Reliable measurements of engineering work and follow-up process

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Mechanical Engineering **Abstract**

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ABSTRACT

This thesis studies the measurement and estimation of engineering costs for Evac, with the objective of identifying reliable solutions to estimate and track engineering costs, enhance project gross margins, and accurately allocate costs between standard product and project-specific engineering. The existing methods used for engineering cost and time estimation at Evac could have been more reliable, as evidenced by issues encountered in multiple projects. Currently, the allocation of engineering costs related to standard product development or corrections is unclear, resulting in some costs being assigned to the project department. This thesis presents constructive research aimed at improving the current practices and tools for engineering cost management. The data gathered through this research will serve as a foundation for developing a comprehensive plan and follow-up process to continuously enhance engineering work and optimize tools and methods for obtaining reliable data in future projects.

Keywords Jira, Engineering, Cost Management, Follow-up process

Pages 54 pages and appendices 6 pages

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List of Abbreviations

AML/AVL	lists of approved manufacturer or vendor parts
CER	Cost estimating relationship
DOE	Design of experiment
ERP	Enterprise resource planning
GA	General arrangement
IE	Energy efficiency class
IOM	Installation, operation, and maintenance manual
KPI	Key Performance Indicators
LMU	Local macerator unit
MA	Manufacturing assembly
MBR	Membrane Bioreactor
MFS-1	Macerator feeding station
OTD	On-Time delivery
PLM	Product lifecycle management
RO	Reverse Osmosis
SLA	Service level agreement
SOS	Scope of Supply
TC	Target Costing
TP	Tie-point
VA	Value Analysis
VE	Value Engineering
WBS	Work Breakdown Structure

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1 Introduction

This chapter introduces the organization to whom the thesis will be made, as well as the aim and purpose. It also focuses on the research methods and design, which will be utilized throughout the work.

The thesis is commissioned by Evac, a pioneering company within the field of sustainable technologies and solutions. Evac provides sustainable solutions for waste, water, and wastewater management both on land and sea. Evac was established in 1979, and during that time, the company provided vacuum toilets and vacuum collection systems. Since those days, Evac has expanded tremendously both by organic growth and by acquiring different companies. It has transformed from a product supplier to a system/solution provider with over 130 patents, over 500 employees in 14 countries, and a turnover of over 166MEUR in 2022. (Evac Company, 2023)

1.1 Aim and purpose of the thesis

Due to Evac's extensive product portfolio and its various projects with often heavily modified products, it is vital to have a functioning process for estimating engineering costs as accurately as possible. The need for the functioning process is to facilitate the creation of a realistic budget and schedule to facilitate the securing of the gross project margin and to have a clear understanding of the workload for each discipline and hence be able to predict the execution time and resources which are reflected in the project's on-time deliveries (OTD) and further to customer satisfaction.

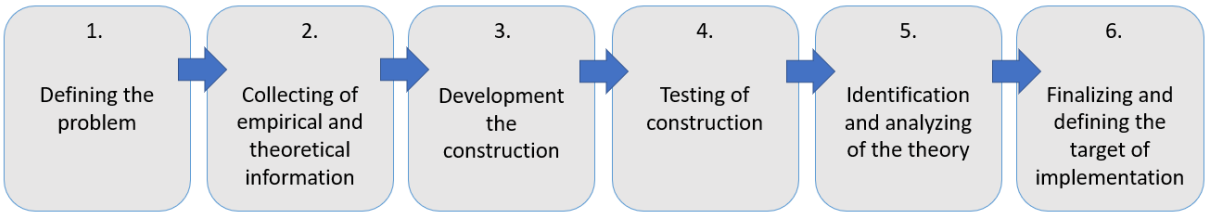
Thus, the thesis aims to build a solid foundation through constructive research on which Evac could build up a process for estimating engineering costs and implement a follow-up process that could be used to have reliable data for costs in engineering in future projects.

1.2 Research approach

The thesis utilizes the constructive research method. The process starts by identifying and defining the problem using the six core bases of the constructive research process, as shown in Figure 1. The second phase focuses more on the theoretical side. It consists of analyzing the issues by

reviewing relevant literature and, in this way, gaining a deeper and more holistic understanding of the issue and the commissioning organization. (Piirainen & Gonzales 2013, p.9) The third and fourth bases are intended for sketching and developing the construction. The construction is tested and re-developed until it becomes usable. By then, the process can proceed to phases five and six, where the process continues pragmatically toward finalizing and defining the implementation target. (Virtanen 2010, p.3)

Figure 1. Constructive research process (Rephrased from Rohweder 2008, p.11)



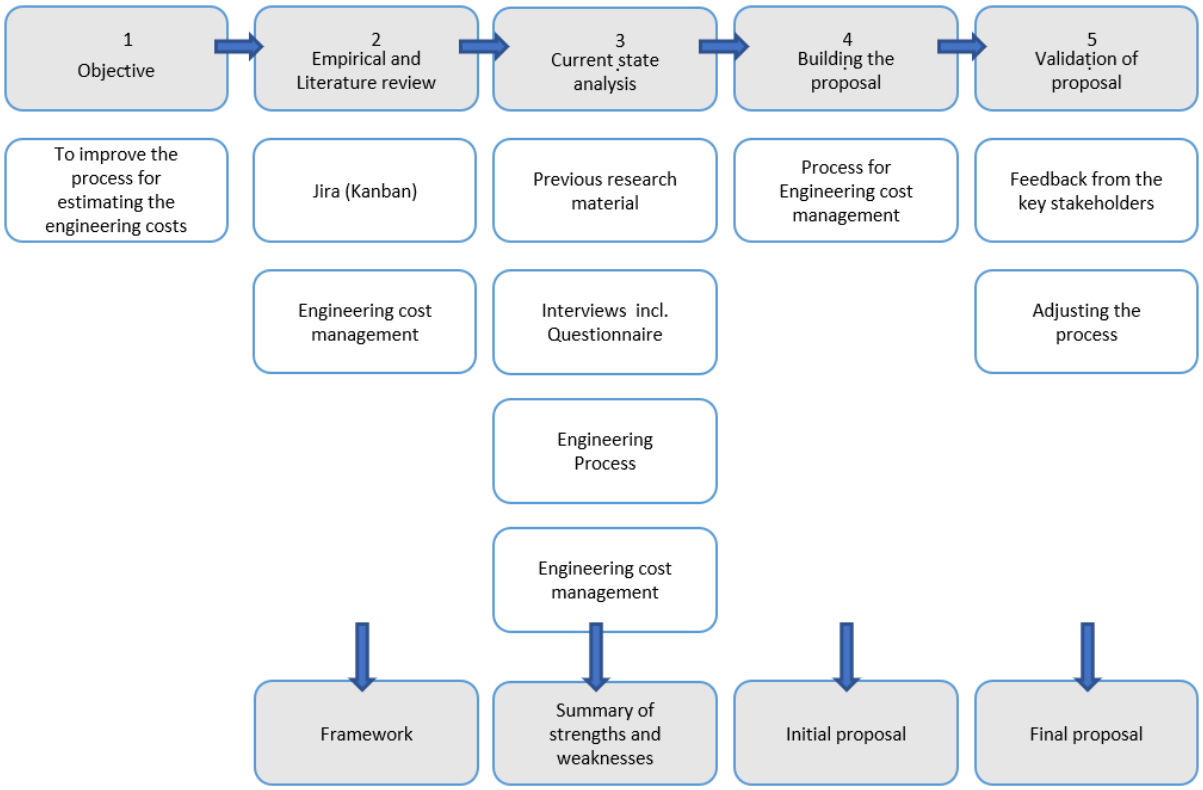
Note. The original Finnish text translated into English

1.3 Research design

As shown in Figure 1, the thesis is separated into six stages, but to have a more pragmatic approach, it was seen that adding the research design would give more deeper understanding of how the thesis was constructed. Thus, the process is similar.

Unlike the constructive research process, Figure 1, the research design in Figure 2 is separated into five steps to reach the objective. The first step in solving the current problem is to identify the objective. The second steps is the theoretical view of the tool in use and the engineering cost management methodologies. Following steps are the current state analysis which consists of the previous research material and the interviews with key stakeholders. The purpose is to get a clear view of the current state by analysing the questionnaires answers and studying the material created earlier on the same topic and the last two steps are building the proposal for the new engineering cost process and the validation of the proposed process. The result of this study is to get the framework for the future proposal for the process.

Figure 2. Research design (Rephrased from Lu 2015 p.8)



2 Theoretical framework

The theoretical framework presents the theory of the practices and tools introduced in the thesis. The theory section shows the possibilities that could be utilized at Evac in some parts where needed.

2.1 Jira

Jira was developed by the Atlassian group in 2002. It was initially designed as an issue tracking system for software bug tracking, but it has since evolved to become a potent and effective agile project management tool for Kanban and Scrum, and due to its advanced customization features, it is nowadays highly suitable for other types of ticketing systems as well, such as work orders, help desks, i.e. (Fisher et al, 2013, p.3)

The term Jira is used to refer to a common platform that encompasses multiple products. Along with Jira Software, which Evac utilizes, there are two other products in the Jira family: Jira Core and Jira Service Desk. (Li, 2018, p.7-8)

Jira Core shares many features with the classic Jira, including extensive customization options and workflow capabilities. However, it differs from Jira Software because it does not support agile methodologies such as Scrum and Kanban. (Li, 2018, p.7-8)

As the name implies, Jira Service Desk is designed for service desk use and is based on Jira Core. It boasts a user-friendly interface and prioritizes end-user satisfaction by establishing Service Level Agreement (SLA) goals. (Li, 2018, p.7-8)

Jira Software, which Evac utilizes, is essentially Jira Core with added agile capabilities. It is specifically intended for teams that employ agile methodologies such as Scrum or Kanban. (Li, 2018, p.7-8)

2.1.1 Agile method (vs. traditional)

The agile project management method is a flexible approach to managing projects. This method is ideal for undefined projects where business needs might change, and decisions might be complex and need creativity. The agile method focuses on continuous improvement, collaboration, and adaptability. The agile method is also called as "iterative" method instead of breaking the project into phases like in traditional project management. In the agile method, the project divided into smaller portions and treat them as separate projects. (Pell, 2022)

Choosing between agile and traditional project management methods depends on the type of project and organizational goals. Agile is often used in software development, where requirements change frequently, and flexibility is required. In contrast, traditional project management is often used in construction and engineering projects, where a detailed plan is essential, and changes are costly. (Salameh, 2014)

The most common differences between agile and regular project management are that agile relies on regular feedback and continuous improvement, whereas traditional project management emphasizes adherence to a predetermined plan. Traditional teams are often organized hierarchically with separate roles and responsibilities, whereas agile teams are self-organizing and cross-functional. (Salameh, 2014)

Overall, agile project management is better suited to projects where the requirements still need to be fully understood or may change frequently. Traditional project management is better suited to projects where the requirements are well-defined and the outcomes are predictable. (Salameh, 2014)

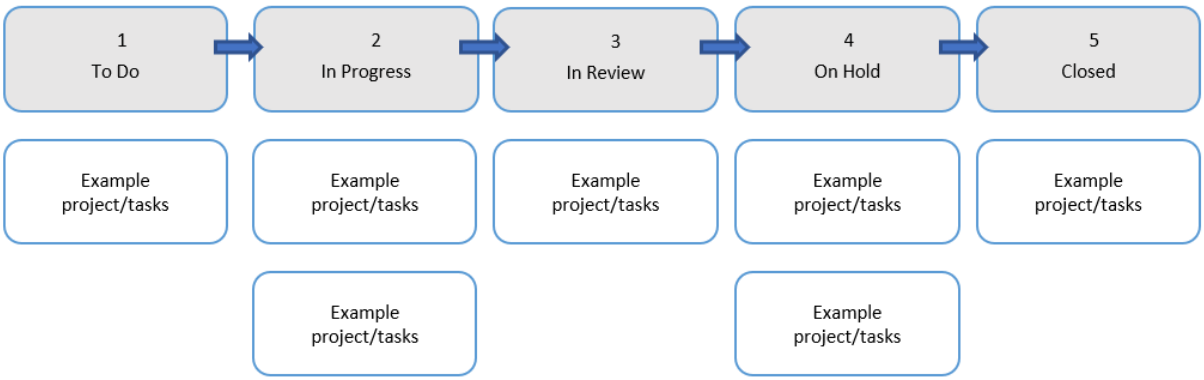
2.1.2 Kanban

The concept of Kanban originated in Japan and was first developed in the 1940s by Toyota. The translation from the Japanese word Kanban means "billboard," Today, it is recognized as one of the agile methods because it prioritizes the critical points for project management, such as efficiency, adaptability, and enhanced collaboration. (Pell, 2022)

The Kanban method is used to manage workflows by visualizing and monitoring the project's status and progress via Kanban boards. (Pell, 2022)

Usually, the Kanban board is divided into separate stages, each referring to the task state. In contrast, every task is represented separately on the Kanban board to represent the current state of the task. (Alaidaros et al, 2021, p.5) States on the current project tasks are presented on the Kanban board as To Do, In Progress, In Review, On Hold, and Closed.

Figure 3. Representation of the Kanban board in Jira



2.2 Engineering cost management

Cost engineering and cost estimation processes are related methods with different purposes. Cost engineering is a wider methodology that focuses not only on estimating the costs but also on cost management and control with the aim of project cost optimization throughout the project lifecycle.

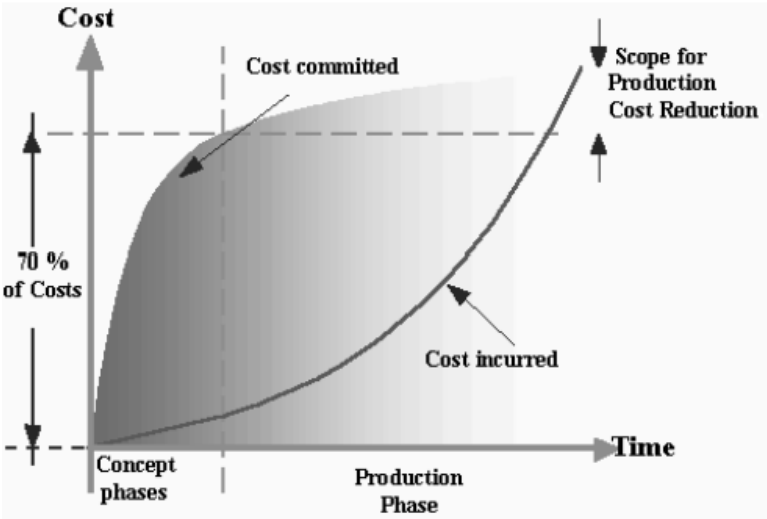
On the other hand, cost estimation is a process that forecasts product or project development costs. This method is usually applied during the planning phase of a project or product development. It uses various tools and techniques to provide a basis for budgeting and resource allocation.

2.2.1 Cost engineering

Cost engineering focuses on the technical aspects of cost estimation, budgeting, and cost management. It involves estimating project costs, developing budgets, and identifying cost-saving opportunities using data analysis and modelling techniques.

Multiple authors have stated that 70 to 80 percent of the product costs are determined during the design phase. Thus, the later in the design or manufacturing process the product or process alterations occur, the more expensive it will be, as presented in Figure 4. (Rajkumar, 2003, p.7)

Figure 4. Cost commitment curve (Rajkumar, 2003, p.7)



The difficulties of estimation in the design phase are well known, and the significant obstacles the engineers who are estimating the costs have to overcome are presented below. Hence the need for internal support in decision-making is vital.

- Working with limited available data on the new development.
- Taking into account technology advances over the product lifecycle.
- Requirements for demonstrating how cost estimates have been derived, including assumptions and risks.
- Costs of outsourcing a part to a subcontractor.
- Estimates must be accurate. (Rajkumar, 2003, p.7)

2.2.2 Cost Estimating

Cost estimating is very complex as it is about predicting the future. Danish physicist Niels Bohr described cost estimating as follows:

> "Cost estimating is the process of collecting and analyzing historical data and applying quantitative models, techniques, tools, and databases to predict an estimate of the future cost of an item, product, program, or task. Cost estimating is the application of the art and the technology of approximating the probable worth (or cost), extent, or character of something based on information available at the time." (Mislick & Nusbaum, 2015, p.11)

The cost estimation process, in general, when commencing cost estimation, is divided into four steps which are described below. However, it is good to remember that the process may vary depending on the organization.

- Definition and planning, including the following
    - Purpose of the estimate
    - Definition of the system
    - Definition of ground rules and assumptions
    - Selecting the estimation method
    - Selecting the team
- Data collection
- Formulating the estimate
- Review and documentation (Mislick & Nusbaum, 2015, p. 43)

2.2.3 Cost estimation methods

The first step in choosing the estimation method and formulating the estimation is to keep in mind that the aim is to produce a realistic and credible estimate. In order to achieve this, the estimator should focus on the following: Anchoring the estimation in historical performance. The estimate must be appealing and accompanied by good statistics. The estimate should be in line with the requirements, and it should be well-defined regarding the risks and content. Estimation should also consider future process and design improvements, and it should be validated by independent means. It should be traceable, auditable, and re-created using the same material, and lastly, the estimation should be explainable to management and other relevant parties. (Mislick & Nusbaum, 2015, p. 49)

The three main methods to be considered for estimating the costs are presented below. The thesis focuses only on the primary levels. However, it is also good to know that each method can be reviewed in more detail as it offers more comprehensive possibilities.

- Analogous estimation

- This approach is based on the assumption that the costs are similar to similar products.

  "The analogous costing methodology is characterized by adjusting the cost of a similar product relative to differences between it and the target product." (Hueber et al, 2016)

- Parametric estimation
  - The parametric method relies on historical data, such as cost and performance, as the method builds on the cost-estimating relationship (CER) developed using this data. (Mislick & Nusbaum, 2015, p. 51) CERs can be thought of as a mathematical relationship between the cost of a product or system and its parameters. These relationships are known as "cost drivers." A simple example of the parametric estimation could be a part size. As the part size increases, so will the manufacturing costs. (Hueber et al, 2016)

- Engineering build-up estimation or bottom-up estimation
  - This method summarizes all the detailed estimates from the material, labor, and manufacturing, i.e., costs, to form the total estimate. This method is considered one of the best due to its great detail. However, as a downside, it is very consuming, data-intensive, and requires deep knowledge of the product and process for estimating the costs and thus is expensive to produce. (Mislick & Nusbaum, 2015, p. 51)

In addition to the three methods, a fourth one is commonly used but usually presented as one of the main methods as it needs to be more comprehensible and repeatable to a third party.

- Intuitive technique or, in other words, rule of thumb or expert judgment.
  - This is the most basic estimation method, relying solely on the estimator's expertise and knowledge. Thus, it has benefits and can be applied when insufficient information or data is available for other techniques. (Hueber et al, 2016)

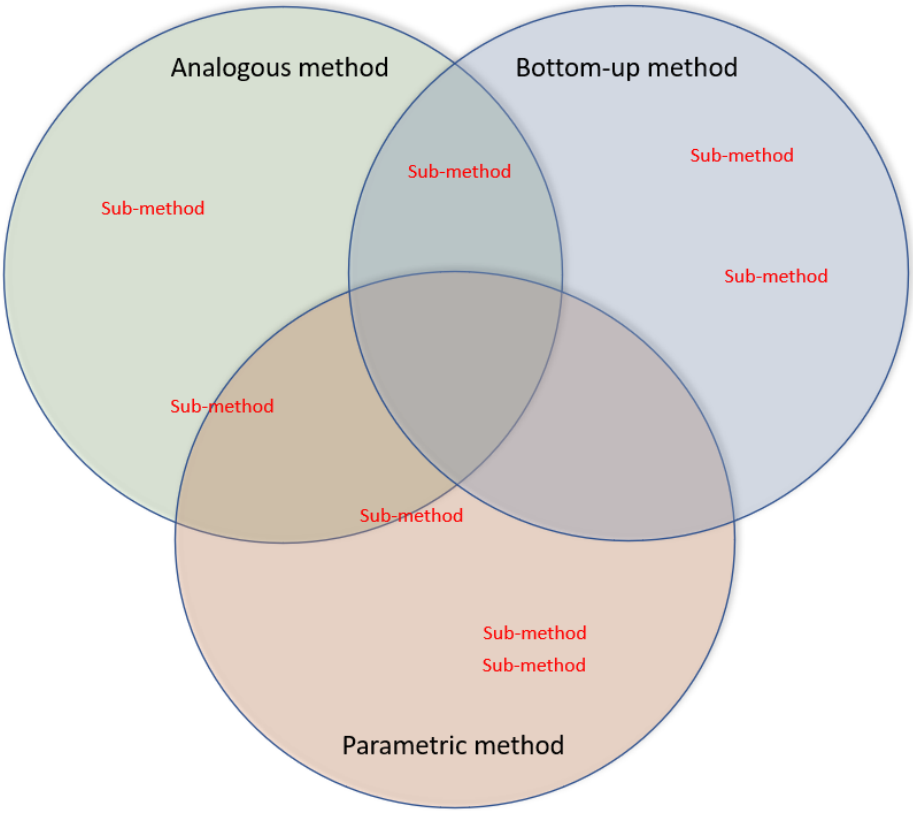
The three basic methods could be studied at a more detailed level using the extensive approach (Niazi et al, 2006). The extensive approach is, for example, dividing the analogous technique into two sub-method, regression analysis, and back-propagation neural network model (Hueber et al, 2016).

2.2.4 Cost estimation models

As mentioned, a cost estimation model may be a frame for integrating the estimation to allow more detailed cost structures for complex systems or products. With the cost estimation model, it is possible to use one or multiple methods simultaneously and for different parts of the system. However, the aim is to combine the strengths and overcome their weaknesses. (Hueber et al, 2016)

Figure 5. presents the criteria for selection where the positioning of the techniques in overlapping areas tells us if the model is using one or several different techniques and their sub-methods for estimation. Chapter 2.2.3 Niazi et al. mentioned that the three basic methods could be studied in more detail. However, for this thesis, it is not seen as necessary to go to a more detailed level but to understand the possibilities with represented sub-methods as part of the models.

Figure 5. Criteria of selection



2.3 Indicators for engineering control

In order to be successful in the engineering cost estimation process, this study focuses on three common methods, which are well-proven and suitable for engineering and estimating the costs in the design phase. The three methods are: Target costing (TC), value engineering (VE), and analysis (VA)

2.3.1 Value engineering and Value analysis

The value engineering (VE) method studies the relationship between the function of a product and its costs while maintaining or improving its quality, performance, and reliability. VE can be applied at the concept phase of product development. (Rajkumar, 2003, p.14)

Value engineering is similar to Value Analysis (VA), but they serve a different purpose. As described, VE focuses more on the function of a product and its costs. In contrast, VA focuses on existing products concerning new processes, new assembly methods, and materials (Rajkumar,

2003, p.14) by analysing the components, assessing their value, and identifying ways of reducing costs and improving performance.

2.3.2 Target costing

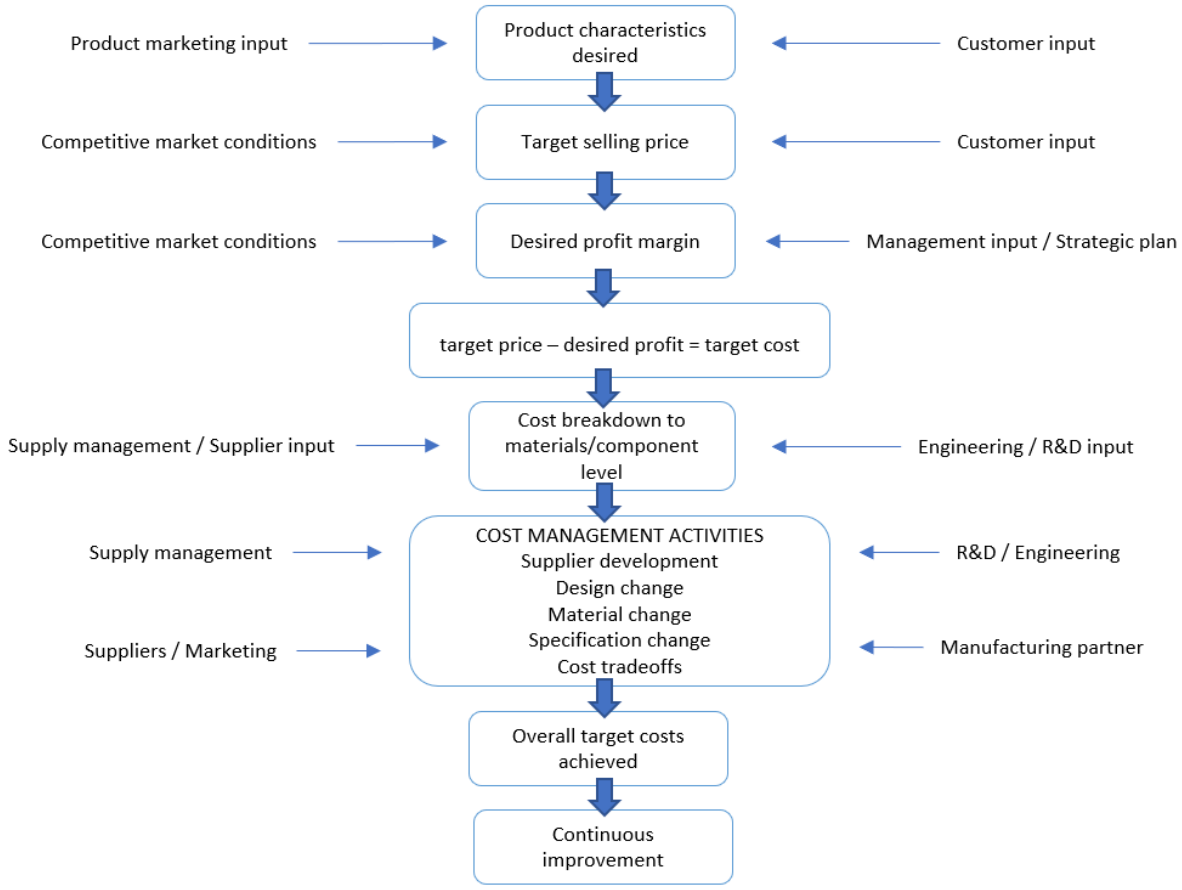
Target costing is a well-acknowledged cost management technique used by several businesses; in particular, Toyota has reported many successful applications of the TC process. (Jariri & Zegordi, 2008, p.3) It is recognized as an important tool for cost reduction and business competitiveness, and in 1991 it was named "Japan's smart secret weapon" by Fortune Magazine. (Ellram, 2002, p.1)

TC technique is highly suitable to use in a manufacturing environment as it provides a framework that emphasizes cost management throughout the product lifecycle, starting from the earliest stages of product development. However, TC is applied mostly in the design and development phases, where most of the decisions affecting the lifecycle costs are made. TC can also be combined with existing cost management and estimating tools, such as Value engineering (VE) and Value analysis (VA). (Rajkumar, 2003, p.17)

TC process starts by focusing on the product's selling price and desired profit margin already in the design phase. The formula by which the allowable target cost can be calculated is based on these two variables. Target price – desired profit = target cost (Jariri & Zegordi, 2008, p.3)

Figure 6. summarizes the target costing process and shows the inputs of different stakeholders in the process.

Figure 6. Target costing process (Rephrased from Ellram, 2002 p.2)



3 Current state analysis

This chapter discusses the current methods of Evac engineering and processes to understand the starting point and to have a reference for later comparison of strengths and weaknesses for current and proposed processes for engineering cost management and estimation process.

3.1 Previous research

This thesis is implemented in cooperation with Evac's project and engineering departments, and the idea came from the need to improve the engineering cost estimation and follow-up process.

The thesis is a continuation of the Six-sigma green belt certification project which was conducted between September 2022 and February 2023. During this time extensive amount of material was gathered regarding the issue, which I was able to use for further processing.

3.2 Interviews

The interviewees were chosen from the engineering and the project department due to their professional skills with the tools used and their close relation to the issues in question. Interviews were mostly arranged at the office face to face, but on some occasions, the answers to the questionnaires were submitted via email. Names of the interviewees were not announced due to their privacy and sometimes sensitive responses.

Table 1. Interviewee information

Order	Date	Role	Notes
1	6.3.2023	Manager, Project and Product design	
2	16.02.2023	Head of the project management office	via email
3	21.02.2023	Project Engineer	
5	17.02.2023	Lead product engineer	via email

The questionnaire included six questions in total which were related to the current ways of working in engineering, and the aim was to lead the respondents to provide a framework of the issues that they see existing in the current tools and methods.

1. As the topic of the thesis is related to Engineering costs and follow-up processes, what, in your opinion, are the three main reasons for Evac's bad performance in estimating the engineering costs for current and future projects?
2. How would you enhance the cost estimation process?
3. Jira is currently used for issue tracking and estimating the issue costs in Evac; how do you see that the software could be enhanced for our better use?
4. In your opinion, is the current Jira layout fit for purpose, or should it be updated, and if so, how?
5. Currently, in Evac, the project and site management-related hours are recorded in the "hour reporting excel-file" Should these be recorded in Jira the same way as the engineering hours, and why?
6. General comments/opinions

3.2.1 Strengths and Weaknesses

The questionnaire itself did not focus on asking about the strengths and weaknesses. However, it mostly focused on the current ways of working as it has already been noticed that the current way has challenges and may not give the best outcomes. As figured, the responses were more related to the negatives than the positives, which also gave the impression that something must be done for a better performance. Responses were also quite similar and focused on some key issues; some are listed here:

- Missing clear references from past projects
- Create processes and tools for estimating the costs more accurately
- Jira to be improved (adding other departments, including more automation, etc.)
- All project-related hours under one platform

Apart from the questionnaire, several known issues are causing different problems and in the engineering phase, such as no proper time tracking on engineering tasks, no accurate data for the engineering time spent on the unit level, no process for evaluating the percentage of custom unit deviation compared to a standard unit, no performance tracking of individuals or departments and no tracking of unpredicted changes and customization on units.

3.3 Engineering process

The engineering process consists of multiple disciplines, such as mechanical, electrical, process, and documentation. Engineering tasks in Evac can vary from small 5 to 20 hours of work up to 800 hours depending on the project's scope and the nature of the task. For example, large system projects include multiple units, and the nature of engineering can be related to electrical cabinet relocation for a black water vacuum unit, which takes approximately eight hours of engineering work all to way up to re-engineering of the reverse osmosis (RO) unit, that requires dozens of hours, possibly even hundreds. The reasons for re-engineering could be, for example, space limitations, etc.

The engineering process in Evac is well-defined. It contains three different engineering gates, followed systematically, meaning that when the EG1 gate is reached, a meeting will be arranged

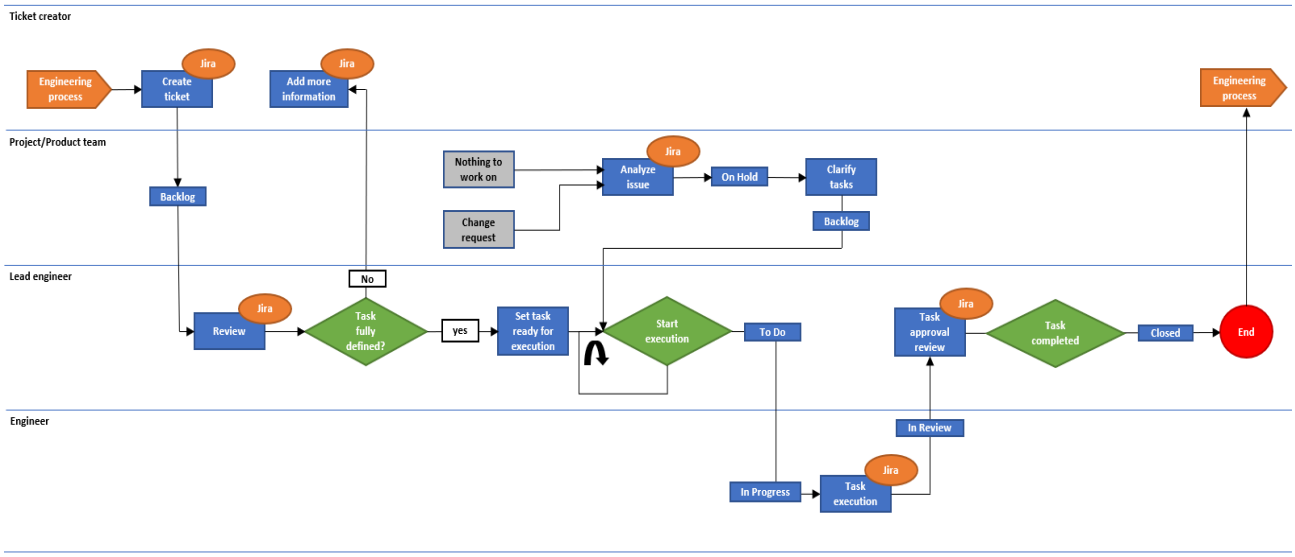
where all the documentation, i.e., shall be reviewed. Once all are proven good, the gate can be passed, and the next phase can begin.

1. EG1 – Initial engineering and basic documentation
2. EG2 – Basic engineering
3. EG3 – Detailed engineering and documentation

These gates are distributed to process, mechanical, electrical, and automation branches, led by the lead engineers of each system and discipline. These items are always documented on the gate memo and followed up on. The gates are not wholly rigid and allow for the passing of gates with the gatekeeper's approval even if not all prerequisites are met, meaning that the process can move forward with comments or notes that may be followed up on separately or even checked at a separate gate review. However, the engineering process starts from the engineering ticket process, which will focus more on the later stages of the thesis related to cost management. The tool (JIRA) is used to launch different project tasks and implement engineering work estimations.

The ticket process in Figure 7. defines the steps for creating the tasks for the engineering department, starting from the initial request from the ticket creator, who may, for example, be a project engineer. Once the ticket is created, the lead mechanical engineer will review it to see that the details are fully defined to start the execution. Another review round will be done after the request has been executed to confirm that it is done according to the requirements, after which the ticket can be closed if approved.

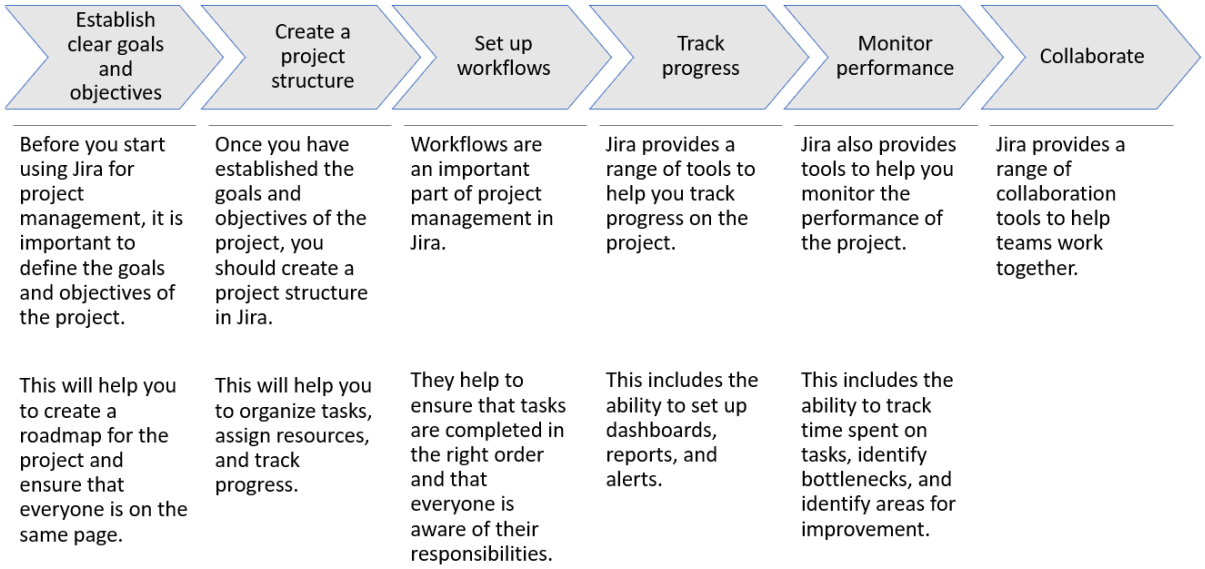
Figure 7. Engineering ticket process



3.3.1 Tools

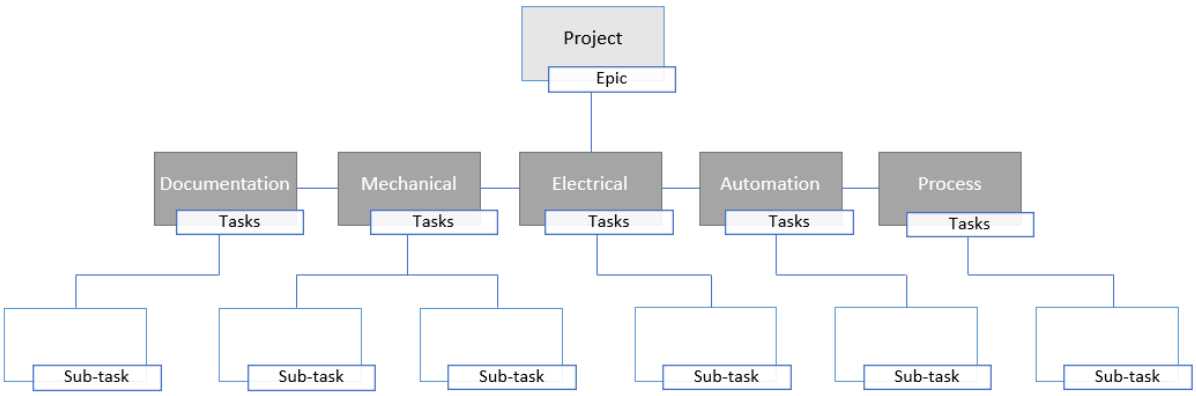
Jira Software is the primary tool in Evac for distributing engineering tasks between internal stakeholders. Jira provides a wide set of tools for tracking and monitoring projects and maintaining good collaboration between team members. Using Jira in new projects starts by establishing clear goals and objectives, which helps to create the roadmap and keep all parties informed. After the goals and objectives are clear, the project structure would need to be created. The project structure includes Epic as the project itself as well as Tasks and sub-tasks as presented in Figure 9. The next step after setting up the structure is to set up the workflows, which helps to keep track of the different tasks, including their priorities and responsibilities. Following figure 8. is representing the use of Jira and different steps for setting up the projects in more detail.

Figure 8. Use of Jira



The current layout in Jira was initially designed based on the need to control engineering tasks by discipline and to be able to follow up on projects. However, it was noticed that the configuration has some space for improvements, which are discussed in more detail later in the thesis. The layout is constructed so that the body of work, called agile EPIC, can be broken down into specific tasks or child issues and sub-tasks according to the customer's needs. (Atlassian, Agile epics 2023) The structure can be considered at Evac so that the EPICs represent the projects. Tasks represent the engineering department, and the sub-tasks represent all department tasks.

Figure 9. Representation of the Current Jira layout



The details which specify the project or tasks are to be filled in during the project initiation in Jira. The details have been made to include all the necessary information; however, keeping it simple and easy to understand and use, as one of the respondents nicely phrased, "The more fields, the less they are filled." Currently, the mandatory fields to be filled are:

- Description, describing the project or tasks in detail level
- Reporter, the person who creates the initial request
- Reviewer, the person who reviews and approves the task
- Assignee, the person who is assigned to the task
- Department, which department the task belongs to
- Engineering task type, type of the task, e.g., mechanical, electrical, documentation
- Original estimate, Estimated time for the task to be completed
- Start date
- Due date
- Priority
- Ready for execution, is the ticket ready to be executed

Following is an example of how the process goes for creating a ticket for Engineering. The electrical panel must be revised for a standard Membrane Bioreactor (MBR) unit in this example. The process would start with the reporter creating a ticket for the engineering department, more specifically, electrical. The reporter, in this case, would be a project engineer. The next steps of the process are listed below in chronological order.

- Reporter to fill out the relevant fields such as department, engineering type, estimates, and due dates, of which the most important is the description.
- Once the ticket is filled, it can be set to "to do" state
- The assigned reviewer will then assign an assignee to perform the requested work
- Once the task has been started, the assignee will set the ticket to an "in Progress" state. During this time, the requested modifications will be implemented. After the assignee has finalized the work, the ticket will circulate to the reviewer, and at this point, the ticket state is changed to "In review."
- After all the changes are reviewed and found ready, the task can be closed. The same method applies to all the requests, no matter if the task is related to Electrical, Process, or Documentation.

3.3.2 Engineering hours in Jira

For every task, the description and related fields shown in the previous chapter, 3.3.1, would need to be filled appropriately to complete the work smoothly. Closely related to this matter is also the work log filled by the designers, i.e., working on the task, and from where one can see the description of the work done and the hours used. The work log would need to be filled so that whoever is reading it understands what has been done and how many hours were used on that specific work per day.

3.4 Current cost-estimating methods

The engineering cost evaluation is based on the intuitive technique and references from previous projects. The cost estimation is made by the lead mechanical engineers with the support of product and project engineers if needed. The estimations are implemented in the estimation Excel, as shown in Figure 10.

Figure 10. Estimation excel

	h	€/h	€
Non-material costs of the Project			**0**
Project Management costs:			**0**
PM work (hours)			**0**
PE work (hours)			**0**
Travel costs (PM and PE)			
Engineering costs:			**0**
Process Engineering			**0**
Lead Process Engineer work			0
Process designer work			0
Mechanical Engineering			**0**
Vacuum scope			**0**
Lead Mechanical Engineer work			0
Mechanical Designer work - Customization 1			0
Mechanical Designer work - Customization n			0
Waster Water scope			**0**
Lead Mechanical Engineer work			0
Mechanical Designer work - Customization 1			0
Mechanical Designer work - Customization n			0
Dry Waste			**0**
Lead Mechanical Engineer work			0
Mechanical Designer work - Customization 1			0
Mechanical Designer work - Customization n			0
Wet Waste			**0**
Lead Mechanical Engineer work			0
Mechanical Designer work - Customization 1			0
Mechanical Designer work - Customization n			0

3.4.1 Real-life cases

In general, it has been noticed that the current methods of cost estimating, in most cases, are not providing the wanted results. However, the differences between estimated and actual can be dozens or even hundreds of hours, ultimately showing a negative in the project's gross margin.

As one common point during the investigation, it became clear that a major part of the challenges has been the changes in the processes and specifically in the quality requirements in Engineering. Due to the requirements, there has been a need to improve product lifecycle management (PLM) software by adding new component libraries and by enhancing product structures. This has caused issues in the estimation processes as, in some cases, the component library improvement-related costs are allocated to different projects.

The quality requirements demand that all the products which are to be purchased need to be in shape, meaning that the product structures need to be complete as well as all relevant documentation such as technical data sheets, 3D CAD model, and manufacturer ID, i.e., need to be placed under the product item code.

Below are two cases where the estimated vs. actual costs have diverged considerably. The cases were studied in cooperation with the related lead mechanical and project engineers and, in some cases, with the designers. Names or other confidential information is not given but only the initial information of the tasks and the estimations.

Case 1.

The first case was related to food waste collecting units where the initial request was to replace the planned Local macerator unit (LMU) unit with another type of third-party macerator MFS-1 unit, due to the customer's request. The MFS-1 unit was in an obsolete state, meaning that it should not be sold, but as the LMU unit did not pass the owner's review, it was agreed to be replaced. A couple of points regarding the LMU and why it did not pass the owners review was the lack of collar on the hopper, which would prevent the excess water from entering the piping during the washing of the tables, i.e., and the hopper height, which in LMU was 25 mm and in MFS-1 is 60mm. This height is directly related to the feeding capacity.

During the design review of the MFS-1 product, it was agreed with the lead mechanical engineer that only the motor would need to be revised due to the IE3 requirement. The design work was estimated to take approximately 15 hours. However, the product structure from PLM software, Windchill, was missing, which according to quality requirements, must be done in order to promote the unit to the released state for purchasing. It is worth pointing out that the product was third-party owned and, as stated in the previous chapter, obsolete and would not need to be fully revised, if any. Nonetheless, the designer had to do the following actions due to the requirements.

Mechanical design

- Creation of new CAD parts & assemblies to fulfill the quality requirements.
- Improvement of piping CAD documents with the aid of the piping tool on Creo for easier modifications.
- Replacement of old fasteners & fittings with standard library items to get the right equipment structure.
- Creation of new drawings for individually manufactured parts.

Product structure

- Creation of equipment structure from scratch since, from reference documents, the equipment structure was missing.
- Definition of old and new spare parts on Windchill by collecting all the relevant data, creating equipment parts and lists of approved manufacturer or vendor parts (AML/AVL) part with the aid of the NPRS team

Ultimately, the estimated 15 hours of work was expanded to 200 hours. In conclusion, it could be stated that the reason for this massive exceeding of planned hours was a sum of many. The lead mechanical engineer appointed to lead the task left the house during the process, thus leaving the decision-making entirely to the designer. This led to revising the obsolete product structure as described above. The process was also unclear as the product was third-party owned, but some Evac components were to be included; it was not fully clear how they should have been treated. Was it relevant to fix the whole structure, or would it have been enough to change the motor only as originally planned and purchase the unit with the manufacturer ID?

Case 2.

The second case was related to RO-unit designing. The project was partially a research and development (R&D) project due to the space limitations on the vessel, requirements for motors, and the level of details in engineering that were about to change. The design work started before the current quality requirements were in place, and initially, the plan was to design the steel frame and include some main components and piping by using the old projects as a reference.

Main Sub-task for reverse osmosis system 900m3/d stated:

- The new number is to be opened
- The very simple model, according to the attached PDF file with tie points (TP's) and overall size dimensions to be created, if possible, size under two m-bytes

The task, which included three sub-tasks for the mechanical engineering of the system, was originally estimated for 500 hours. However, in the end, it exceeded almost double the original with 989 hours. The hours for the main sub-task were distributed as follows: After 250 hours were used, the frame and first edition of the complete piping were reviewed. Three hundred seventy-

five hours; this point included plenty of component checking and investigation, i.e., 450 hours; all manufacturing drawings were checked in, after which some update requests came for the piping, some details as well as pumps to be revised, which in total took approximately 100 hours. In this stage, 550 hours were spent. Along the way, the scope expanded as the requirements were changed, and it was required to have the structure in perfect condition, which caused several actions to be made.

Completing the WT structure means fixing all the "in work" status items to get them into a "released" state. In order to get the state into "released," requires someone to review and promote the items one by one, which is very time-consuming. Secondly, several RO components needed to be investigated and specified to get them into the system, as they were not documented properly. The level of detail in the model was also unclear as, in the past, only a piping & instrumentation diagram (P&ID) and a general arrangement (GA) were sufficient. Due to the new requirements, a full drawing package was required to be submitted to the manufacturer. The level of detail in the model ended up being very high, which caused a lot of additional questions from the manufacturer, like how and what, which were normally handled in production.

In conclusion, it could be stated that the estimated time did not consider how much work fixing the structures took. Multiple project-related hours were used to improve the standard item library by investigating and defining the items and communicating with relevant parties to get the standard "in work" items released. New ways of working required a lot of communication between Evac and the manufacturer as they had a lot of questions and requests regarding the model, drawings, and general support.
In general, for the previous studies, it became clear that the biggest issues were related to the process, which at that time was rather new, and the people working around it did not consider how much work fixing the structures would take. However, there are multiple similar cases where the estimated costs have exceeded and are unrelated to any of the issues mentioned in cases one or two.

3.4.2 Analysis of Jira data

As mentioned at the end of the previous chapter, there are multiple cases in addition to the two studies where the estimated costs are deviated from the actual. This section is digging into the Jira data to understand the amount and possible reason behind the current state.

There are currently over 2300 (checked in October 2022) tickets open in Jira, including Epics, Tasks, and Sub-tasks. The distribution between these is Epics 181, Tasks 858, and Sub Tasks 1334. As we can see, most open tickets are sub-tasks with less than 100 hours. More detailed information on the number of tickets per category and the distribution between departments by percentages is shown in Figure 11.

Figure 11. Number of tickets per category

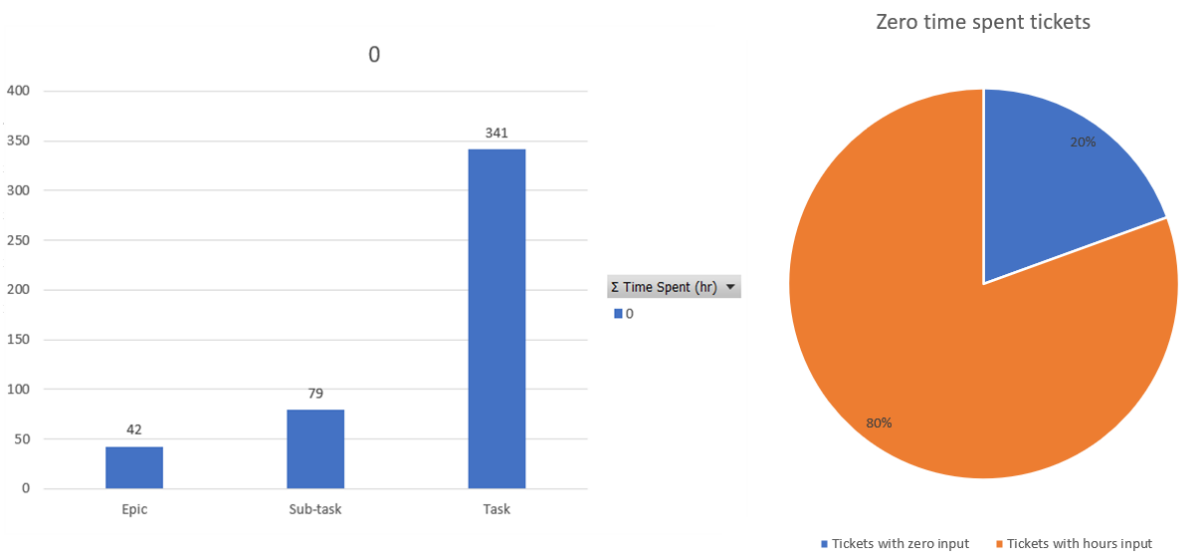
	Projects	Tasks					Sub-tasks				
Sorting condition	Epic data	All	Mech.	Docu.	Elec.	Process.	All	Mech.	Docu.	Elec.	Process.
Greater than 5K hrs.	2	5	5	0	0	0	3	3	0	0	0
1K <x< 5K hrs.	11	12	7	5	0	0	1	1	0	0	0
500 <x< 1K hrs.	15	22	10	8	3	1	5	4	1	0	0
100 <x< 500 hrs.	40	101	33	44	2	22	100	49	37	3	9
Less than 100 hrs.	113	718	214	180	188	136	1225	532	467	21	196
Total	181	858	269	237	193	159	1334	589	505	24	205

	Projects	Tasks					Sub-tasks				
Sorting condition	Epic data	All	Mech.	Doc.	Elec.	Process.	All	Mech.	Docu.	Elec.	Process.
Greater than 5K hrs.	0,08 %	0,21 %	0,21 %	0,00 %	0,00 %	0,00 %	0,13 %	0,13 %	0,00 %	0,00 %	0,00 %
1K <x< 5K hrs.	0,46 %	0,51 %	0,29 %	0,21 %	0,00 %	0,00 %	0,04 %	0,04 %	0,00 %	0,00 %	0,00 %
500 <x< 1K hrs.	0,63 %	0,93 %	0,42 %	0,34 %	0,13 %	0,04 %	0,21 %	0,17 %	0,04 %	0,00 %	0,00 %
100 <x< 500 hrs.	1,69 %	4,26 %	1,39 %	1,85 %	0,08 %	0,93 %	4,21 %	2,06 %	1,56 %	0,13 %	0,38 %
Less than 100 hrs.	4,76 %	30,26 %	9,02 %	7,59 %	7,92 %	5,73 %	51,62 %	22,42 %	19,68 %	0,88 %	8,26 %
Total	7,63 %	36,16 %	11,34 %	9,99 %	8,13 %	6,70 %	56,22 %	24,82 %	21,28 %	1,01 %	8,64 %

Many of those 2300 plus tickets are empty, meaning there is no input on estimated or spent hours. In the long run, this causes multiple tasks to stay in the backlog for the project as they are not needed, but they are still showing in the metadata. This is caused by creating the projects in Jira as every time a new epic is opened, the tool creates the tasks like electrical, automation, mechanical, and process automatically for it.

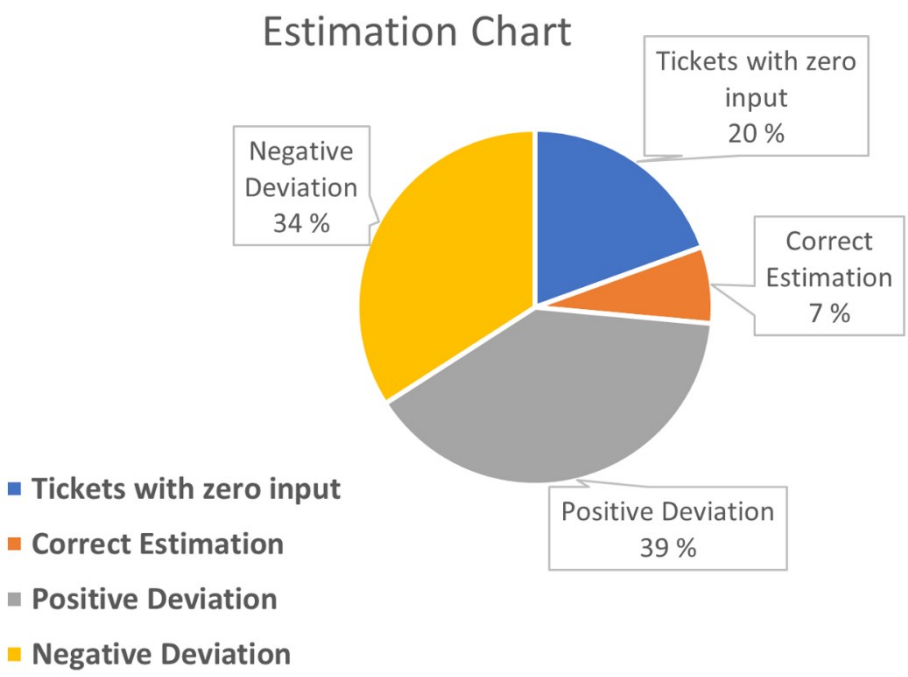
Of all the tickets, 462 are without input, which equals 20% of the total amount. Following Figure 12. shows the distribution of zero time spent tickets by the categories.

Figure 12. Zero time spent tickets by categories



Regarding the estimated hours, the total amount of correctly estimated tasks is only seven percent of the total amount of opened tasks, and wrongly estimated is 73 percent. The deviation between the wrongly estimated tasks was separated into two categories, positive deviation, and negative deviation. Positive deviation means that the time spent is less than estimated; for example, the estimated is 20 hours, and the actual is 15 hours. While negative deviation is the other way around, time spent is higher than estimated.

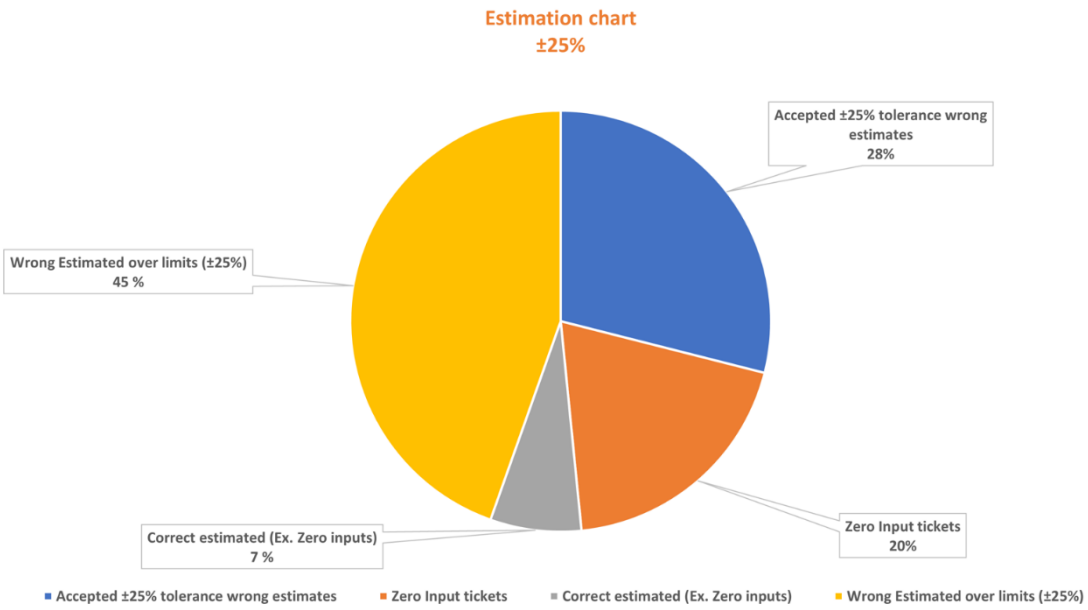
Figure 13. Positive vs. negative deviation



The estimation process is never linear. Thus, it seemed reasonable to add a tolerance of 25 percent on the estimations chart, which changed the results for the better by changing the

incorrectly estimated 73 percent down to 45 percent. However, 45 percent is still a huge amount of incorrectly estimated tickets and would need to be highly improved.

Figure 14. Positive vs. negative deviation with 25% tolerance



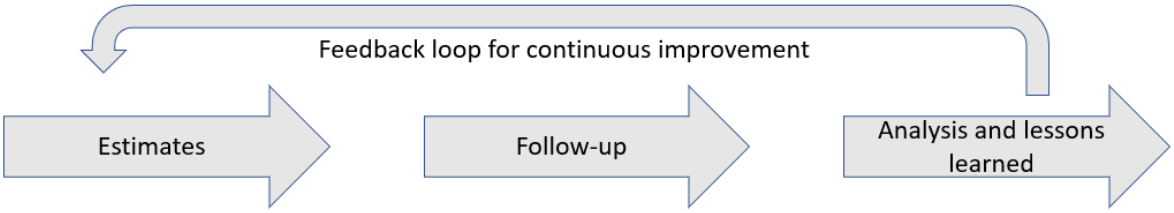
4 Building of the proposal

The proposal is based on the follow-up process for cost estimation, which seems to be missing in total. The process is meant to be a guideline of how the engineering costs could be measured to get reliable data for the future and what needs to be learned from this. The learning curve in the process is one of the key factors for success in future project cost estimations.

The previous chapters discussed the estimation and engineering methods and processes and briefly scratched the surface of how the estimates are predicted in Evac engineering. The following chapters will dive deeper into the essence of the problems and, as a result, will propose how some issues could be fixed by adjusting the tools and methods in use.

Figure 15 is a baseline of the proposed follow-up process, which will be reviewed more in the following chapters.

Figure 15. Cost estimating process



4.1 Estimation

The cost estimate is one of the main points of the study as it has been noticed not to be aligned with the actual costs. These misalignments lead to exceeding the engineering budget and thus show a negative impact on the project's gross margin.

Poor performance is a sum of many things and, firstly, will be focused on the estimation tools and Format in which the data would need to be shown, as well as the person(s) who would be responsible for the estimations prior to new projects.

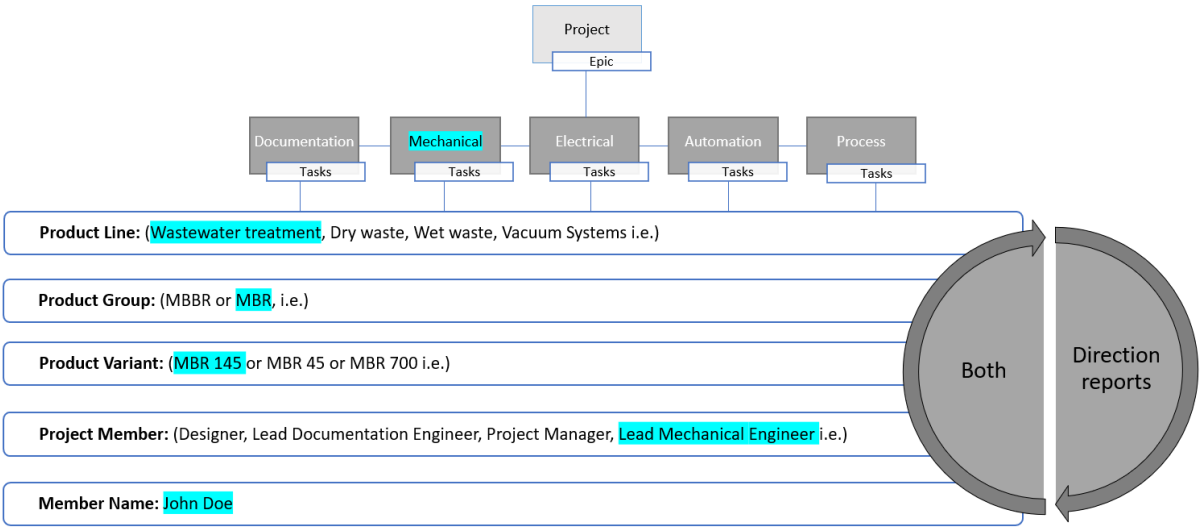
4.1.1 Process

To enhance the process for estimating the costs, it would need to be started from the sales department, where the initial selection of the units and systems are made. The selection of units and estimating the costs would need to be done in cooperation with the engineering departments, and to have a cross-functional technical review to estimate the need for revising the standard units per technical specifications and the owner's requests.

The systematic collection of cost information from previous projects is also crucial, as these are mainly used in the estimation process. However, it requires revising the tools to give more specific information about each discipline and unit. One solution could be to divide the reporting into smaller segments instead of collecting only the engineering hours. As an example, a documentation task where it could be measured how long it took to create an installation, operation, and maintenance manual (IOM) for a certain product or system.

The structure of Jira tasks could also be enhanced for better reporting and to filter more detailed information on the costs per unit. The solution for this would be to use a modular structure where under each task or department explained in Figure 9. could be a selected product line, e.g., Wastewater treatment, Dry waste, Wet waste, etc., and each line could be a selected related product group and product variant which follows the product member. Later on, it would be easy to filter and find specific products and to see how many hours were used for the engineering. To ease the filtering, the previously mentioned criteria selection could be made the other way around, starting from the product member followed by the product variant. For example figure 16 below shows in turquoise how lead mechanical engineer John Doe is choosing MBR 145 unit for the project.

Figure 16. Modular way of reporting structure



4.1.2 Cost estimating framework

The cost-estimating framework consists of multiple different pieces. However, the result would need to be a systematic, reliable, and accurate way of measuring the costs for different products or systems.

A reliable cost-estimating framework typically comprises six steps associated with a product or system. The framework should be flexible and adaptable so that it can be adjusted in case new

information occurs. It should also be transparent and documented. Stakeholders should be able to understand how cost estimates have been developed and have confidence in their accuracy.

1. **Define the scope of work:** The first step is clearly defining the scope of work, which would be a system or a product to be estimated. This includes defining the deliverables, requirements, etc.
2. **Identify the work breakdown structure (WBS):** The second step is to create a clear WBS, which breaks down the system or a product into more manageable components. Each component is then assigned a cost estimate in Excel for example.
3. **Identify the cost drivers:** The third step is to identify the cost drivers. These factors have the most impact on the overall cost of the system or product.
4. **Develop the cost model:** Several cost modeling techniques and applications can be used here, such as bottom-up, analogous, and parametric, i.e., More about these in chapter 2.23. The model should also consider the cost drivers and any other relevant factors.
5. **Estimate the costs:** Estimating the system or a product can be done using the cost model. These estimates can then be aggregated to determine the total cost of the system or a product.
6. **Validate the estimates:** The estimates can be validated using historical data from the systems or products delivered. This helps to ensure that the estimates are accurate and reliable.

4.1.3 Estimator

One of the important questions in starting the estimation process is who should be doing the estimations. In some larger companies, there is a dedicated estimations engineer whose responsibilities might, for example, include the following:

- To determine cost estimate targets during the design and development process and recommend cost-effective solutions.
- To utilize cost methodologies, tools, and appropriate software models and packages to prepare and maintain reliable and accurate data.
- To establish cost estimates of production processes, review alternatives, and recommend improvement.

- To investigate and identify cost reduction opportunities through cost analysis review.

At Evac, the engineering cost estimations rely mostly on the lead mechanical engineer, which is a suitable option as they, besides the product manager, are the most aware of the systems and products in the category. However, the methods and tools, such as estimations Excel, still need improvement.

Once the estimations process is clear and well defined, some statistical measuring tools, such as the design of experiment (DOE), could be implemented for better optimization.

4.1.4 Format and initial data for the estimates

Currently, as already described in Chapter 3.4, the estimations are calculated based on the knowledge of the lead mechanical engineers and the references from the past. The outcome of the estimations has also impacted the fact that some estimations are predicted by people who are not qualified, as one of the respondents stated: "For example, the documentation team has estimated how long it takes that mechanical design is ready." This indicates that the estimates are made at too high a level, and no clear accountability has been given to the estimators.

This is not directly related to the cost estimates, but it is also good to notice that the change orders should be offered and invoiced via the correct processes as it is consuming the engineering department with urgent tasks, which then might lead to a vicious cycle with several issues such as:

- Overloading the engineering department
- Quality issues due to time and resource limitations
- Uneven workload depending on the project phase
- The previously mentioned poor performance of estimating the costs leads to a snowball effect, which leads to shortened manufacturing times, unfinished products that need to be fixed onboard, and poor quality.

The estimation excels of which the estimations are put is merely focused on the costs for each discipline and does not necessarily give the full picture of how much the actual design changes of

each unit are taking or how many hours are needed to update the related documents, but just showing the overall figure or lump sum of the work.

The past references used for estimating the costs do not give reliable data or they do not even exist. This leads to the tool (JIRA) for distributing tasks to different departments. Currently, the estimations for each task are set in Jira, from which the initial data of the misalignments between estimated and actual is coming.

4.1.5 Cost allocation between departments

In many cases, the product-related tickets via Jira are appointed to the engineering department without a thorough investigation to whom the cost should be allocated. For example, the standard unit modifications should not be allocated to the project as the cost of updating a certain unit belongs to the product department. This leads us to recognize the costs between standard products and project-specific products so that they would be allocated correctly.

Standard product: The definition of a standard product in Evac may vary depending on the product line. Toilets are a good example of a mass product where the customization is very low or non-existing. In contrast, other units can simply be defined as a recommended product configuration that is fully supported and aims to keep in the catalogue for a long time.

Project product: Project-specific products are usually customized standards per the project's technical specifications. The specification may state that, for example, the layout of the equipment would need to be changed due to space limitations, or the electrical panel and/or the components need to be revised due to electrical specifications. In most cases, it is quite simple to notice if the unit is modified according to technical specifications from the customer. However, there are also cases where the ticket reporter may not be sure whether to allocate the costs to the project or another department. An example of one of the tasks could be an energy efficiency class (IE) update for motors, e.g., IE2 class motor upgrade to IE3 class due to new regulations, which should be directed to the product department as this request is applicable for all motors between 0.75kW and 1000kW and not only as project specific.

4.2 Follow-up

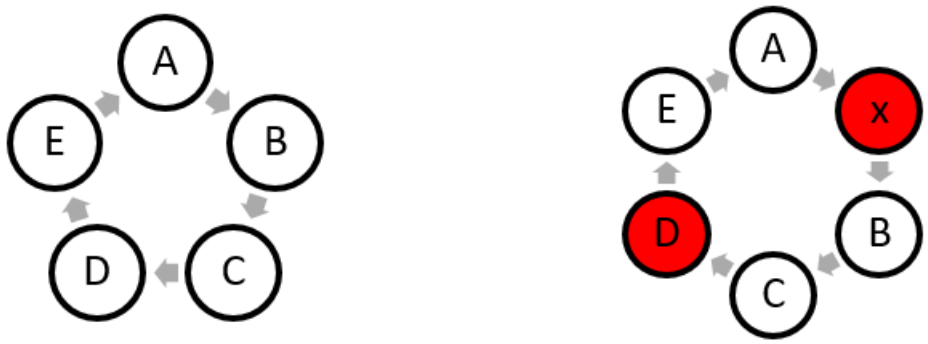
The second stage of the process is Follow-up, in which the costs are followed up during the ongoing projects. Some of the key points in the engineering cost estimating follow-up process are: reviewing the actual costs, analyzing the deviations between the actual and estimated to determine the reasons behind the deviations, documenting all the changes, updating the estimates to meet the actual costs to keep the project on track and within the budget, clear communication between stakeholders and continuous improvement.

This chapter focuses mainly on the tools used and the practicalities that would need to be implemented for better continuous improvement of the process.

4.2.1 Format and tools

Engineering in ongoing projects contains a lot of variables as usually the initial design is not compatible, and revisioning is needed. A good example is the continuous flow of unit changes for different reasons and in the units' scope of supply (SOS). Figure 17 presents a pattern where each alphabet presents a unit in the scope. On the left side, the SOS is presented as it would look in the ideal world, whereas on the right side is the modified SOS, where additional unit X was added to the scope during the project and unit D was modified.

Figure 17. Scope of supply patterns, ideal vs. modified



The engineering phase is partly starting on the sales phase with the concept design. For example, the following documents: process flow chart (PFD) and scope of supply (SOS) are submitted to the

customer. Once these are agreed upon and the contract signed, the project continues toward the basic and detailed design. The documentation flow normally continues by submitting the mechanical drawings like General arrangement (GA) and 3D step files to the yard as soon as possible and the Manufacturing assembly (MA) drawings to the manufacturer to start the manufacturing. Layout drawings of the vessel are to be asked from the yard as these are needed for planning the equipment layout, which is then agreed upon in cooperation with the yard. Part of the basic design is also the electrical and automation-related lists and drawings, such as Electrical drawings of the units, system integration, software, IO-lists, etc., as well as other documentation like IOM manuals, spare part lists, control documentation, etc.

Engineering, or, more specifically, the detail design phase, is usually intended to be closed as the procurement phase is starting, but on some occasions, due to the changes in the scope, engineering errors, i.e., it can last throughout the project up to commissioning.

4.2.2 Jira

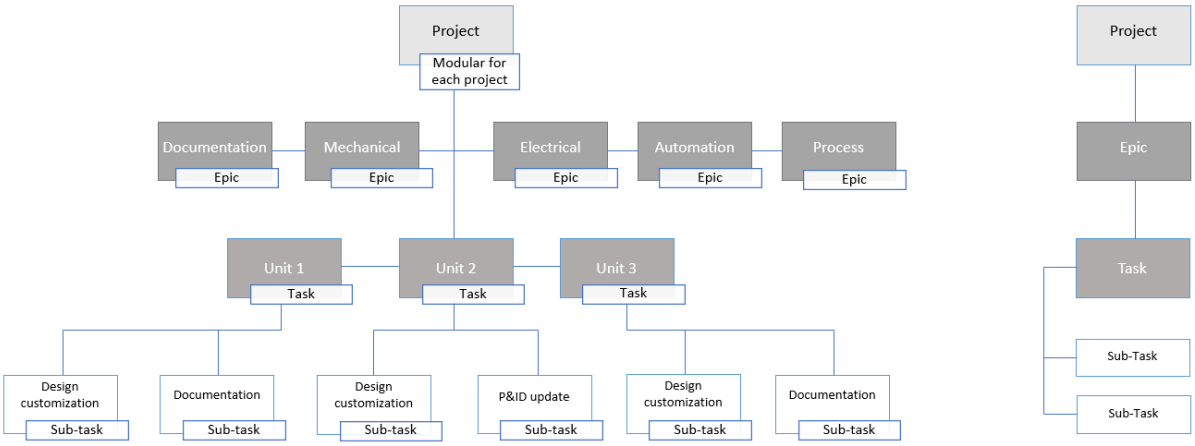
As mentioned several times, Jira is the tool used for distributing the engineering task between departments and where the initial estimations are put for each task. The current way of using Jira at Evac has been presented in the engineering process 3.3 and tools 3.3.1. The current layout is functioning, but some points would need to be improved upon to enable its full capabilities to be used.

The Jira layout is currently divided into three steps: epic, tasks, and sub-tasks, where the sub-task represents all the department-specific tasks. However, this way might not be the best for measuring the allocated hours for specific units as, most likely, several tickets are opened for the same unit during the project. Afterward, it is almost impossible to filter the actual hours.

To improve the measuring of the hours and to be able to collect the data more efficiently, the way of presenting the projects could be done slightly differently. The proposed structure would start with the project object, a specific modular way for each project. Under the project would be the Epic, which in the current system represents the project. The structure under the Epic would be similar to the current one with slight modifications, starting by presenting the departments as epics followed by tasks which would be the project-specific units, and only under them would be

the sub-tasks representing the project unit-specific tasks. Figure 18. presents the modular project in Jira, but it is to be noted that the project item would consist of other departments, like logistics, project management, and commissioning, i.e., which are not shown here as the thesis only concerns engineering.

Figure 18. Proposed Jira layout



Some other findings, excluding the Jira layout, are also to be considered, as these greatly affect the outcome. Firstly, there is no way of measuring the performance of individuals, such as designers. By measuring the performance of designers, it could tell us the strength of individuals, and thus, one could be assigned according to competence instead of random allocation. For example, one individual could possess more information on MBR units and perform better in designing that unit, as the other might be better on dry waste units.

In addition to measuring the hours engineering-wise for each unit and the performance for individuals, it should also be considered for product lines as well as the readiness of certain systems or units, which would need to be measured continuously in order for the project team to be able to have the current engineering status whenever needed.

Another issue is considering the allocation of the hours. It has been noticed that in some cases, the hours are allocated randomly under different tasks or even under different projects. This probably originates from the lack of training as some might not know how to navigate through Jira to find the correct project or ticket, not to mention create one.

The training for Jira should not be limited to considering the creation of tickets or allocating hours but to be widened as there are many currently unused features. However, using those tools could give so much more information than we are currently getting. The Project dashboard can be filtered to show the exact information needed, i.e., statistics for all the tickets, activity stream, several different average charts, etc. Gant charts, different pie charts, and others for better follow-up for projects, engineering tasks, etc.

4.2.3 Project needs vs. Engineering department needs.

Project departments and engineering departments within an organization have different needs and responsibilities.

The project department is responsible for planning, organizing, and overseeing projects from start to finish. They focus on ensuring that projects are completed on time, within budget, and according to quality requirements. The project department typically works closely with stakeholders to define project goals, establish schedules, allocate resources, and monitor progress.

The engineering department is responsible for designing, developing, and implementing products and systems. Typically, they are engineers specializing in different areas such as mechanical engineering, electrical engineering, documentation, etc. The engineering department is also responsible for ensuring that products or systems are in accordance with technical specifications together with the project engineer.

The needs of project departments and engineering departments can sometimes overlap. However, they have different priorities and objectives. For example, project teams meet project timelines, while engineering teams focus on ensuring that products or equipment meet technical specifications. In addition, project departments may have a focus on project management tools and processes, whereas engineering departments may have a focus on technical tools and software such as Creo, Windchill i.e.

Both departments need to work together to ensure the successful completion of the project which is why it is essential to build up good collaboration and communication channels throughout the project.

4.2.4 Hour Reporting

Currently, there are a couple of different ways of reporting the hours depending on if a person is employed by Evac directly or working through some other company as an external employee. One of the ways which are used by Evac project engineers, project managers, lead engineers, etc., is to report the project-related hours through an online Excel spreadsheet, from which they are directed to specific projects in enterprise resource planning (ERP), E9. However, this excludes the project specialists, coordinators, purchasers, and logistic specialists who do not report their hours to projects. The other way the externals use it is to report the hours through Jira for the specific project. The Project engineer and manager then use the hours reported in Jira to crosscheck the invoices shown in the invoice handling platform Basware. After the verification, they are directed to ERP, E9. In addition, the service and commissioning engineer hours are not reported anywhere. However, they are shown only as an invoice to Project engineers and managers, the same as fixed costs and hourly-based installations. In addition, it would be beneficial for bidding and fixed contract purposes to report the data regarding the spent hours on manufacturing and installations.

As shown, the reporting of the hours varies a lot depending on the position, and not even all the project hours are gathered. As the externals are already using Jira to report the hours, it might be beneficial to unify the methods and start to report all the hours in Jira; the tool is already in everyday use. This way, there would not be any reason to maintain excess excels.

There are many different applications for time tracking in Jira, such as activity timelines and work logs, to mention a few. However, for testing purposes for this thesis, Everhour was used as the application was free and seemed to have all the needed figures. The purpose was to see how it would work in real life and if it would be easy to use. One of the most important criteria was to have all the relevant projects or tickets under the same list so that the reporting of the hours could be done feasibly and without opening all the tickets separately one by one. This is important as

some engineers might have 10 to 20 projects or tickets simultaneously, and implementing the hours might take some time.

During the test period with the Everhour app, it became obvious that the hours are indeed easy to maintain through the application, and the tickets can be easily listed and filtered. As Figure 19 shows, the hours can be reported through the ticket, and if needed, the tracking could also be started by the timer. Another way to maintain the time tracking, as seen in Figure 20, would be through the Everhour application, from where it is possible to gather all the different projects and/or tickets so that the reporting can be done feasibly from one page and the table can also be downloaded as an excel, pdf or CSV Format.

Figure 19. Test of Everhour time tracking via ticket

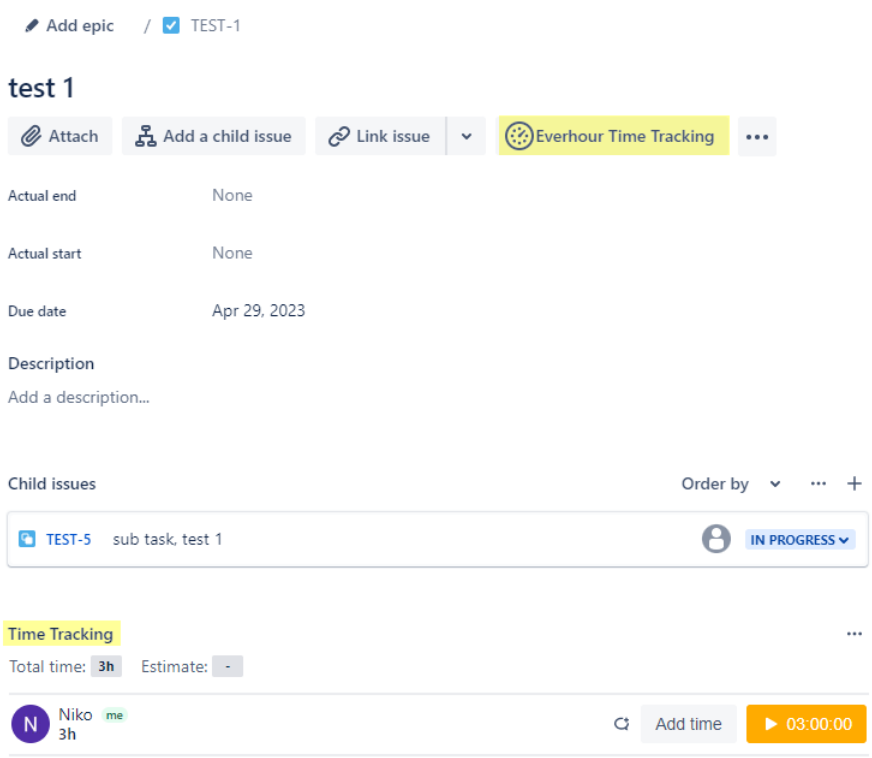


Figure 20. Test of Everhour time tracking via app

Tasks	Sun APR 23	Mon APR 24	Tue APR 25	Wed APR 26	Thu APR 27	Fri APR 28	Sat APR 29	Total
	-	8:00	8:00	8:00	8:00	8:00	-	40:00
test 1 #TEST-1 TEST - test	-	-	2:00	3:00	5:00	5:00	-	15:00
test 2 #TEST-2 TEST - test	-	-	3:00	3:00	2:00	-	-	8:00
test 3 #TEST-3 TEST - test	-	4:00	2:00	-	1:00	2:00	-	9:00
test 4 #TEST-4 TEST - test	-	2:00	-	-	-	1:00	-	3:00
sub task, test 1 #TEST-5 ‹ test 1 TEST - test	-	2:00	1:00	2:00	-	-	-	5:00

4.2.5 Follow-up process

In order to maintain the follow-up process, it is necessary to have the following steps taken into account:

- Roles and responsibilities are clarified on the person(s) working on the matter
- practicalities, which are listed in more detail in Chapter 4.3.1 below
- instructions and training for different tools and systems are in place and use

As also mentioned in chapter 5.1.1 for Jira, there are many features only in this tool that are not known, and by giving the training, the tools could be utilized in many more ways to get the most out of it.

The person(s) who would maintain the continuous improvement process for engineering work and cost estimating would need to understand the different cost estimating principles and methods and the best project management practices. They should also be able to identify the areas that need improvement and address these in a relevant manner throughout the company. In addition, they should be able to present the findings clearly and make recommendations based on them.

4.3 Analysis and lessons learned

As the headline explicates, this chapter discusses the analysis and lessons learned from the previous estimates and follow-up process. This is the last part of the process, where all the lessons learned are documented and circulated to the engineering cost estimations to keep up the continuous improvement process.

The chapter consists of practicalities, meetings that need to be held to have clear communication channels, the analysis of budget overcomes and when and how these need to be considered for future projects, and the documentation needed.

The analysis for the engineering work and the process of estimating the cost of systems and products might include the following points, which are based on industry standards and frameworks, such as the Project Management Institute's (PMI) and Lean Six Sigma methodology.

- **Gather data:** Collect all data relevant to the engineering and estimating process, which should be made according to relevant methods like bottoms up etc. Include the project schedules, budgets, resources, and other relevant metrics.
- **Identify Key Performance Indicators (KPIs):** Determine which KPIs are the most important for measuring the success of a process. These may include metrics such as cost estimate accuracy, and overall project budget i.e.
- **Analyze the information:** Use statistical analysis and other analytical techniques, such as regression analysis, to identify patterns, trends, and areas for improvement in the data. This could include identifying areas where cost estimates have been consistently inaccurate, or resources have not been fully utilized.
- **Compare with industry benchmarks:** Benchmark against industry benchmarks and best practices to see where you stand against other companies.
- **Identify areas for improvement:** The engineering and estimating process could be improved based on the analysis findings. This may involve implementing new tools or technologies, improving team communication or collaboration, etc.
- **Develop an action plan:** Based on the identified areas for improvement, develop a detailed action plan that outlines specific steps that will be taken to improve the process. This plan should include timelines, responsibilities, and key performance indicators that will be used to measure the success of the improvements.
- **Monitor and adjust:** Continuously monitor the process and track progress against the identified KPIs. Adjust the action plan as necessary to ensure that improvements are made, and the process becomes more efficient and effective over time.

4.3.1 Practicalities

Lessons learned and practicalities are important to keep the process continuously improving. The process could be established in Jira, but it is to be done so that it is easy to follow and that everyone can contribute. A responsible person must be assigned to review, record and implement the improvements regularly. This would also need to be emphasized and encouraged for all team members to take action and share their ideas for improvements. Documentation is an important

part of the process. Lessons learned should be continually documented and feedback sought from the team to make the necessary changes and keep the process efficient.

4.3.2 Meetings

Meetings for following up on the lessons learned for engineering work and cost estimations would need to be held approximately once a month. The participants who would need to be part of the meeting are the engineering, project, and quality departments. These individuals can provide various perspectives considering the engineering and cost estimation process.

The engineering departments can provide insight into the technical aspects of the work and any challenges or issues that have arisen during the project. Project managers can provide insight into project planning, scheduling, costing, and resource management issues. The quality department can provide insight into any issues that may arise during the project concerning quality or safety.

4.3.3 Triggers

Usually, the lessons-learned process is started by the end of a project or the major phase of the project. The process may also be triggered during the project due to unexpected delays or issues. For example, there could be unexpected cost overruns in the project. In this case, the process may be initiated to identify the root causes and develop strategies to prevent these incidents from happening again.

In addition to the previous, the trigger may also be when it is noticed that the identified KPIs are exceeded or near to being exceeded, or it has been noted that a similar recurring problem occurs, e.g., in relation to a certain supplier, process, etc., or that someone is reporting an issue through the lessons learned process.

4.3.4 How the corrective actions are taken, and the results are documented

This is usually a practice that is fully dependent on the company. At Evac, the practice for internal development and improvements projects process is based on six questions to map the issue, how

to solve it, and the benefits for the company. This process could easily be adjusted to work with the lessons learned for engineering work and the cost estimation process.

- Current problem or issue?
- Idea - How to solve the problem?
- What is the benefit of the development project?
- Select the most suitable category area of the proposed development project.
- The first idea about the needed resources and timeline?
- In case you have related files, please attach them here.

There are also three steps of how the lessons learned are currently implemented, and the same methods could be used for the process.

- The first one is the informative way, which contains very little to no documentation and would only be considered as a notice, e.g., consider this while working on the issue.
- The second one would be so-called fast lane development, where the corrective action proposal is published, and based on the information, something small such as instruction, is modified to prevent the issue from happening again.
- The last one is the internal development process, which would need a budget and resources to create a new process, working methods, etc.

Documentation: There are a couple of ways of how the changes and so on could be documented. The first is to report an issue through the lessons learned process in Jira, or Excel, i.e., where it stays for others to see. Another way to document actions is by adjusting the current processes and instructions or, as mentioned above, starting an internal development process for creating new processes, etc.

5 Conclusion

In conclusion, several factors regarding the engineering cost estimation process could be improved. One of the most important aspects to consider is cost engineering, as multiple authors have stated that up to 80 percent of product costs are determined during the design phase. Therefore, alterations made later in the design or manufacturing process are more expensive. In

order to improve the process, some of the cost estimation methods, such as bottom-up, discussed in section; 2.2.3, could be utilized. Also, what needs to be noticed is the overloading of the engineering department, as discussed in section 4.1.4. This may happen when several urgent issues are brought up simultaneously, leading to severe quality issues due to time and resource limitations and uneven workload depending on the project phase. These issues also impact manufacturing as they lead to shortened manufacturing times and, at worst unfinished products that need to be finalized onboard.

The study also revealed that some of the estimations are predicted at a high level, using only the rule of thumb method and the historical data of the older projects. One possible reason for the poor performance of the estimations may be that the people are not qualified and lack knowledge of the products, i.e., this way of estimating the costs may lead to inaccurate estimations and thus cause issues down the line, such as budget overruns improper allocation of resources, cost competitiveness, etc. It is also essential to recognize the costs between standard products and project-specific products to allocate them correctly, as discussed in Section 4.1.5.

Section 4.2.2 highlights the importance of measuring the hours engineering-wise. The measuring could be done for each system or unit by the spent hours and customization level, i.e., the performance for individuals could, for example, be done by tracking the efficiency for specific design work, and a similar way could also apply to product lines. In addition, it would be good to measure the manufacturing, installation, and commissioning phases to get different data on the manufacturing and installation times, for example. One critical step would be continuously measuring certain systems or units' readiness, allowing the project team to have the current engineering status whenever needed.

Finally, section 4.2.4 discusses the importance of work time reporting per issue and the possible implementation of the Everhour application or something similar. This would allow for more accurate time tracking and reporting for individuals regardless of the position or if they are employed by Evac, or if they are externals.

In addition, it is good to note that the needs of the project and engineering functions can sometimes overlap, but they have different priorities and objectives. While project teams meet project timelines, engineering teams ensure that products or equipment meet technical specifications. Furthermore, project functions may focus on project management tools and

processes, while engineering functions may focus on technical tools and software such as Creo, Windchill, etc.

In conclusion, the cost estimation process can be improved by considering cost engineering, utilizing cost estimation models and methods, ensuring accountability and accurate allocation of costs, continuously measuring the readiness of systems or units, recognizing the differing needs of the project and engineering functions, implementing a reliable and unified hour reporting system and by starting systematically and continuously to learn from the past projects and experiences.

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Questionnaire for thesis (Engineering cost management)

1. **As the topic of the thesis is related to Engineering costs and follow-up processes, what, in your opinion, are the three main reasons for Evac's bad performance in estimating the engineering costs for current and future projects?**

Respondent 1

1. Scope of supply has changed during the project from the original scope, which causes extra costs; Evac is doing too much "goodwill" for free. We should pressurize and invoice more for additional changes.

2. Engineering costs haven't been estimated accurately, and the process hasn't been developed

3. Sales contracts have been made quite quickly without cross-functional reviews, or the wrong departments have estimated engineering costs (for example documentation team has estimated how long it takes that mechanical design to be ready)

Respondent 2

1. Evac is missing clear references for product and engineering task hours from previous projects

2. Reporting process is not well defined for Internal and external engineering individuals

3. Unplanned customization is not taken into consideration during the estimation process

Respondent 3

1. Standard product readiness and level of documentation

2. Standard product designs and documentation not matching project requirements

3. Sales and business support competence in evaluating engineering costs during the sales phase

Respondent 4

1. Estimates made at too high a level and without a clear cost structure

2. No real accountability for the estimates given

3. We don't systematically utilize the information from previous projects

2. How would you enhance the engineering cost estimation process?

Respondent 1

Develop the process of how engineering costs are estimated.

Create templates for sales organizations that they have something to start with; this reduces many risks and improves the process.

Add an internal approval process if possible so that the sales contract can't be signed without having a cross-functional technical review (lightweight).

Project schedules & project budgets should be reviewed and estimated realistically.

Respondent 2

Enhancing reporting process

1. Divide the reporting into smaller segments (currently, only engineering hours are collected). For example, smaller segments could be measured according to documentation "how many hours did it take to create IOM-manual" or by system "how many hours were spent to customization of certain product line or system."

2. Reporting structures could be enhanced in a modular way. Project → Discipline → Product line → Product group → Product variant → Project member and name.

Once the reporting process is clear, we could implement measuring tools such as the Design of Experiment (DOE)

Respondent 3

Create tools for sales and business support to do an initial evaluation of engineering costs and then have lead engineers review those estimates before bidding.

Respondent 4

Make a clear structure for estimates.

Start systematically collecting the cost info from earlier projects and, based on that, develop the estimates little by little.

3. **Jira is currently used for issue tracking and estimating the issue costs in Evac; how do you see that the software could be enhanced for our better use?**

Respondent 1

Add other departments to JIRA (purchasing, sourcing, logistics), and improve Jira automation; for example, when the design is ready, the automated notification goes to the purchaser that procurement can be started.

Respondent 2

It is evidence that Jira is not used correctly. It could be enhanced by defining what needs to be measured on top of hours, i.e., project behavior during the project execution. Currently, this is measured monthly, and in between, there is no live data.

Respondent 3

Getting all project stakeholders to use it properly. Create JIRA processes that would govern the whole project lifecycle.

Respondent 4

A clear structure for cost estimating.

All the cost bookings in Jira instead of multiple Excel (if feasible in practice)

4. **In your opinion, is the current Jira layout fit for purpose, or should it be updated, and if so, how?**

Respondent 1

Jira is a good tool related to engineering tasks and communication.

For engineering estimations, we should be able to extract more and better data from Jira if we want to learn from our mistakes and make any progress.

For example, if we could sort and filter out how many engineering hours have been used on average for a single MBR unit, we could improve our budgets and therefore improve profitability in the long run. This would reduce risks.

There is much potential in Jira, but it should be utilized more for other departments, also.

Respondent 2

The current layout is not serving the project department's needs to track the units, departments, and system hours due to the limited levels (Epic, task, and Sub-task)

It can be updated that project to be used as projects, and the departments represented by Epics.

Respondent 3

It should be updated to support all project-related functions or at least different boards to be created for different functions and purposes.

Respondent 4

More project-specific approaches are needed. We need to clearly indicate in the Jira structure, "When this ticket/epic is ready, we have all the technical documentation to start purchasing this item."

5. **Currently, in Evac, the project and site management-related hours are recorded in the "hour reporting excel-file" Should these be recorded in Jira the same way as the engineering hours, and why?**

Respondent 1

Yes, it is not convenient that some employees (external) put hours into Jira and internal (Evac) employees put them into Excel. We end up in a situation where the hours are not

marked correctly, and there are two different systems. I don't believe that there is good transparency in hour tracking or overall information with current tools.

If we follow up on how many external engineering hours are used, why don't we have the same practices for everyone? The current way treats employees differently, and most importantly, we don't get reliable data out.

There have also been situations where project managers or project engineer hours have been allocated to mechanical engineering hours. The same thing was noticed with electrical or process departments.

Respondent 2

It would be more beneficial if we reported all project-related hours under one platform, which would allow the PM and stakeholders to understand and control their projects better.

Respondent 3

Everyone who is working on a project should report their hours to JIRA tickets, and those hours should be automatically transferred to ERP from JIRA to track all project expenses.

Respondent 4

Yes, if easy to use Hour booking user interface available in Jira

6. General comments/opinions

Respondent 1

In 2022, Evac has already developed the process of estimating engineering costs quite a lot. We have a common Excel file where every department estimates the non-material costs (design hours), then we also give comments about project schedules and overall project scope. There has been good progress and spirit between sales, sales support, and engineering. During 2023 I am preparing a template to support sales in how to estimate mechanical engineering costs.

This template would be a kind of "shopping list"; you add the customizations, and the calculator estimates preliminary design hours. The goal is that this speeds up the sales process and supports engineering.

Last but not least: Evac has had different quality requirements in the past; if we want better quality, we can't reduce resources or reduce the budget.

Respondent 3

Kokonaisten projektien vieminen Jiraan ei toimi, koska softa itsessää ei jaksa pyörittää niin isoa kokonaisuutta. Tämän hetkinen ETM-board tyyppi on parempi ratkaisu, mutta tähän tulisi tuoda myös osto, service yms mukaan.

Mitä kenttiä Jira tiketissä voisi olla ja mitä kannattaa poistaa. Mitkä ovat relevantteja tietoja liittyen mitä raportteja halutaan ulos Jirasta tai mitä halutaan nähdä. Hyödyllinen versus ”nice to know”.”Mitä enemmän kenttiä, sitä vähemmän niitä täytetään”. Toimintatavat pitäisi olla selvä ja kaikki kentät tulisi täyttää.

Jira EPIC layout. Tämän hetkinen layout on tehty niin, että Epicciin on merkattu systeemi, laitteet, laitteen tiedot. Jiraa tulisi käyttää change management tapaan ja ainoastaan päätökset, esim suunnittelumuutoksista tulisi kirjata ”comments” kenttään, eikä käyttää sitä chattina. Dokumenttien hallinta ei myöskään kuulu Jiraan vaan Sharepointiin ja ainoastaan linkit tulisi liittää tiketteihin.

Esimerkki: Päivä, kuka päätti, mitä päätettiin, kuka hyväksyi, vaikutukset esim tuntiarvioon/due dateen.

Tiketti on yhtäkuin ”Work order”! Annettuihin tunteihin tulee sitoutua, kuten muihinkin työtilauksiin.

Projektipäällikön tulisi olla kartalla suunnitteluun menevistä tunneista, tai Projekti-insinöörillä tulisi olla budjetti jonka mukaan mennä.