School of Industrial

and Systems Engineering, Georgia Institute of Technology, Atlanta, GA, 30332-0205,

[22] KovĞcs, G., Spens, K.M., (2005), 'Abductive reasoning in logistics research', *International Journal of Physical Distribution & Logistics Management*, Vol. 35, No. 2, PP. 132-144

[23] Yin, R.K., (2002), '*Case study research: design and methods*', Sage Publications, Inc

[24] Fraelle, E.H., (2001),' *World-Class Warehousing and Material Handling*', R.R. Donnelly & Sons Company

[25] Rushton, A., Croucher, P., Baker, P., (2006), '*The handbook of Logistics and Distribution Management, 3rd edition*' Bell & Bain

[26] Yu, M-C., (2011), 'Multi-criteria ABC analysis using artificial-intelligence-based classification techniques', *Expert Systems with Applications*, Vol. 38 No. 4 PP. 3416-3421

Appendix A

Interviews and Observations

In the appendix the interviews made and the observation plans that were used to collect data in the warehouse are presented.

A.1 Interviews

Interview with Harald Pihl AB's CEO and warehouse manager with their combined answers. The objective was to collect information about the warehouse, what the CEO and management expects of the warehouse. This interview with some further discussion were the foundation of this thesis.

- **Primary Question**
- Background
    1. Tell me how the warehouse performs today?
    2. How many works in the warehouse?
    3. What is your desired service level? How did you choose your service level?
    4. Do you fulfill this service level? Why not? When?
- Problem
    1. What is the problem today?
    2. Where do you think the problem occur from? Inventory levels? Resources? Operation?

3. What area gets most effected?

- Thesis mission
  1. What would you like to do about it?
  2. We need to define effective? What do you mean by that? From what aspect do you mean more effective? Service level? Lead-time? Resource utilization?
  3. What is the most important part to fulfill? Where should we start?

- **Secondary question**
- Strategy
  1. How do the warehouse operate?
  2. Is the warehouse following any strategic or tactical level framework or is that set on operational level?
  3. Who decide the layout and placement of items?
  4. How are the inventory levels set? Who purchase? Does this person have any insight in inventory levels?

- Workflow
  1. How many orders do the warehouse process per day?
  2. What is the average size of an order? Amount of different SKUs?
  3. What service level do you have today?
  4. Do you have any performance measurement today?

Interview made with CEO and the manager in the Warehouse and their combined answer regarding an appropriate goal for the project.

1. What is a good goal, according to you, for the warehouse?

2. How should the performance measurement be designed?

3. What do you experience as constraints?

4. What make these activities constraints?

5. What activity are you spending most time with every day?

6. What activity has the most waste involved?

7. Any ideas for changes?

Harald Pihl AB is a quite small company where most of the employees are working with sales. For this thesis most of the contact and discussion have been held with the companies CEO and with the warehouse employees, this discussions were not classified as interviews and were instead classified as secondary data about the company, and have been taken under consideration through the project.

A.2 Observation plan

A lot of observations were made in this project. The main observations were made to identify Undesirable Effects, how the warehouse performed, identifying flows and how actives and process were executed. Some smaller observations were made to make sure that the right information were gathered or to confirmed that an solution could work. The observation plans were based on a general plan and than it was filled in for each flow, process and activity. The information gathered from the observation was noted by hand so the observation plan described here is the predetermined points to look after and investigate.

- What is being observed? Flow? Activity? Process?

- What steps is included?
- Is the order of step necessary to be carried out in one way or can it be done in different ways?
- What are value-adding and what are not value-adding?
- What are the desirable and Undesirable Effects?
- Are there a strategy for how the task is performed?
- If there is no strategy how does the execution of the task differ between the employees?
- Do any of the employees perform the task better than someone else?
- How is this task linked to other tasks?
- How much time is spend on the different steps of the tasks?
- Is the time spent justified if not why?
- How often does the Undesirable Effects occur?
- How much resources are used during the task?
- Are all resources just justified for the task?
- General disruption in the tasks?
- How much transport and dead-heading does the task consist of?
- Are there steps in the task that is world-class performed?
- Are there steps in the task that seems unnecessary?