CHALMERS
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Clarification of Engineering Roles in a Protype Realisation Process Saves Cost and Leadtime

A process analysis project using the Lean Six Sigma methodology

Bachelor's thesis in the mechanical engineering program

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PREFACE

This bachelor thesis was performed at an automotive developing company, during the fall of 2017. This project comprises 15 credits and is the final stage of the Mechanical Engineer program, 180 credits, at Chalmers University of Technology.

A special thanks to Alexander Wingfors and Ellinor Lundgren at The Company and Peter Hammersberg, senior lecturer at CTH, for all the support throughout the project.

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Hanna Bengtsson & Desiree Nilsson

Gothenburg, December 2017

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ABSTRACT

This project was conducted at a relatively new enterprise in the automotive industry. The goal was to find the reason for cost variations when building boxcars. This was a process analysing project conducted using the Lean Six Sigma methodology. First thing was to map the process, since the current boxcar process was undefined and therefore unclear, even for the employees. The boxcar process has many process steps, involving handovers to different functions, a long lead time and much manual labour. Many boxcar parts are subject to deviation during the process and needs to be re-ordered, which causes time delay and excessive costs. When working with this project, it was early discovered that important basic statistics that should be easy to find, was not. Today it is hard to keep track of where the money goes since several Purchase Requisitions (PR's) are used for the same boxcar and sometimes the same PR is used for different boxcars. To be able to keep track of the cost for each boxcar, a suggested action is to only make one PR for each boxcar status. The costs should be tracked and visualized in, for example, a control chart. The quality of the collected data for this project affects the validity of the results. Available statistics for example boxcar costs, reasons for deviations and number of deviations has a low precision. This report relies on a correlation between number of deviations and total cost and between lead time and total cost when building boxcars. This statement has not been proved, but should be further investigated. Working with the project, it became clear that one of the departments that supply input for the process, are not aware of their importance and involvement in the boxcar process. This means that working with the boxcar process is extra work for the engineers at this department. Therefor another suggestion of improvement is to start a discussion whether it should be a part of the engineers' job description.

Keywords: boxcar, Lean Six Sigma, deviation, process

TABLE OF CONTENTS

ABBREVATIONS

BOM - Bill of Materials
ECU - Electronic Control Unit
EE - Electrical Validation
HW&B - Hardware & Build
MBOM - Master Bill of Material (List of parts for complete car)
MP&L - Material Planning & Logistics
MRD - Material Readiness Date
NCM - Node Check-up Meeting
PBOM -Purchasing Bill of Material
PFMEA – Process Failure Modes and Effect Analysis
PRC - Part Change Request
PSS – Product System Structure
RPN - Risk Priority Number
RTY – Rolled Throughput Yield
PR - Purchase Requisition
TC - Team Center (Electronic data System)

1 INTRODUCTION

This is a project which aims to analyse the boxcar process in an automotive developing company. The aim is to find the reason for cost variations when building boxcars, by using the Lean Six Sigma methodology.

1.1 Background

This project is to be conducted for a relatively new enterprise in the automotive industry, from now on referred to as "The Company". The Company was founded in 2013, with only seven employees and has rapidly expanded, currently providing jobs for 2200 employees. The Company is successively developing new car models and is continuously expanding their staff. The development of organisational processes is not growing as fast as the company. Hence, an unclear distribution of work duties. Also, the market is moving fast and a product development company needs to keep up with the speed to be able to compete with their products.

Before the company build a complete version of the car model. They first build several different test objects. One type of test objects is called boxcar. This test object is utilized to test the entire electrical function of a car. Hardware & Build, from now on referred to as HW&B, is a part of Vehicle Integration and is the department specifying the test object content.

After the test object build, HW&B delivers the output to Electrical Validation, from now on referred to as EE, for integration tests. This department is testing the functionality of hardware and software of boxcars.

There is not a well-defined process today. Problems that come up during the way is often solved differently every time. No department is keeping track of the statistics regarding the boxcars but it is known that they vary in cost. Statistics of some of the previous boxcars can be found as well as the number of deviations that were made during the process as well as the delay of the different boxcars. HW&B is in need to analyse the process of building boxcars to find the root-cause of cost variation when completing a test object. (Source: Internal documents and interviews with employees at The Company)

1.2 Aim

Because the current boxcar process is unclear, the project aims to map and describe the current process. To reduce the cost variations of the boxcars the project aims to come up with suggestions of improvements.

Solving this problem and improving the boxcar process could potentially lead to less manual work, better communication, less rework and lower costs for the department and therefore also for the entire company.

1.3 Limitations

The project will be focusing on the car series of a hybrid car model, from now on referred to as Hybrid. This is a project that is ready for launch and has gone through the whole process at The Company. It is therefore possible to gather required data on that specific car model.

The Six Sigma method consists of five phases (Define, Measure, Analyse, Improve and Control) but due to time limitations only the first four phases will be covered. That is Define, Measure, Analyse and Improve. Control will not be featured in this report, which means that improvements to the problem shall be presented but not implemented within the company.

In this project assumptions of a linear relationship have been made between deviations and total cost of a boxcar and between lead time and total cost of a boxcar. This relationship will not be proved in this project.

1.4 Research Questions

The project aims to answer the following main questions:

- What activities are included in the process today?
- How can cost variation be reduced when building boxcars?

2 THEORETICAL FRAMEWORKS

This chapter explains the background information used for this project. First an introduction of boxcars and how they are used at The Company is presented. Continuously, information about process development and Lean Six Sigma follows.

2.1 Boxcar Build at the Company

The purpose of building boxcars is to test all the electronic parts on a rig before the prospective car is being mass produced. The organisation strives to find problems at an early stage and when they are found on a boxcar rig, parts can easily be replaced, as opposed to if they were built into a complete car. All different parts, both the hardware and software need to be compatible with each other. Therefore, integration tests are run, to see that the car's electrical parts are functioning properly. One example is a deep-sleep test. The boxcar is put into sleep, as when a car is turned off, and if any part is using power, it is detected and can be fixed.

For a specific car model, several boxcars are made along the way. They are called to have different statuses and the last status is the boxcar most similar to the final car. The statuses, in order, are at The Company called E1, E2, E3, E4, VP, TT and PP. For every status, a small number of boxcars are built and tested, with different focus for each status. The reason why sometimes more than one boxcar for each status is needed is because the final car will be available with different parts, depending on if it is a high-specification car or a low-specification car. EE informs HW&B of how many boxcars they will need and how they should be specified. Then, HW&B makes a so called MBOM-extraction. A Master Bill of Materials (MBOM) is extracted and all electrical parts are manually sorted by HW&B in to a Purchasing Bill of Materials (PBOM). The PBOM contains all the parts for a complete boxcar. HW&B sends out a finalised PBOM to Purchasing for them to order the parts in the PBOM.

It takes approximately one week to assemble a boxcar when all the parts are in the warehouse. Some parts are more important in the early stages of the boxcar assembly, as for example the cables and the ECU (Electronic Control Unit) parts. Without the cables, it is impossible to start the assembly.

When a part is exposed to a major delay, it is sometimes possible to reflash an old part. This means that new software is loaded onto old hardware. The new software will be tested but not the hardware that the future car will contain. Reflash old parts is not a very big problem if it is done for an early status boxcar, but if it is a later boxcar status the importance of having the correct hardware is higher. This is a solution only to be used when there is no other option. (Source: Internal documents and interviews with employees at The Company)

2.2 Vehicle Development Processes

A process is a group of coexisting or of each other affected activities that reshapes inputs to outputs. The ISO definition of a process is the following: ”a set of interrelated or interacting activities which transforms inputs into outputs”. (ISO 9000:2005)

Developing vehicles can range from producing different specifications on a car model to a single build of one vehicle. It can be a matter of a simple improvement or a complete redesign. These projects may differ in order of needed technical contents, financials and the time to get the job done. Design level, design content, innovation level and number of options are the main categories that drive the required needs. Either way, a project that aims to develop an automotive must follow a well-planned process. (Weber, 2009)

According to Weber (2009), a good way to develop a large number of cars fast and to lower the cost, is the use of the same components in many different vehicles. Having standardised building blocks for electronic components, chassis and engines etcetera for different car model lines or variants is beneficial. It can contribute to reduced cost and lead time for designing and evaluate vehicle components. It lowers the demand of the car assembly equipment and reduces handling and maintenance cost. The usage of well-known components will also increase the quality of the vehicle. These applications are mainly for the non-visible or non-differentiating parts. (Weber, 2009)

2.3 Six Sigma

The Six Sigma method was originally introduced in the 1980’s by Bill Smith and has been used since then to improve processes (Orner, 2016). Many big companies such as ABB, Motorola and Sony has used Six Sigma to improve their organisations. (Saghaei, Najafi and Noorossana, 2012) Six Sigma is used when the problem is complex, where the causes and the solutions are unclear. The roots to a problem are found by gathering people from different departments and with different degrees of knowledge. It is important to collect all kinds of data before patterns can be discovered that will lead to the roots of the problem. (George, 2005) The main principle for Six Sigma is to mitigate the influence of variation. Lean manufacturing has its root in manufacturing philosophy from Japan with the main purpose to establish process flow and a pull-thinking culture at the company. The main metric in Lean philosophy is reduction of lead time and increase of the value-adding relative the non-value adding activities, that is, to reduce waste. In this project the Six Sigma methodology has been used to investigate a typical Lean manufacturing issue: to establish and visualize flow.

2.3.1 Variation

Variations are differences in the outcome of a process and are divided into two categories, common cause variation and special cause variation. Common cause variation is always present and therefore also predictable within limits – usually called control limits. When a process contains only common cause variation, it is said to be in control. Special cause variation is not always present and is unpredictable. Processes containing special cause variation is not in control.

The goal is to understand and mitigate the influence of variations in a process, or at least reduce the impact on the process and outcome. By doing this, the process in question becomes more stable and robust which leads to a more predictable outcome.

The strategies for reducing variations is dependable on the type of variation. When dealing with common cause variation, the everyday work must be changed and new methods must be used. If the goal is to eliminate special cause variation, the reason for the variation must be found and studied to prevent it from happening in the future.

Variations can be analysed and visualised using time series plot and control charts. These tools are helpful when separating common cause variations from special cause variation and for finding the underlying reason for the variations. (George, 2005)

2.3.2 DMAIC Cycle

DMAIC is used to improve speed, quality and cost in a process, product or service. The letters stand for Define, Measure, Analyse, Improve and Control, which are the five phases of Six Sigma.

Define: The Define Phase is the first phase of the Lean Six Sigma improvement process. It is important to understand what key output metric, (in Six Sigma referred to as Y) to be improved. The project team needs to create a Project Charter (a high-level map of the process) to understand the needs of the customer. This is a critical phase in which the project team outlines the focus of the project. (George, 2005)

Measure: Measurement is critical throughout the entire project. Collecting data is about focusing on both the process as well as measuring what the customer think is important. The inputs that affects the process in Six Sigma is referred to as x and the output as y (Magnusson, Kroslid & Bergman, 2003). In this phase, the team determines the performance of the process as it currently is.

Analyse: In this phase, it is important to find factors in the underlying system that can explain the behaviour of the output metric. Brainstorming is used to find symptoms (not solutions) and set up different hypotheses for the current problems. Then to prove or disprove these hypotheses.

Improve: To improve the process, several solutions must be tested and evaluated. The goal is to come up with a stable process that meets the requirements of the customer. All the improvements should be implemented in the department. The objective in Improvement phase is to find potential solutions and verify that works logically and technically. If it cures the problem in the organisation and is validated takes typically a longer period of time and often become the controllers’ responsibility in the project post-work.

Control: In this final phase, an upstream metric, suitable for the *current stage* of the organisations understanding of the problem, is developed that monitors essential inputs or control factors (x’s) needed to keep the output variation under control. And the main delivery from the C-phase is a control plan the defines what to monitor and what actions to take when these x’s starts do deviate.

This method is an ongoing cycle. It is possible to go back and forth between phases. (George, 2005)

3 METHOD

In this chapter, all methods that have been used in the project are described, together with an explanation to why they were chosen.

3.1 Data Collection

This process developing project was conducted using the Six Sigma methodology. According to George (2005) Six Sigma is used when the problem is complex and where the causes and the solutions are unclear. The project fits this description and the Six Sigma method is a good way to approach and to solve the problem. Therefore, the first thing was to study the method. The literature used was the *Lean Six Sigma pocket toolbook* by Michael L George. During the project, the team members were supported by a mentor with deep knowledge in the Six Sigma method.

The first step in Define is to collect both qualitative and quantitative data about the problem, organise it and visualise it for the stakeholders. In order to understand the current situation the project members observed some of the employees involved in the process by attending their meetings. Through the meetings, the cooperation and communication between different departments was also observed.

Semi-structured interviews were held with employees from different departments that are involved in the boxcar process. Customers, which receive the outcome of the process, were also interviewed. Half of the interview questions used, were the same for all interviewees (see Attachment 1) and the other half was more specific depending on their role in the boxcar process.

For collecting specific data about the Hybrid boxcars, excel lists from the boxcars were studied. The lists contain information about how many parts that were ordered, the dates the parts were ordered, when they arrived, if they were subject of any deviation along the way and so on.

3.1.1 Ishikawa Diagram

Once the problem is defined and the driving metric for the process exploration is defined, one way to move forward is to create an Ishikawa diagram. By creating an Ishikawa diagram, it is possible to identify the main categories that may be the root causes of a problem. By doing this a list of possible causes is generated. The diagram is created in four steps. The first step is to identify the problem that is to be analysed. Step two is to set up headlines or main categories of possible causes. Underneath these main categories, the different causes are identified and written down more detailed. The final step is to draw the diagram, like a fishbone with the main problem on the right side of the diagram. This is done to be able to discuss the problem and make it clearer. (Law, 2009)

3.1.2 Three-Point Estimate

When analysing a process, numerical data is preferred. In absence of numerical data, the Three-Point Estimate method gives a good indication of the real value. An expert estimate three numbers; one most optimistic (a), one most pessimistic (b) and one most likely (m). The expected value (e) and the standard deviation (σ) is calculated using the formulas:

$$e = (a + 4m + b) / 6$$

$$\sigma = (b - a) / 6$$

This method can be used to estimate for example cost or time, when no data is available. (Kerzner, 1998)

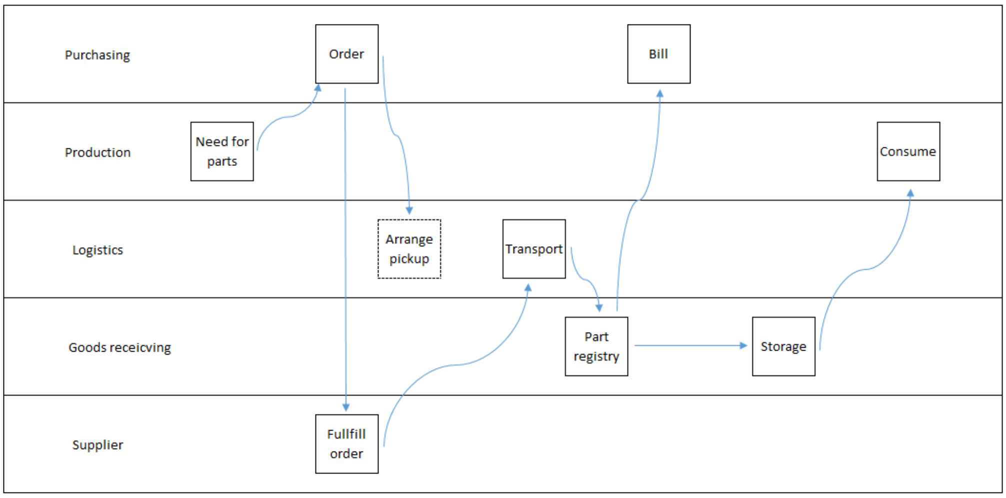
3.2 Process Mapping

Process maps are used to provide detailed information about what factors the influence variation in a process. Different process maps are used to highlight different things. The basics to all process maps are the same; identifying steps in the process and arrange them in order. Process maps are created in the Define and Measure phases of the Six Sigma methodology, typically in companion with a value stream map that visualises the flow. (George, 2005)

3.2.1 Swim-lane Flowchart

The swim-lane flowchart is used to map a process from start to finish and to help distinguish which department is responsible for the set of actions along the way. It is a good way to see how information flows between different departments, very useful to identify hand-overs and bottlenecks.

The swim lane flowchart differs from other process maps because the process actions and decisions are grouped by placing them in lanes. Horizontal lines divide the chart into lanes, with one lane for each person, department or sub process. The lanes are labelled to show how the chart is organized, for example different departments. Boxes representing different activities are placed in the lane for the department that is performing the activity. A box with a dashed line is to mark an event that only happens occasionally. Arrows between boxes in different lanes represent how information or material is passed between departments. An explanatory swim-lane diagram is shown in Picture 3.1.

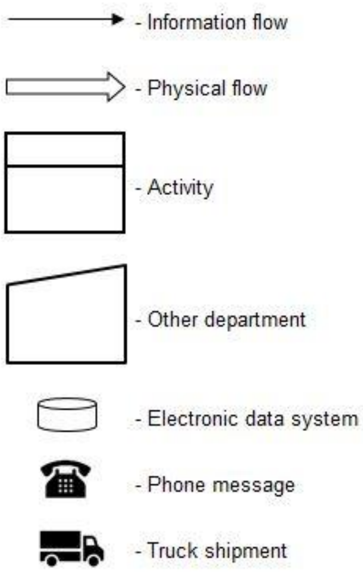


Picture 3.1. Swim-lane flow chart

The final step is to discuss how to improve the workflow in the process. (George, 2005)

3.2.2 Value Stream Map

A value stream map is used mostly for visualising flow and identifying waste in the terms of cost and time. The process map is created by first drawing the process flow with its main activities and the customer. Next thing is adding the material flow and the suppliers. Later the information flow is added. Lastly data is found and added to the activities in the chart. That means for each activity, information such as; trigger, setup time and processing time per unit, takt time, percent of defects and number of people can be added. (George, 2005) The process map is constructed using the symbols in Picture 3.2.



Picture 3.2. Explanation of the symbols used in the value stream map.

In this project yield, lead time and process time were used as data for each activity and was found using a form. The form was given to the boxcar manager at The Company, to make qualified estimations. See Attachment 2. Process time is the amount of time actually spent on a task. Lead time in this report refers to:

Lead time = queue time before processing + processing time + waiting time + moving time (Gao & Low, 2014)

3.3 Process Analysis

Efficiency and quality are two things to be considered when analysing a process. Methods for measuring efficiency and quality is presented down below.

3.3.1 Metrics of Time Efficiency

Metrics of time efficiency are helpful methods to identify time waste in a process and how much the waste impacts the efficiency of the process.

A good way to measure the efficiency in a process is *Process Cycle Efficiency* (PCR), which is a percentage value.

PCR = Processing time / Lead time

Knowing the current PCR of the process, the next step is to identify Target PCR. For a service business process the *typical (low-end)* value is 10% and the *world-class (high-end)* value is 50%. The Target PCR should therefore be 50% which is *world-class*. By determine the Target PCR it is possible to calculate Target Lead time.

$\text{Lead time}_{\text{target}}$ = Processing time / Target PCR

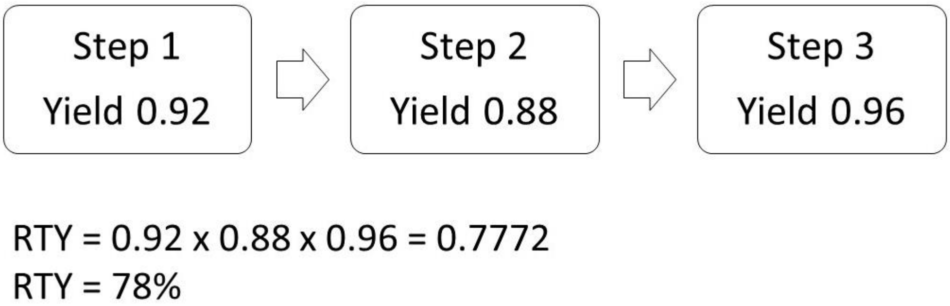
Target lead time is the cycle time for a *world-class* process.

Important aspects to consider in parallel with Lead time is Demand rate; how many products and/or services that needs to be processed within the available time. (George, 2005)

3.3.2 Rolled Throughput Yield

The quality of a process can be measured in many ways, including sigma quality level, yield, Defect per Unit (DPU) and Rolled Throughput Yield. Rolled Throughput Yield, RTY, measures the chance of a defect free output, (Saghaei, Najafi and Noorossana, 2012). Using RTY is recommended because it is high correlation with waste, rework and customer satisfaction. First the percentage of defect free products, the yield, is found for each step or sub process. Then the

RTY is calculated by multiplying the yield from every sub process in the process by each other, as illustrated in the picture below, see Picture 3.3. (Graves, 2002).



Picture 3.3. Illustration of the RTY calculation.

In the example above, it is a 78% possibility of an error free product. In this project, the yield in question is ordered parts for the boxcar that were correct and not in need of any deviation. The data for calculating RTY in this project, was collected using the form in Attachment 2.

3.3.3 Cause and Effect Matrix

A Cause & Effect matrix is a qualitative tool used for identifying the potentially most important inputs in the process that needs to be taken in account when improving the output of the process, based on the current knowledge and experience of the process behaviour. The inputs are stated for every step of the process**.** A maximum of five outputs in total are placed on the top of the matrix. These outputs should be what the customer requires of the process. The outputs are ranked on a scale from 1-10, with 10 being the most important. On the left side of the matrix, all the important inputs and steps in the process are listed. Later, the inputs together with the outputs are ranked based on their correlation with each other, using the scale below:

Blank = No correlation
1 = Remote correlation
3 = Moderate correlation
9 = Strong correlation

By cross-multiplying correlation scores with customer required scores and then adding them across for each output, the total score is generated. (George, 2005)

3.3.4 Process Failure Modes and Effects Analysis

Process Failure Modes and Effects Analysis, PFMEA, is also a qualitative tool that in a structured way finding in which ways a product, service or process can fail. It can be used when designing new processes or make changes in already existing processes. PFMEA is used when improving existing processes to see how people, materials, equipment, methods and environment contribute to problems in the processes. When seen how the process can fail it is easier to come up with solutions to prevent the process from failing.

When performing a PFMEA, it is important to start with the activities that are the most important for the costumer in the process. Next step is brainstorming and figuring out in what ways the process can fail to do what it is meant to do. Listing effects of each failure mode is the next step in the analysis. Then rate on a scale from 1-10 the severity and the occurrence. 10 on this scale meaning most severe impact on customer or respectively is most likely to occur. Also list the current controls for each failure. The current controls are the actions that are being done today to prevent the activities from failing. Rank the detectability of failure, from 1-10, with 10 being least likely to be noticed using the current controls. A risk priority number (RPN) is calculated for each failure effect by multiplying *severity*, *occurrence* and *detection*. A high RPN's indicates a failure modes with high priority. The RPN's with the highest score are the ones that needs to be addressed first and a plan to reduce or eliminate the risks for these failure modes should be prepared.

If the plan is implemented to an organisation, the last step is to re-compute the RPN. (George, 2005)

In this project, a plan with possible actions to reduce or eliminate failure effects will be presented in the PFMEA.

Since complete PFMEA for a process tend to be extensive and tedious execute, the Six Sigma project typically uses the FMEA methodology focused on the subset of relevant factors that showed up most promising in cause and effect analysis above.

4 RESULT

This chapter is presenting the results from the research, using the methods described in the previous chapter.

4.1 Data Collection

Problems that came up during the interviews were:

- There are problems with the quality of the MBOM, it is not up-to-date for all parts. This leads to poor quality of the PBOM. *[HW&B]*

- It is not a part of the System engineers job description to have up-to-date information about their part in TC. HW&B and Purchasing needs to contact the System engineers to get the information they need from them. *[Coordinator, PSS]*

- There is a lot of manual labour when rewriting a MBOM to a PBOM. The list is sorted manually. *[HW&B]*

- PBOM does not get updated, only copied from previous projects. Important information goes missing (e.g. parts that does not have a part number and therefore cannot be ordered is in the new PBOM because it is a copy from a previous list). This leads to repetition and rework for Purchasing and HW&B. *[MP&L]*

- Problems with the quality of the PBOM from the start. When HW&B creates a PR, and Purchasing begins to send out orders, supplier replies that the part number has expired. HW&B must do a deviation and update the PBOM. *[MP&L]*

- Purchasing need to spend a lot of time correcting the PBOM-list instead of placing orders directly, and often, orders comes in late in the process which makes it difficult for Purchasing to order and for HW&B to get the parts in time for assembly. *[Purchasing]*

- Many System engineers does not know how to use TC and does not understand the importance of a part change request. The System engineers sometimes make part number changes without communicating it to other departments. *[Coordinator, PSS]*

- It is very time consuming for the System engineers to do a part change request (change part or part information in TC). As a result, deviations come in late in the project. *[System engineer, PSS]*

- The warehouse is disorganised. It can take up to three weeks for the boxcar build team to find a received part. *[Boxcar Build Team]*

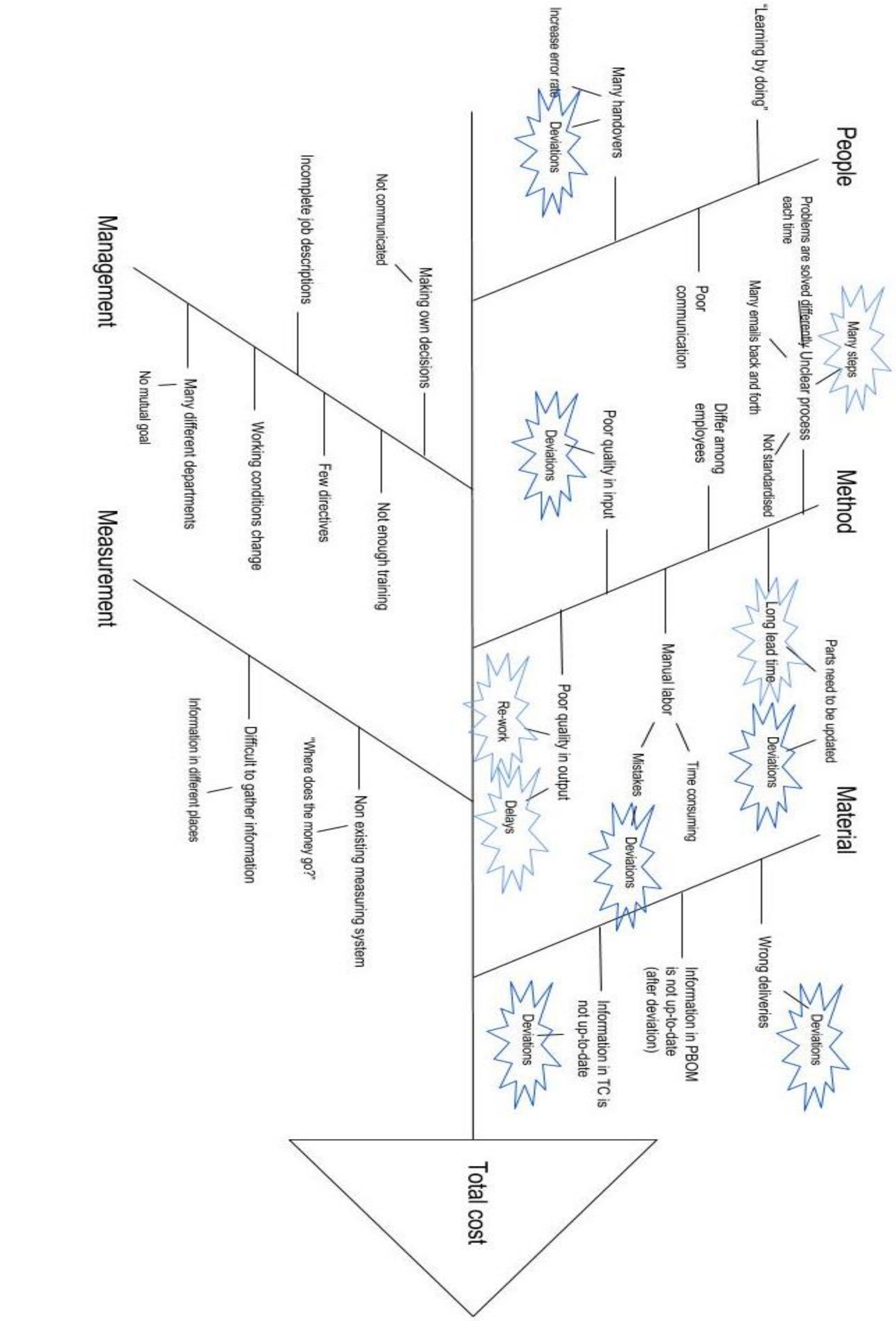
- The goods received in the warehouse does not match the PBOM. The boxcar build team needs to do research to know what part is what. *[Boxcar Build Team]*

- Projects that gets terminated results in spare parts that could be used in a later project. The problem is that there is not a good system to keep track on which parts are available and when and who in the process to check for spare parts. Some parts have the same status all the time, but still gets ordered, instead of reusing what is already in warehouse. There are some different material-lists to keep track of spare parts, but not one that everyone uses. Everybody should update on the same list. *[MP&L]*

- Because deviations are made constantly, it is hard to get the right material in the boxcars. *[EE]*

4.1.1 Ishikawa Diagram

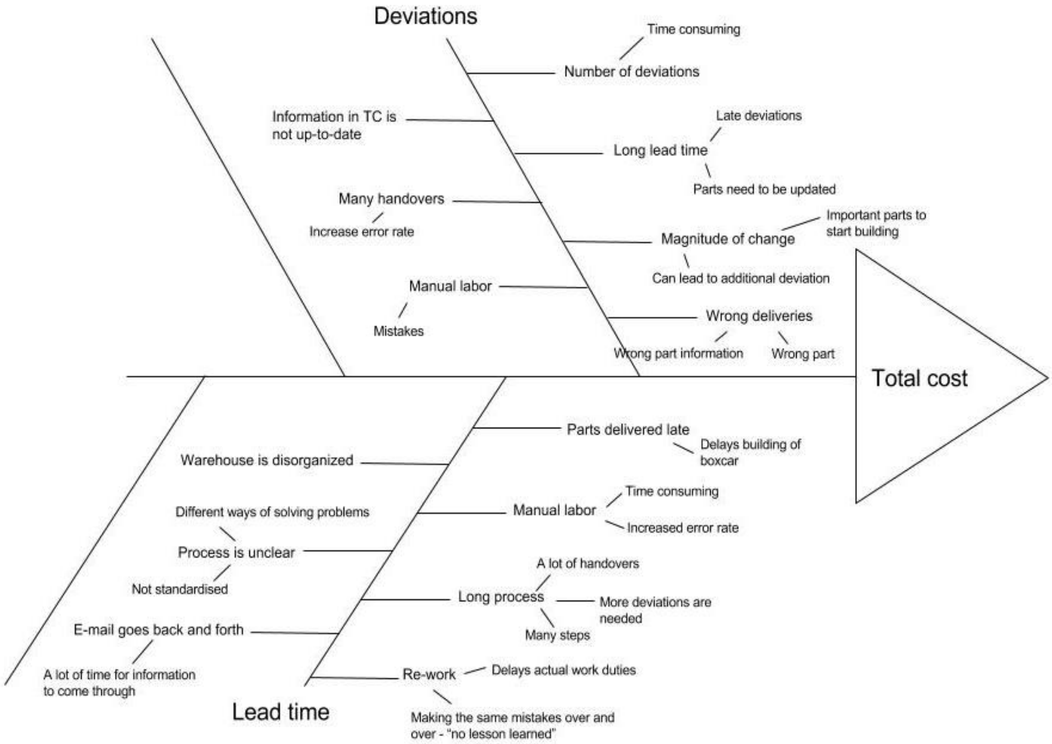
Factors that are affecting the total cost of a boxcar, are being visualized using an Ishikawa diagram, see Picture 4.1 or Attachment 3. These factors are possible underlying problems for why the boxcars vary in cost. The information used to create the diagram are from the interviews with stakeholders, involved in the boxcar process.



Picture 4.1. Ishikawa diagram showing causes for cost variations.

In Picture 4.1, *Deviations* and *Lead time* are highlighted. They are causes that occur in several major categories. Since they are occurring repeatedly, this project will assume that there is a linear relationship between *Deviations* and *Total cost* and between *Lead time* and *Total cost*.

A new Ishikawa diagram where made where Deviations and Lead Time were seen as major causes. The underlying factors were found and are presented in Picture 4.2 and Attachment 4.



Picture 4.2. Ishikawa diagram showing causes for cost variations with focus on Deviations and Lead time.

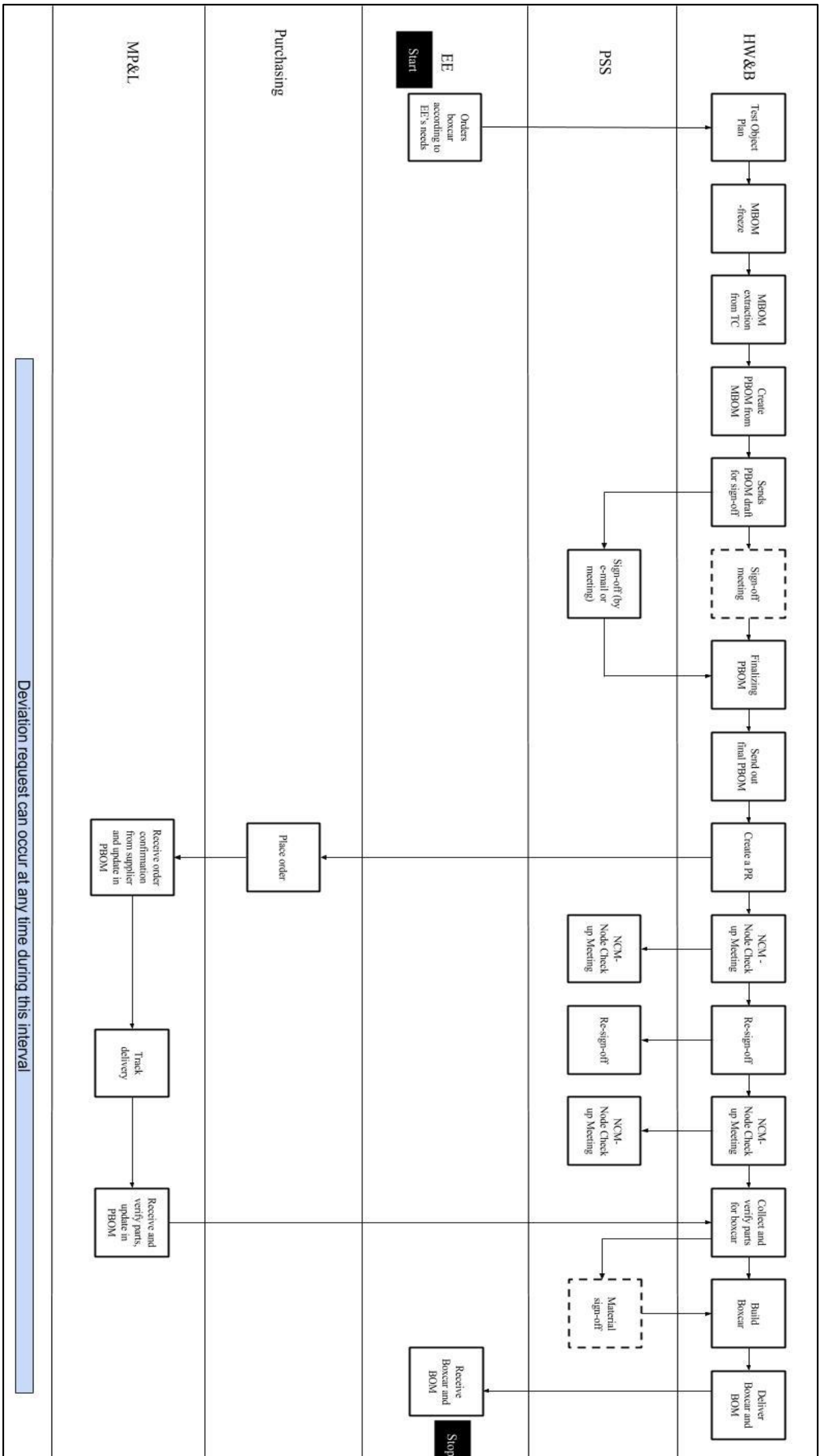
Picture 4.2 shows that deviations and lead time are connected. Deviations can often lead to delays depending on when they were placed. Long lead time results in more deviations since the development of new products never ends. Using the linear relationship between deviations and total cost, and lead time and total cost makes it possible to study variations in total cost by studying variations in lead time and deviations. Deviations and lead time are now the project's focus. The reasons why deviations are placed were later researched and what can be done to minimise the deviations' impact on the process, to have a more standardised and robust process.

4.2 Process Mapping

A swim-lane flowchart and a value stream map were created and is presented below.

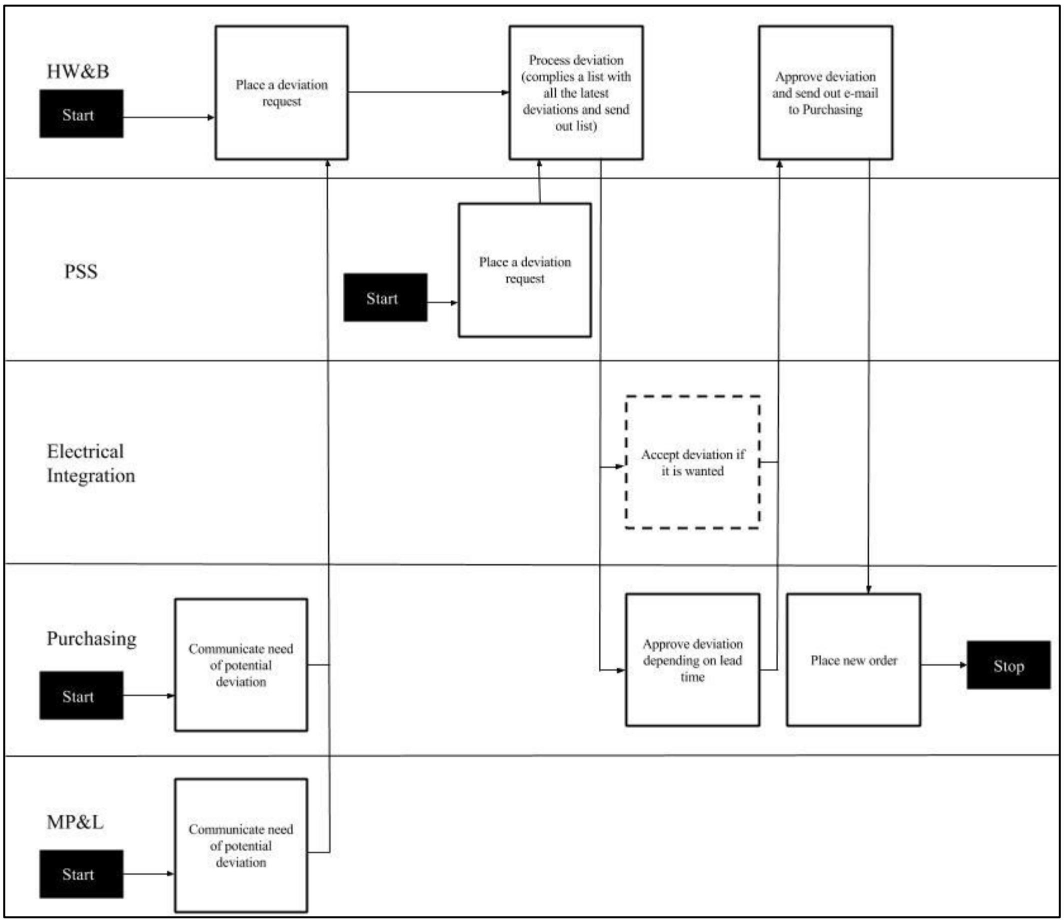
4.2.1 Swim-lane Flowchart

Two swim-lane flowcharts were made, since the boxcar process contains an underlying process. The two charts are shown in separate diagrams. The underlying process is the deviation process and can occur at almost any time, as demonstrated by the blue bar in Picture 4.3 and Attachment 5. After the extraction from TC, deviations can be placed and they continue to be accepted even as late as MRD, although they delay the assembly of boxcar.



Picture 4.3. Swim-lane flowchart showing the boxcar process.

There are several ways the deviation process can be triggered. A reason for a deviation can be detected in different process steps and by different departments, see Picture 4.4 or Attachment 6.



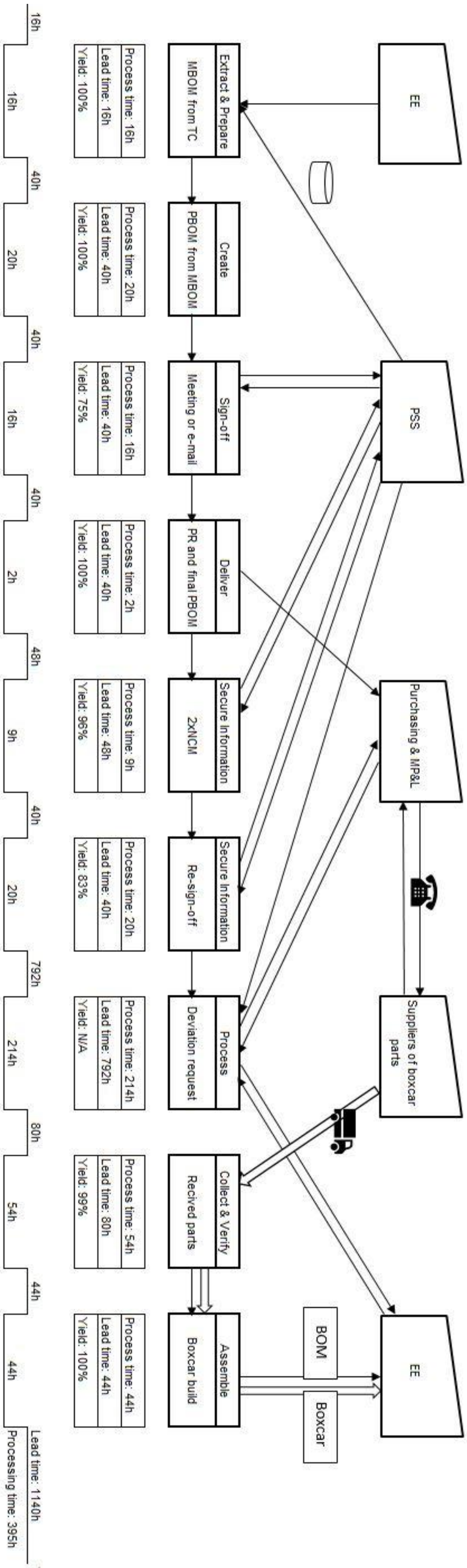
Picture 4.4. Swim-lane flowchart showing the deviation process.

As seen in Picture 4.4, a deviation can be a correction of the PBOM, often based on information from the supplier to purchasing. It can also be an update of the PBOM, for example due to newer version of hardware is available.

As shown in both swim-lane flowcharts, there is not a lot of information that travels back and forth. Except in the deviation process, which include many handovers. Several steps have been added to the process already to secure input information and therefore improve the output quality, including two sign-offs and two Node Check-up Meetings.

4.2.2 Value Stream Map

The VSM diagram below is visualising HW&B's activities in the boxcar process and their involvement with other departments, see picture 4.5 or Attachment 7.



Picture 4.5. Value stream map showing HW&B's activities.

Below each activity in the VSM chart, a data box showing yield and time span, is placed. The yield stated for each activity are the parts that were not in need of any deviation. The timeline below the activities shows lead time versus process time.

The VSM diagram shows that the PSS department is involved, in some way, in many of the process steps.

4.3 Process Analysis

The result of the process analysis is presented down below.

4.3.1 Metrics of Time Efficiency

Using the data presented in the VSM chart; process time and lead time. Calculating the ratio between these numbers gives a measure of the process cycle efficiency, PCE.

Process cycle efficiency = Processing time / Lead time

395h / 1140h = 0.3464 = 34.6%

This is the percentage of the total processing time that adds value to the process. According to George (2005) the low-end value is 10% and the high-end value is 50%. The calculated number above lies within these values. Therefore, the target PCE value should be set to 50%. The target lead time can be calculated:

Target lead time = 395h / 0.5 = 790h
Today's lead time = 1140h
Excessive lead time = 1140h - 790h = 350h

This means that, to achieve a "world-class" process efficiency, the process must be shortened with 350h, which corresponds to 44 work days or 9 work weeks.

4.3.2 Rolled Throughput Yield

A simplified process map, including only HW&B's activities in the boxcar process is shown in Picture 4.6. The ratio of parts without a deviation is shown as a number below each process step.

Picture 4.6. Process map showing HW&B's activities and calculated RTY.

Calculating the RTY:

RTY = 1.0*1.0*0.75*1.0*0.98*0.83*0.98*0.99*1.0 = 0.5919
RTY = 59.2%

This means that, in this case, only 59.2% of all parts went through the whole process without a deviation. The rest, 40.8%, was subject for deviation. It is a high number but the numbers are realistic, since they match statistics found, and presented later in Chapter 4.3.4.

Using the linear relationship between deviation and total cost of boxcar, the RTY should be increased to reduce boxcar cost.

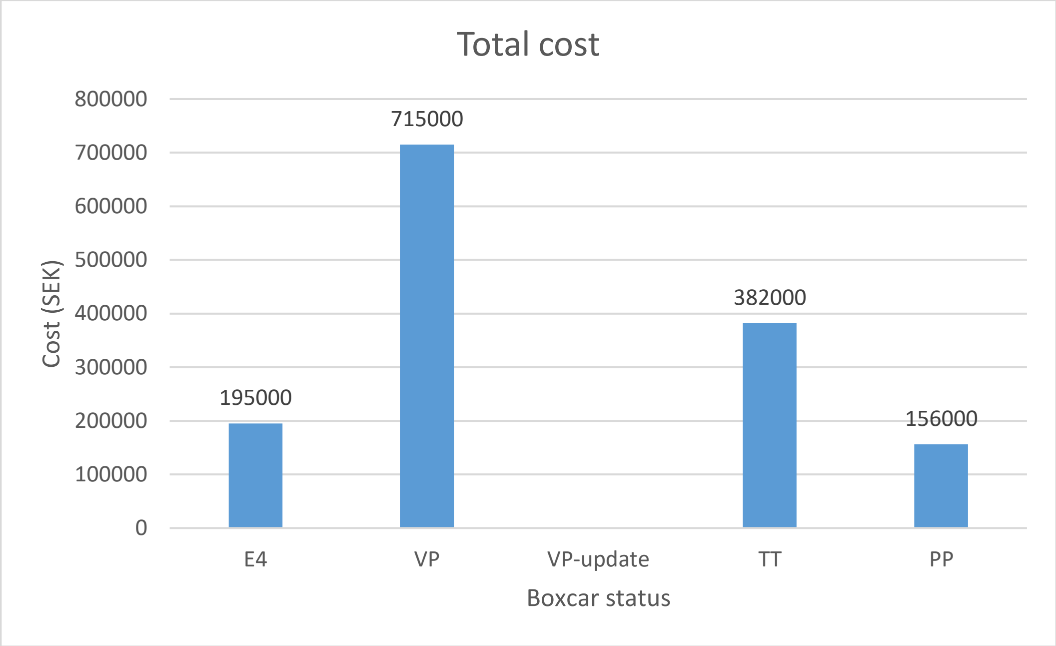
4.3.3 Cost of Boxcars

Expected costs for the different boxcar statuses are shown in Picture 4.7 below.

Hybrid Boxcars	Expected cost (one boxcar)		Setup	Expected cost (SEK)	Actual cost (SEK)
	New (SEK)	Update (SEK)			
E4	N/A	N/A	2 updates	N/A	195 000
VP	200 000	150 000	2 new	400 000	715 000
TT	100 000	75 000	2 new	200 000	382 000
PP	75 000	50 000	2 updates	100 000	156 000 (estimated)

Picture 4.7. The expected and actual costs for different boxcar statuses.

Picture 4.7 shows the preliminary costs and are used as a guideline when the PR’s are created. For the Hybrid project, E4 and PP were updates and VP and TT were new boxcars. For PP, only ECU’s were bought. The cost for E4, VP and TT was provided by Purchasing. The cost for PP status is an estimation made by the boxcar manager at HW&B, using a Three-point Estimation. The cost for the Hybrid boxcars can be seen in Picture 4.8.



Picture 4.8. The actual costs for different boxcar statuses.

The boxcars for the Hybrid project has exceeded the preliminary costs as seen in Picture 4.8. Two boxcars with VP status was predicted to cost 400 000 SEK but the actual cost was 715 000 SEK. For TT status, the preliminary cost was 200 000 SEK for two boxcars, but the actual cost was almost twice as much. Information about expected cost for E4 is not available. None of the boxcars build stayed within the budget.

4.3.4 Deviations

Studying old PBOM's from the previous boxcars gave the following result, see Picture 4.9. The reasons for why the deviations were placed were categorised into six categories:

Added part - An additional part must be ordered, due to for example a CCR (Content Change Request) or a human error when creating the PBOM and is missed out at sign-off.

FFF Change - Form Fit Function Change, meaning for example that the part does not fit into the construction and that the dimensions of the part has to be changed.

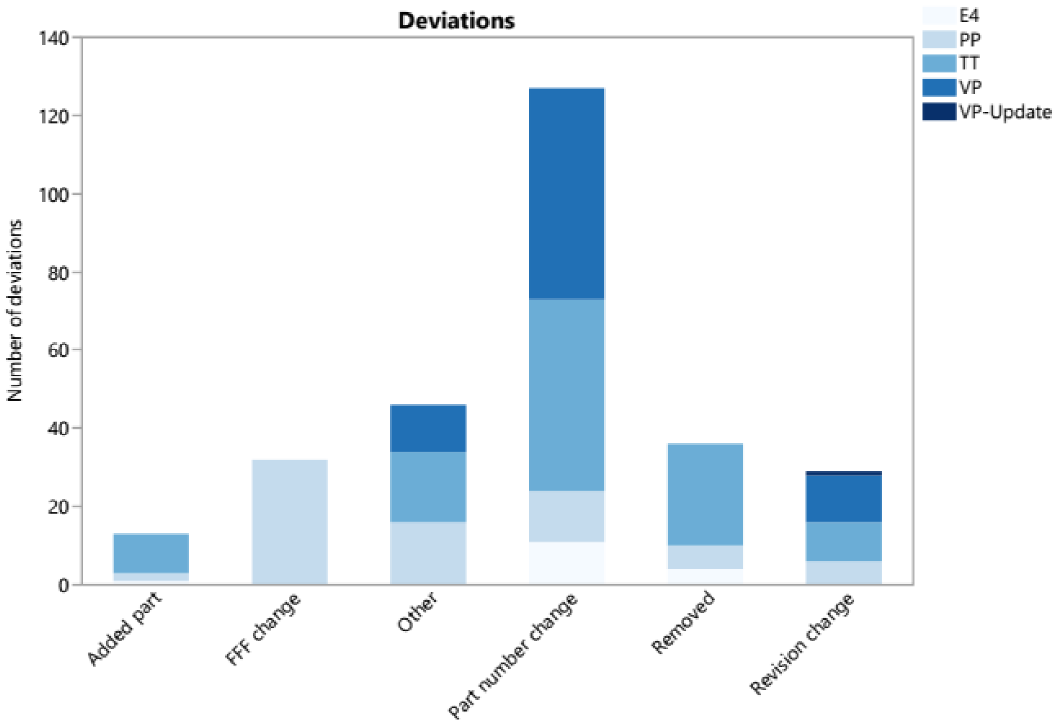
Other - All other reasons or that information is missing

Part number change - The part number in the PBOM is not correct. A reason can be that another part is needed or the part number stated in the PBOM is old and a newer number has to be used.

Removed - The part is not needed and is removed from the PBOM, due to for example a CCR (Content Change Request) or a human error when creating the PBOM and is missed out at sign-off.

Revision change - The part has been updated to another revision.

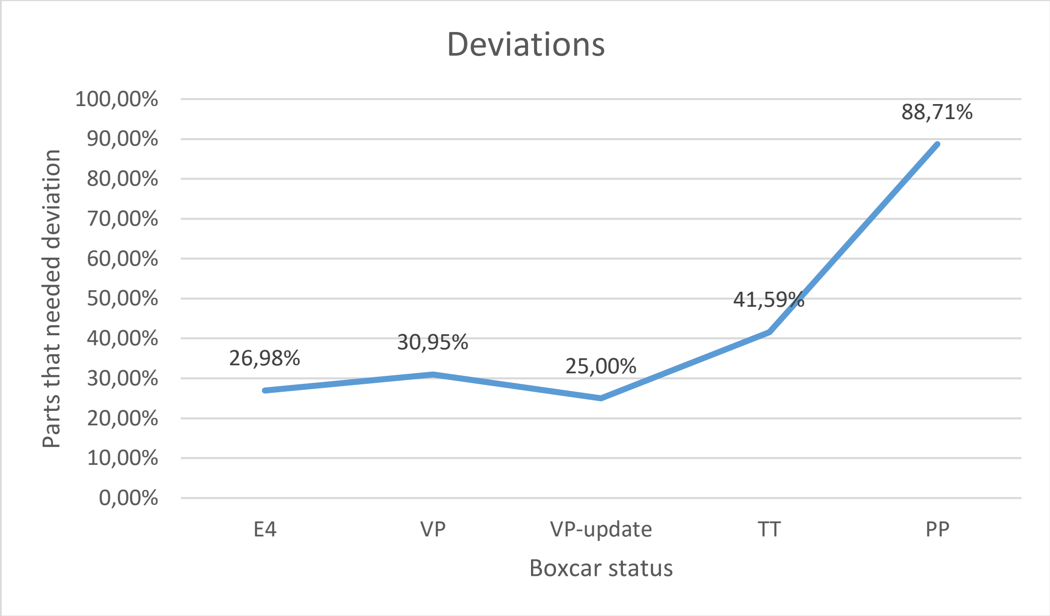
Picture 4.9 is showing how many deviations that were placed in each category. The different colours in the stacked staple diagram is representing the different boxcar statuses.



Picture 4.9. Staple diagram showing the reasons for deviations.

Picture 4.9 shows that the main reason for why a deviation is placed is because of a part number change. That staple is containing the colours representing E4, VP, TT and PP meaning that part number change was needed in all those projects. In PP, FFF Change was a major reason for the deviations and FFF Change could not be detected in the other boxcar statuses.

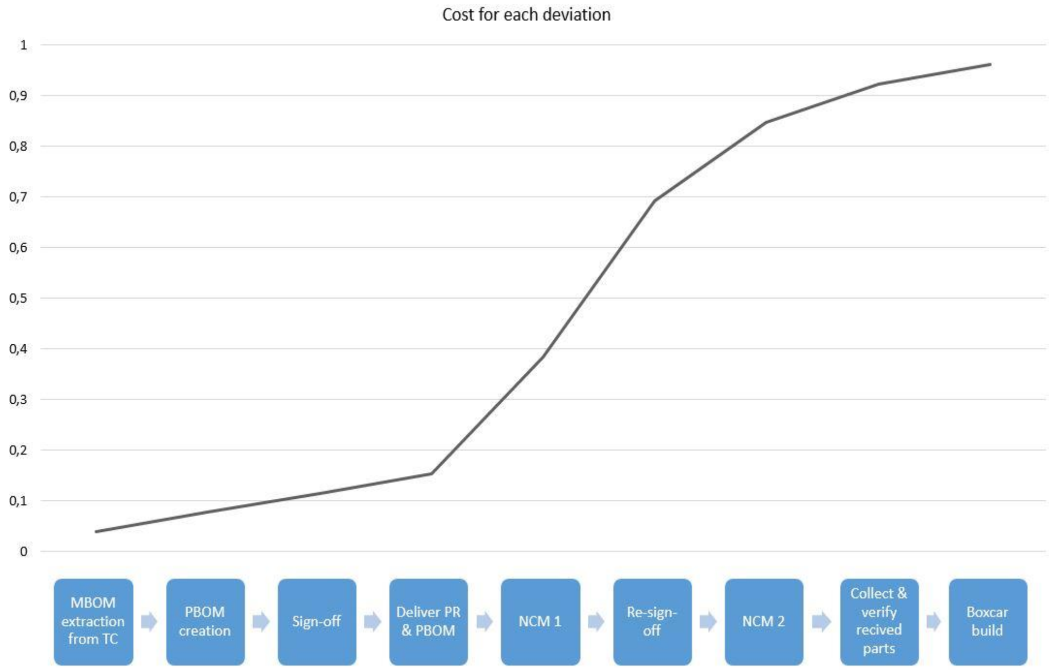
How many parts that needed a deviation for each boxcar status is visualised in Picture 4.10.



Picture 4.10. Deviations for boxcars in the Hybrid project.

From E4 to VP the parts that were subjects for deviation were around 30%. The TT status had around 40% deviations. Almost 90% of the parts for PP status needed deviation. The number of deviations increases the closer it gets to final production of automotive. The PP status consist out of ECU's that are more likely be a subject for deviation.

It is reasonable to assume that deviations placed later in the process, increase the total cost of a boxcar. For example, the risk of ordering two parts is more likely later in the process. Assuming a linear relationship between the cost of a boxcar and the date when a deviation is placed gives the following graph, see Picture 4.11. The highest number, 1, on the y-axis represent the maximum cost of a deviation. The x-axis is a time line where each activity represents the weeks they are performed (from week 1 to week 26).



Picture 4.11. Expected cost for deviations in each step in the process calculated using a linear relationship.

Picture 4.11 show that up and till NCM 1 the cost of one deviation is significantly lower than in the steps that comes later. This means that the more deviations discovered before this stage, the lower the total cost of a boxcar will be.

4.3.5 Cause and Effect Matrix

A Cause and Effect matrix is presented in Picture 4.12. The two process outputs, quality of boxcar and on time delivery have each been weighted according to their importance regarding cost variation. The matrix is sorted by the calculated *Total* column.

Cause and effect matrix					
			Quality of boxcar	On time delivery	Process outputs
		Importance	7	10	
	Proocess step	**Process input**	**Correlation of input to output**		**Total**
23	Collect & verify recived parts	Boxcar parts	9	9	153
26	Boxcar build	Boxcar parts	9	9	153
14	Deviation request	Complexity	1	9	97
10	NCM	Part information	9	3	93
11	Re-sign-off	Part information	9	3	93
13	Deviation request	Date recieved		9	90
15	Deviation request	Lead time		9	90
7	Sign-off	Part information	9	1	73
20	Deviation request	Old part number	1	3	37
8	Deliver PR & final PBOM	PBOM	3	1	31
16	Deviation request	Part change request		3	30
18	Deviation request	Added part		3	30
1	MBOM extraction	Electronic info in TC	3		21
5	PBOM from MBOM	MBOM	3		21
6	Sign-off	PBOM	3		21
22	Collect & verify recived parts	PBOM(recived date)		1	10
24	Collect & verify recived parts	Part information		1	10
4	PBOM from MBOM	Operator	1		7
2	MBOM extraction	Boxcar order			0
3	PBOM from MBOM	Boxcar order			0
9	Deliver PR & final PBOM	Boxcar order			0
17	Deviation request	Deleted part			0
19	Deviation request	Part information change			0
21	Collect & verify recived parts	Assembly list			0
25	Boxcar build	Assembly list			0

Picture 4.12. Cause and effect matrix of the boxcar process.

As seen in Picture 4.12, the boxcar parts are highly correlated with boxcar quality and on time delivery of boxcar, which can easily be understood. As number three, in the matrix, the complexity of a deviation is highly correlated with on time delivery, and has a remote correlation to the boxcar quality. The eight top rows have a significantly higher total, and will therefore be further studied in a PFMEA.

4.3.6 Process Failure Modes and Effects Analysis

The eight top rows in the Cause and Effect matrix is profoundly studied in a PFMEA, see Picture 4.13 or Attachment 8.

Process Failure Modes and Effects Analysis										
Process name: Boxcar process										
Responsible: HW&B				PFMEA date (orig): 12/11-17						
Process step	Process input	Potential failure mode	Potential failure effects	SEVERITY	Potential causes	OCCURENCE	Current controls	DETECTION	RPN	Actions recommended
Collect & verify recived parts /Boxcar build	Boxcar parts	Wrong part	Deviation	8	Misstake by supplier	1	Follow up with supplier	4	32	-
				8	Wrong information in PBOM	3	Sign-offs and NCM	3	72	Lift the problem to R&D's manager - add updating TC to engineers job description
		Delayed part	Borrow from previous boxcar	5	Deviation was placed too late. Old HW is avalible.	2	None	5	50	Last date for deviation - need to be communicated
			Travel and get HW	2	Deviation was placed too late. No HW is avalible.	1	None	5	10	Last date for deviation - need to be communicated
			Update old HW with new SW	7	Deviation was placed too late. Old HW is available but new SW must be tested.	1	None	5	35	Last date for deviation - need to be communicated
		Part number not updated	Information differ, time consuming	2	Assembly list has not been updated	3	None	10	60	Add a process step in the deviation process where the assembly list is updated
Deviation request	Complexity	More deviations needed	Delay boxcar build	4	Wrong information in TC	3	E-mails to R&D, sign-off	3	36	Lift the problem to R&D's manager - add updating TC to engineers job description
NCM	Part information	No updated information	Deviations plac ed later in process	3	Lack of communication between HW&B and R&D	5	E-mails are send out 3-5 days before meeting	8	120	Inform R&D early in the process what is needed from them and a reminder at least one week before meeting
				3	New information not availble yet	2	None	10	60	Evaluate consequenses if devations do not get accepted
Re-sign-off	Part information	No updated information	Deviations placed later in process	4	Lack of communication between HW&B and R&D	4	E-mails are send out 3-5 days before meeting	5	80	Inform R&D early in the process what is needed from them and a reminder at least one week before meeting
				4	New information not availble yet	2	None	10	80	Evaluate consequenses if devations do not get accepted
Deviation request	Date recieved	Late in process	Delay boxcar build	4	A newer/better solution was found	1	Sign-offs and NCM	2	8	Evaluate consequenses if devations do not get accepted
				4	Existing solution is not working	2	Sign-offs and NCM	2	16	Add a function to PBOM with "parts likley to be subject for deviation"
				4	New information from supplier	1	Sign-offs and NCM	8	32	Add a function to PBOM with "parts likley to be subject for deviation"
Deviation request	Lead time	Accept long lead time articles	Delay boxcar build	4	No other solution is found	3	Purchasing check lead time before approval, still NOK parts are approved	8	96	Evaluate consequenses if devations do not get accepted
			Time for more deviations	5	No other solution is found	3	Purchasing check lead time before approval, still NOK parts are approved	8	120	Evaluate consequenses if devations do not get accepted
Sign-off	Part information	No updated information	Deviations placed later in process	2	Lack of communication between HW&B and R&D	8	E-mails are send out 3-5 days before meeting	8	128	Inform R&D early in the process what is needed from them and a reminder at least one week before meeting
				2	New information not availble yet	4	None	10	80	Evaluate consequenses if devations do not get accepted

Picture 4.13. Process Failure Modes and Effects Analysis of the boxcar process.

In the PFMEA in Picture 4.13, some failure modes got a high RPN and should be considered important. For example, *No updated information* in the NCM process step got a RPN of 120. Today, an email is sent out three to five days before the meeting, to avoid that the System engineers come unprepared. The recommended action for this failure is to inform the System engineers early in the process about what is needed from them. The reminder for the meeting should be sent out at least one week before the meeting. The recommended action would reduce the meeting time and improve the outcome of the meeting.

5 DISCUSSION

During the interviews, a lot of problem regarding the boxcar process, became clear. Problems like a lot of manual labour, many handovers to different people, many process steps and a long lead time. With all these issues, a high error rate is not surprising. Many boxcar parts are subject to deviation during the process and needs to be re-ordered which causes time delay and excessive costs. EE is affected as their integration test, that follows the boxcar delivery, are constantly being delayed and their results are often inaccurate, since they receive incorrect parts in the boxcars.

The PBOM is today an interactive excel list, shared by all the involved departments. However, two people cannot work in the same file at the same time. One suggestion to The Company, for reducing manual labour and human errors, is to investigate the possibility of using another type of database. A database that is more accessible and stable. When a change is done by a System engineer regarding a part that will be used in the boxcar, this information should go into the PBOM directly and automatically.

When working with this project, it was early discovered that important basic statistics that should be easy to find, was not. The total cost for each boxcar was received late in the project and the numbers are doubtful. They were based on estimations. There was no possibility, due to time limitations, to find out how many parts that were ordered twice or in any other way find what really caused the cost variations. A linear relationship between deviations and total cost and between lead time and total cost**,** was therefore assumed. This way, the research could still proceed.

The VSM diagram showed that PSS is involved in the boxcar process in many process steps. However, during the interviews it became clear that, at least some of the engineers are not aware of their involvement in the boxcar process. This means that working with the boxcar process is extra work for the people at PSS. It is not a part of their job description to update TC with correct information. There needs to be a discussion whether it should be a part of their job description. The System engineers should be informed, by their manager, what is needed from them. If the System engineers are involved early in the process, deviations might come in early. This would, as seen in Picture 4.11, lower the total cost of each boxcar.

From the process analysis, it was stated that the current process is 350 h away from being a *world-class* process. It is not realistic to cut these hours from the process, because of the lead time on certain parts. Purchasing need a minimum of 20 weeks to buy boxcar components because that is the lead time on some parts. Adding an additional order release, for the parts with shorter lead time, could simplify the process and avoid that multiple orders get sent out for the same part (due to deviation). This would minimize the deviations impact on the process, in other words make it more standardised. It would also decrease the total cost since the risk of double purchase is minimized and decrease the work load for the purchasing department. This suggestion needs further investigation.

When ordering parts for boxcars, HW&B creates a purchase request upon a certain amount that is approved to use for the respective boxcar. In case this amount is exceeded, a new PR is created. Today it is hard to keep track of where the money goes since several PR’s are used for the same boxcar. In some cases, the same PR has been used for more than one boxcar status. The expected costs, that the PR’s are based on, are not accurate. The previous boxcars have in this project been seen to end up costing a lot more. To be able to keep track of the cost for each boxcar, the first action from HW&B’s side should be to only make one PR for each boxcar status. This PR must contain enough money, so that there will be no need to open a new PR. The excess money, should after the project, go back to HW&B. This way, it would be easier to keep track of the cost for each boxcar and get control of the cost for each boxcar, which later can be used to base future budget proposals upon. The costs should be tracked and visualized in, for example, a control chart. The PR’s should be created well ahead of time before the MBOM-extraction.

Analysing deviations from previous boxcars, was difficult. The reason for why a deviation was made was not always stated in the PBOM and in some cases the stated reason was hard to interpret. To improve the possibility for analysing deviations in the future, the reasons for deviations should be standardised. The PBOM could have the following categories for common causes of deviations: *Added part, FFF Change, Part number change, Removed part, Revision change* and one for *other reasons.*

The quality of the collected data for this project affects the validity of the results. Available statistics for example boxcar costs, reasons for deviations and number of deviations has a low accuracy. In addition, it was difficult to say when the boxcars were assembled and delivered, therefore no data on the delays could be found. The information used when creating the VSM was an estimation done by the boxcar manager at The Company and the accuracy is not known. This report relies on a correlation between number of deviations and total cost and between lead time and total cost when building boxcars. This statement has not been proved, but should be further investigated.

6 CONCLUSION

The boxcar process has many process steps, many handovers to different functions, a long lead time and much manual labour. Many boxcar parts are subject to deviation during the process and needs to be re-ordered which causes time delay and excessive costs.

Suggestions to minimise cost variations when building boxcars and improve the current process at The Company are presented below:

1. The boxcar manager makes sure that the department only creates one PR for each boxcar status. After finished project this results in one metric for a cost of a boxcar and the financial manager keeps track of the costs using a control chart.

2. HW&B's manager to communicate with PSS's managers what is needed from the engineers. Discuss the possibility of adding to the System engineers' job description to update in TC.

3. Use another database than excel for the BOM-lists and make sure that information from a System engineer, regarding a part that will be used in the boxcar, goes into the PBOM directly and automatically. HW&B's manager should select one person to investigate possible solutions.

4. Investigate the possibility to have two different order releases; one for *long lead time parts* and one for *short lead time parts*. This needs to be done in cooperation with the purchasing department.

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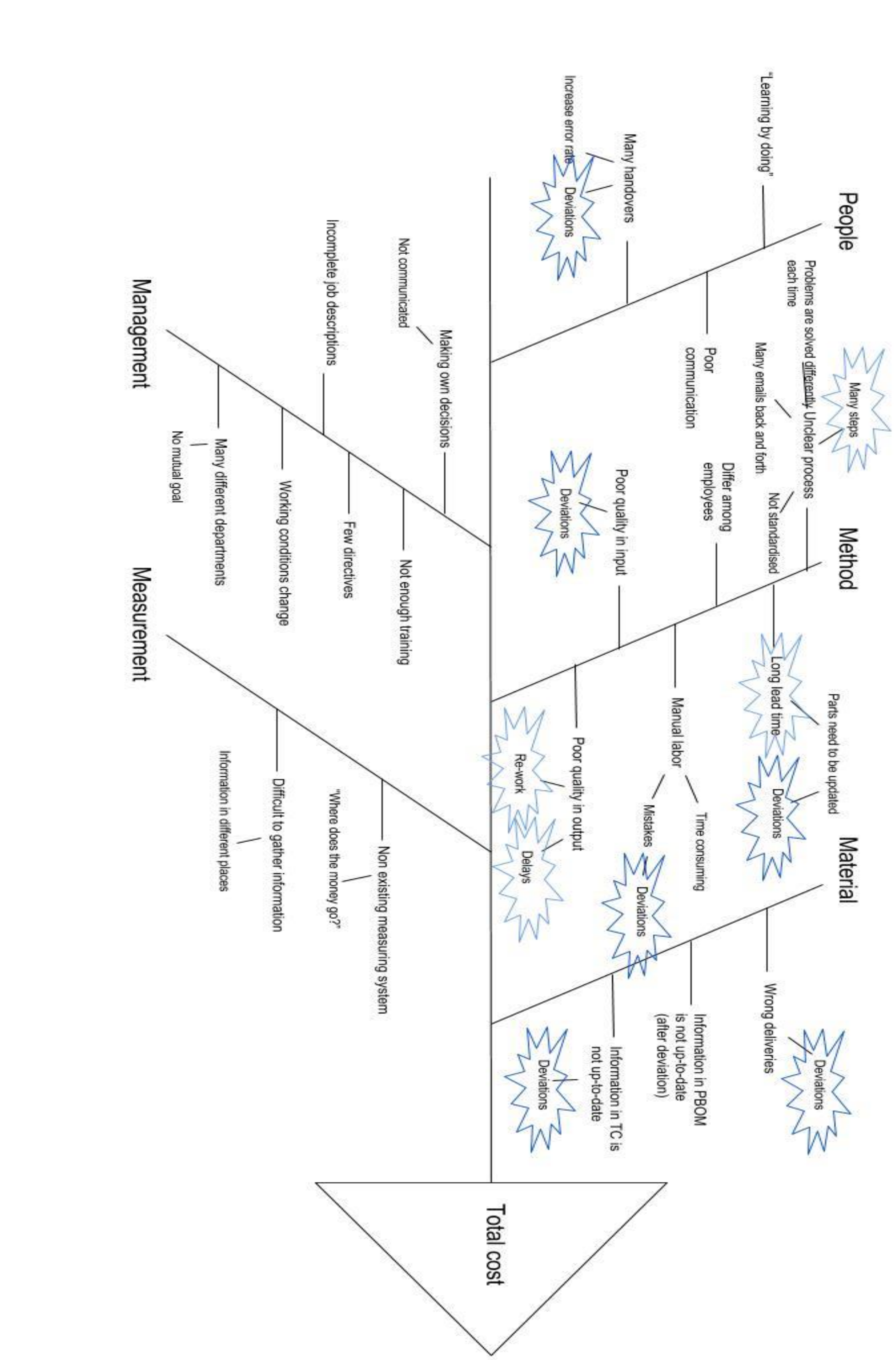
ATTACHMENTS

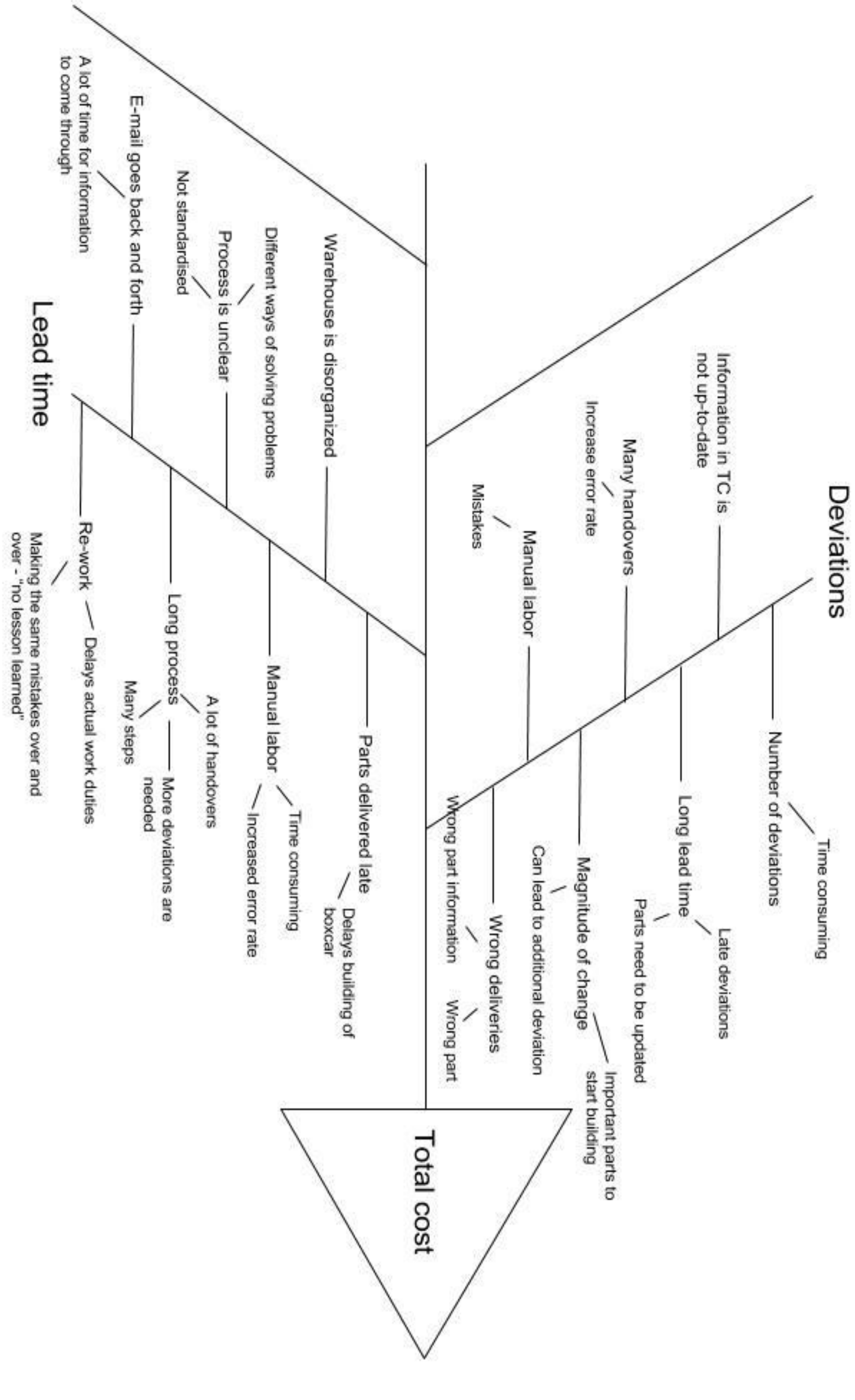
1. Interview Questions
2. Data Collection Form
3. Ishikawa Diagram 1
4. Ishikawa Diagram 2
5. Swim-lane Flowchart 1
6. Swim-lane Flowchart 2
7. Value Stream Map
8. PFMEA

General questions:

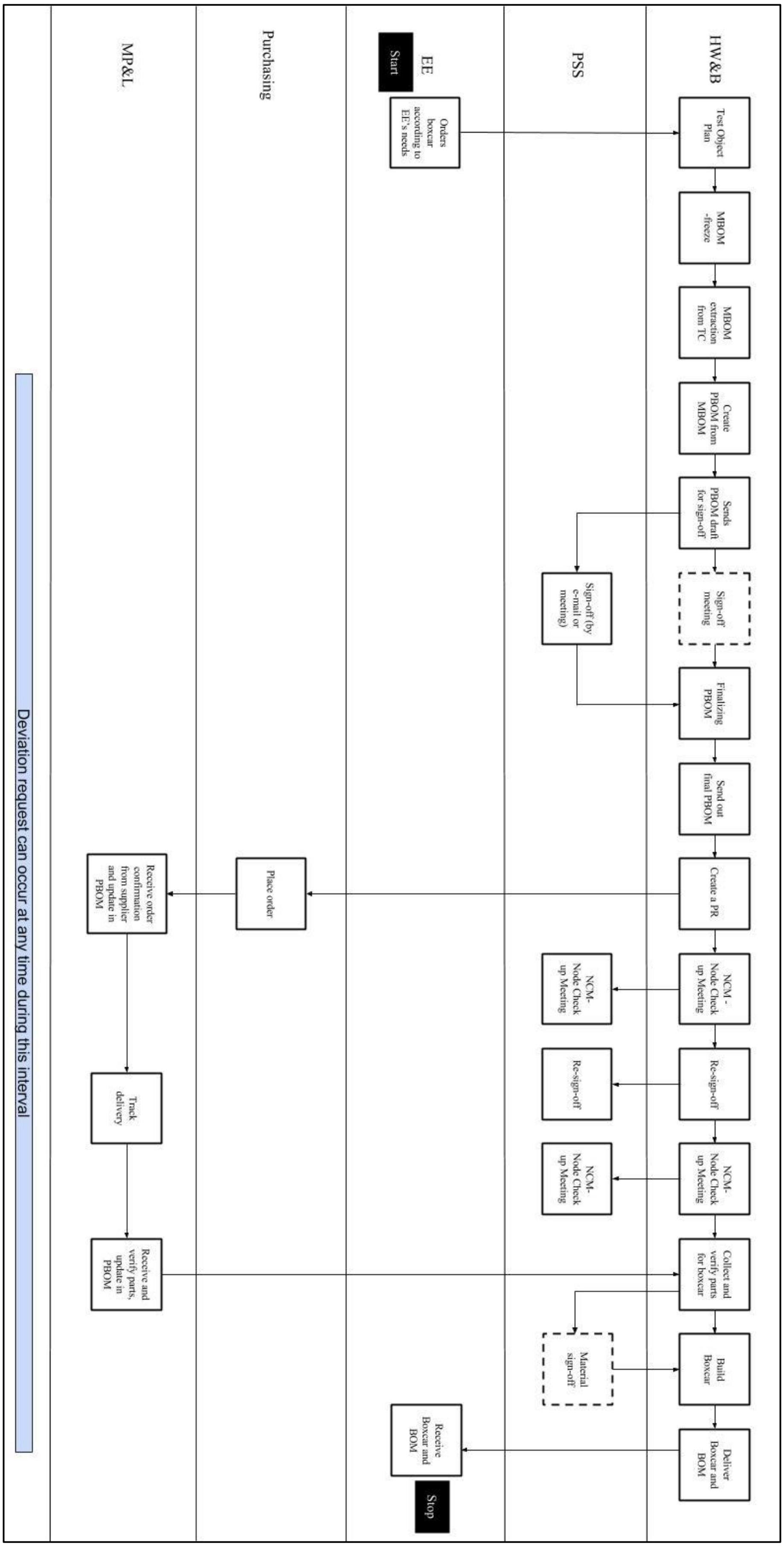
- What is your role?
- What is your opinion on the boxcar process? What is working and what is not working?
- Explain your contribution to the boxcar process, step by step.
- Explain “the deviation process” (change management).
  - What is your role in it?
  - How often does it occur?
  - Does this process look the same every time?

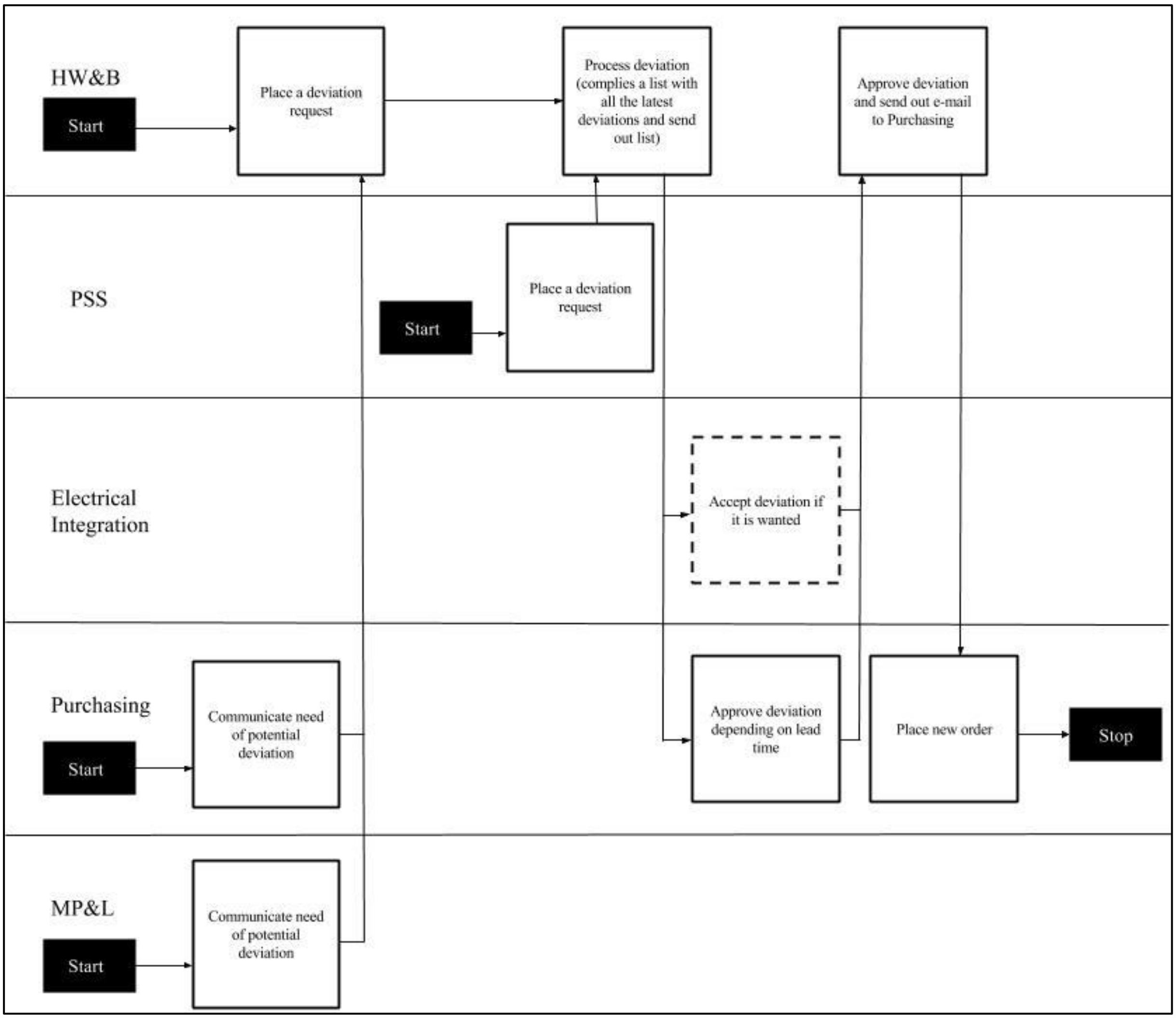
Activity	Process time (h)	Lead time (h)	Number of devations in each step (%)
MBOM extraction from TC	16	16	0
Create PBOM from MBOM	20	40	0
Sign-off	16	40	25
Create PR & send out final PBOM	2	40	0
Process one deviation	1.5	40	N/A
NCM 1	5	32	2
NCM 2	4	32	2
Re-sign-off	20	40	17


People
"Learning by doing"
Many handovers
Increase error rate
Deviations
Problems are solved differently each time
Poor communication
Many emails back and forth
Unclear process
Many steps
Not standardised
Differ among employees
Method
Poor quality in input
Deviations
Manual labor
Time consuming
Mistakes
Deviations
Long lead time
Parts need to be updated
Deviations
Poor quality in output
Re-work
Delays
Material
Wrong deliveries
Deviations
Information in PBOM is not up-to-date (after deviation)
Information in TC is not up-to-date
Deviations
Management
Making own decisions
Not communicated
Incomplete job descriptions
Not enough training
Few directives
Working conditions change
Many different departments
No mutual goal
Measurement
Non existing measuring system
"Where does the money go?"
Difficult to gather information
Information in different places
Total cost

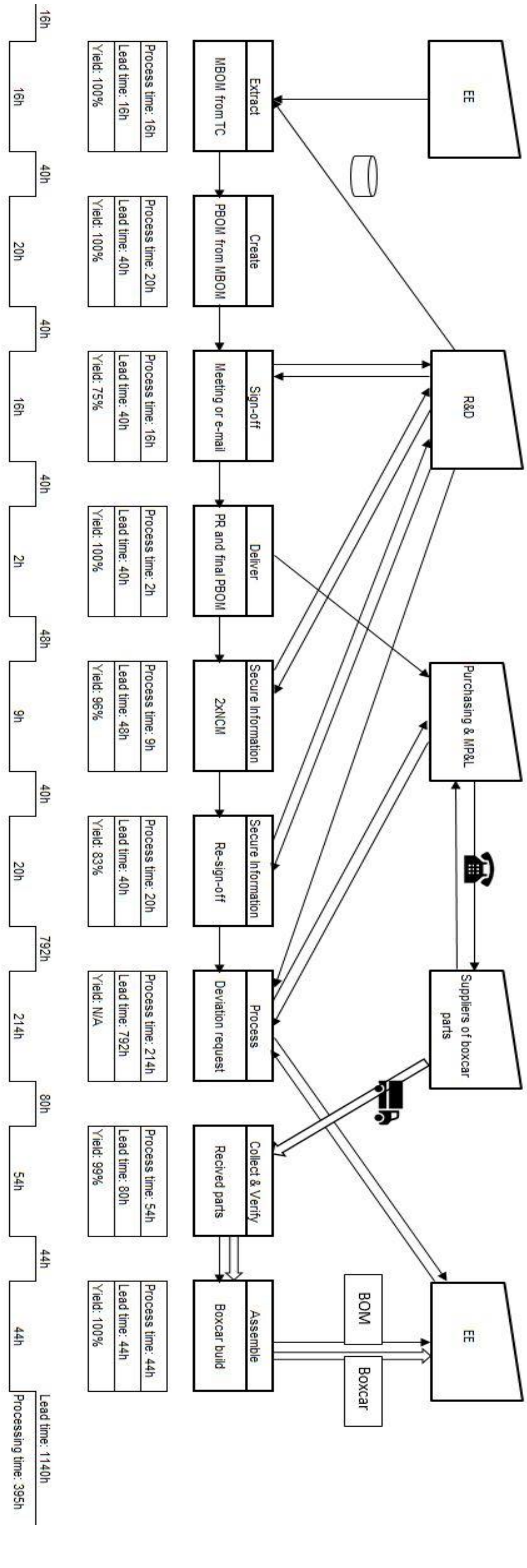


Lead time
Deviations
Total cost
Warehouse is disorganized
Process is unclear
Different ways of solving problems
Not standardised
E-mail goes back and forth
A lot of time for information to come through
Parts delivered late
Delays building of boxcar
Manual labor
Time consuming
Increased error rate
Long process
A lot of handovers
Many steps
More deviations are needed
Re-work
Delays actual work duties
Making the same mistakes over and over - "no lesson learned"
Information in TC is not up-to-date
Many handovers
Increase error rate
Manual labor
Mistakes
Number of deviations
Time consuming
Long lead time
Late deviations
Parts need to be updated
Magnitude of change
Can lead to additional deviation
Important parts to start building
Wrong deliveries
Wrong part information
Wrong part


HW&B
PSS
EE
Start
Purchasing
MP&L
Orders boxcar according to EE's needs
Test Object Plan
MBOM -freeze
MBOM extraction from TC
Create PBOM from MBOM
Sends PBOM draft for sign-off
Sign-off meeting
Sign-off (by e-mail or meeting)
Finalizing PBOM
Send out final PBOM
Create a PR
Place order
Receive order confirmation from supplier and update in PBOM
NCM - Node Check up Meeting
NCM- Node Check up Meeting
Re-sign-off
Re-sign-off
NCM- Node Check up Meeting
NCM- Node Check up Meeting
Track delivery
Collect and verify parts for boxcar
Receive and verify parts, update in PBOM
Build Boxcar
Material sign-off
Deliver Boxcar and BOM
Receive Boxcar and BOM
Stop
Deviation request can occur at any time during this interval


HW&B
Start
Place a deviation request
Process deviation (complies a list with all the latest deviations and send out list)
Approve deviation and send out e-mail to Purchasing
PSS
Start
Place a deviation request
Electrical Integration
Accept deviation if it is wanted
Purchasing
Start
Communicate need of potential deviation
Approve deviation depending on lead time
Place new order
Stop
MP&L
Start
Communicate need of potential deviation

ATTACHEMENT 7. Page 1(1)



Process Failure Modes and Effects Analysis

Process name: Boxcar process

Responsible: HW&B — PFMEA date (orig): 12/11-17

Process step	Process input	Potential failure mode	Potential failure effects	SEVERITY	Potential causes	OCCURENCE	Current controls	DETECTION	RPN	Actions recommended
Collect & verify recived parts /Boxcar build	Boxcar parts	Wrong part	Deviation	8	Misstake by supplier	1	Follow up with supplier	4	32	-
				8	Wrong information in PBOM	3	Sign-offs and NCM	3	72	Lift the problem to R&D's manager - add updating TC to engineers job description
		Delayed part	Borrow from previous boxcar	5	Deviation was placed too late. Old HW is avalible.	2	None	5	50	Last date for deviation - need to be communicated
			Travel and get HW	2	Deviation was placed too late. No HW is avalible.	1	None	5	10	Last date for deviation - need to be communicated
			Update old HW with new SW	7	Deviation was placed too late. Old HW is available but new SW must be tested.	1	None	5	35	Last date for deviation - need to be communicated
		Part number not updated	Information differ, time consuming	2	Assembly list has not been updated	3	None	10	60	Add a process step in the deviation process where the assembly list is updated
Deviation request	Complexity	More deviations needed	Delay boxcar build	4	Wrong information in TC	3	E-mails to R&D, sign-off	3	36	Lift the problem to R&D's manager - add updating TC to engineers job description
NCM	Part information	No updated information	Deviations plac ed later in process	3	Lack of communication between HW&B and R&D	5	E-mails are send out 3-5 days before meeting	8	120	Inform R&D early in the process what is needed from them and a reminder at least one week before meeting
				3	New information not availble yet	2	None	10	60	Evaluate consequenses if devations do not get accepted

Re-sign-off	Part information	No updated information	Deviations placed later in process	4	Lack of communication between HW&B and R&D	4	E-mails are send out 3-5 days before meeting	5	80	Inform R&D early in the process what is needed from them and a reminder at least one week before meeting
				4	New information not availble yet	2	None	10	80	Evaluate consequenses if devations do not get accepted
Deviation request	Date recieved	Late in process	Delay boxcar build	4	A newer/better solution was found	1	Sign-offs and NCM	2	8	Evaluate consequenses if devations do not get accepted
				4	Existing solution is not working	2	Sign-offs and NCM	2	16	Add a function to PBOM with "parts likley to be subject for deviation"
				4	New information from supplier	1	Sign-offs and NCM	8	32	Add a function to PBOM with "parts likley to be subject for deviation"
Deviation request	Lead time	Accept long lead time articles	Delay boxcar build	4	No other solution is found	3	Purchasing check lead time before approval, still NOK parts are approved	8	96	Evaluate consequenses if devations do not get accepted
			Time for more deviations	5	No other solution is found	3	Purchasing check lead time before approval, still NOK parts are approved	8	120	Evaluate consequenses if devations do not get accepted
Sign-off	Part information	No updated information	Deviations placed later in process	2	Lack of communication between HW&B and R&D	8	E-mails are send out 3-5 days before meeting	8	128	Inform R&D early in the process what is needed from them and a reminder at least one week before meeting
				2	New information not availble yet	4	None	10	80	Evaluate consequenses if devations do not get accepted