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Recommendations to Improve the Manufacturing Process of the Case Company

Metropolia University of Applied Sciences

Master's Degree

Industrial Management

Master's Thesis

30 May 2023

Abstract

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Title:	Recommendations to Improve the Manufacturing Process of the Case Company
Number of Pages:	60 pages + 1 appendices
Date:	30 May 2023
Degree:	Master’s Degree
Degree Programme:	Industrial Management
Professional Major:	
Supervisors:	Dr. Thomas Rohweder, Principal Lecturer Sonja Holappa, M.A., Senior Lecturer

The objective of this thesis was to propose recommendations to improve the manufacturing process of the case company. Due to the combination of increasing demand, low-volume and high complexity of the final product, traditional manufacturing line approaches were found to be unsuitable.

The study began with a current state analysis to gain an understanding of the existing manufacturing process, identifying its strengths and weaknesses. A review of relevant literature was conducted to identify best practices for addressing the identified weaknesses, forming the conceptual framework of the study. This conceptual framework served as a guide for co-creating initial recommendations during a workshop.

The initial recommendations were then validated and based on received feedback, they were refined into the final recommendations, which form the outcome of the study. The implementation of these recommendations would assist the case company to increase the efficieny and effectiveness of its manufacturing process.

Keywords: manufacturing, kpi, assembly, matrix team, hybrid scrum

Acknowledgement

As I finally finish this study, I am filled with both relief and gratitude. It is hard to believe this is over and at times the finish line seemed more like a dream, than a reality. The initial timeline for the graduation went completely off the rails due to various personal issues, yet here I am. Despite all these challenges I am very glad I started this journey.

I would like to thank the staff at Metropolia for instructive lessons and for being able to quickly adjust to the challenges of remote lecturing brought by Covid. The start of my studies coincided with my career transition to a leadership position and you equipped me with invaluable skills and knowledge to tackle the challenge.

I would like to thank my case company and my supervisor Mr. Tommy for providing the platform and resources for this study and for accommodating my schedule. The gratitude extends to my team as well, whose dedication, enthusiasm and unwavering commitment were a constant reminder of why I am doing this in the first place.

I would not be able to go through the journey without my girlfriend Maimuna, whose support and encouragement grounded me and kept me focused. My cats, Masha and Kimchi, despite not having any formal education, provided me with much-needed companionship during the long nights, for which I am forever grateful. This also extends to my parents Aleksandr and Valentina, my brother Dmitry and my cousin Roman, for their unending belief in me.

Thanks to Panu Leppäniemi, Patrik Luoto, Mikaa Oni and Patrick Ausderau for the LaTeX thesis template, Alexandra Elbakyan for her controversial, yet fearless commitment to the open access movement, Semantic Scholar and Zotero for making citation management a breeze.

At last, I would like to thank my friends for their shared experiences and wisdom.

Misery loves company and talking to other people going through their Master's programs and PhDs gave me a sense of shared understanding.

Thank you, everyone, who has been a part of this journey. While it brings mixed emotions, every end is a new beginning. While I am immensely glad to have reached this milestone, I am excited for the new challenges that lie ahead.

Sergei Ossif
Espoo
May 25, 2023

Contents

1 Introduction

The modern world relies heavily on the use of satellites to provide information, communication, and entertainment. The low-orbit satellite swarms provide internet in remote places of the world where infrastructure is limited. Additionally, satellites provide emergency response services if one would get injured in the backcountry and provide essential weather data that is utilized to develop accurate weather and climate models, as well as monitor and track climate change. Various global positioning constellations, such as GPS, GLONASS, and Galileo revolutionized logistics by providing accurate positioning data for trucks, planes, and ships. One particular application is Earth observation, driven earlier by the Cold War (Tatem, Goetz and Hay, 2008) is now booming due to advances in electronics and optics, lowering the entry barrier for private companies.

With recent events in Ukraine, the demand for Earth-observation satellites increased dramatically (Werner, 2022). The manufacturing of satellites is a complex process, requiring a deep understanding of the technology and a significant investment of time, money, and resources. As the cost of launching spacecraft lowered due to high competition from private launch service providers, many so-called ‘new space’ companies emerged and the topic of the effective yet low-cost manufacturing process is very popular.

This thesis seeks to explore the various issues involved in the manufacturing of satellites and ways to improve them. In doing so, the author hopes to provide insight into how to address these issues and how to improve the quality and reselience of satellite manufacturing. With this knowledge, it is possible to improve the manufacturing process and make it more cost-effective, and efficient.

1.1 Business Context

The case company is a provider of earth observation services and solutions. The company was founded in 2014 as a continuation of the Aalto-1, Aalto Business School and Standford University Technology Ventures collaboration. Since then the company acquired over 150 million in investments and launched multiple satellites, becoming the first commercial satellite provider in its class and its country. The vision was always to develop a small, low-weight, lower-cost SAR (synthetic aperture radar) satellite, which would allow keeping a constellation of satellites in orbit, significantly reducing the request to delivery time from typical 24 to 48 hours to less than 3 hours.

Synthetic aperture radar imaging differs from more conventional optical imaging. Optical imaging utilizes sophisticated and precise camera systems which provide great ground resolution, however, are subject to weather effects and light conditions. As many countries of interest, i.e. in Europe, experience yearly total cloud cover of over 50% (Tzallas et al., 2019), the applications of optical imaging are limited. The SAR works by emitting specially constructed radar signals toward the Earth's surface and capturing reflected signals over a longer period of time. Leveraging clever processing algorithms over the collected data enhances the effective aperture of the radar from the physical span of half of a meter to synthesized one of several kilometers. While SAR images are harder to interpret (i.e. figure 1) and analyze, they are not subject to the same constraints as optical images. The radar frequencies are selected to be able to penetrate cloud cover and are not affected by light conditions, allowing truly on-time delivery of analytical data.

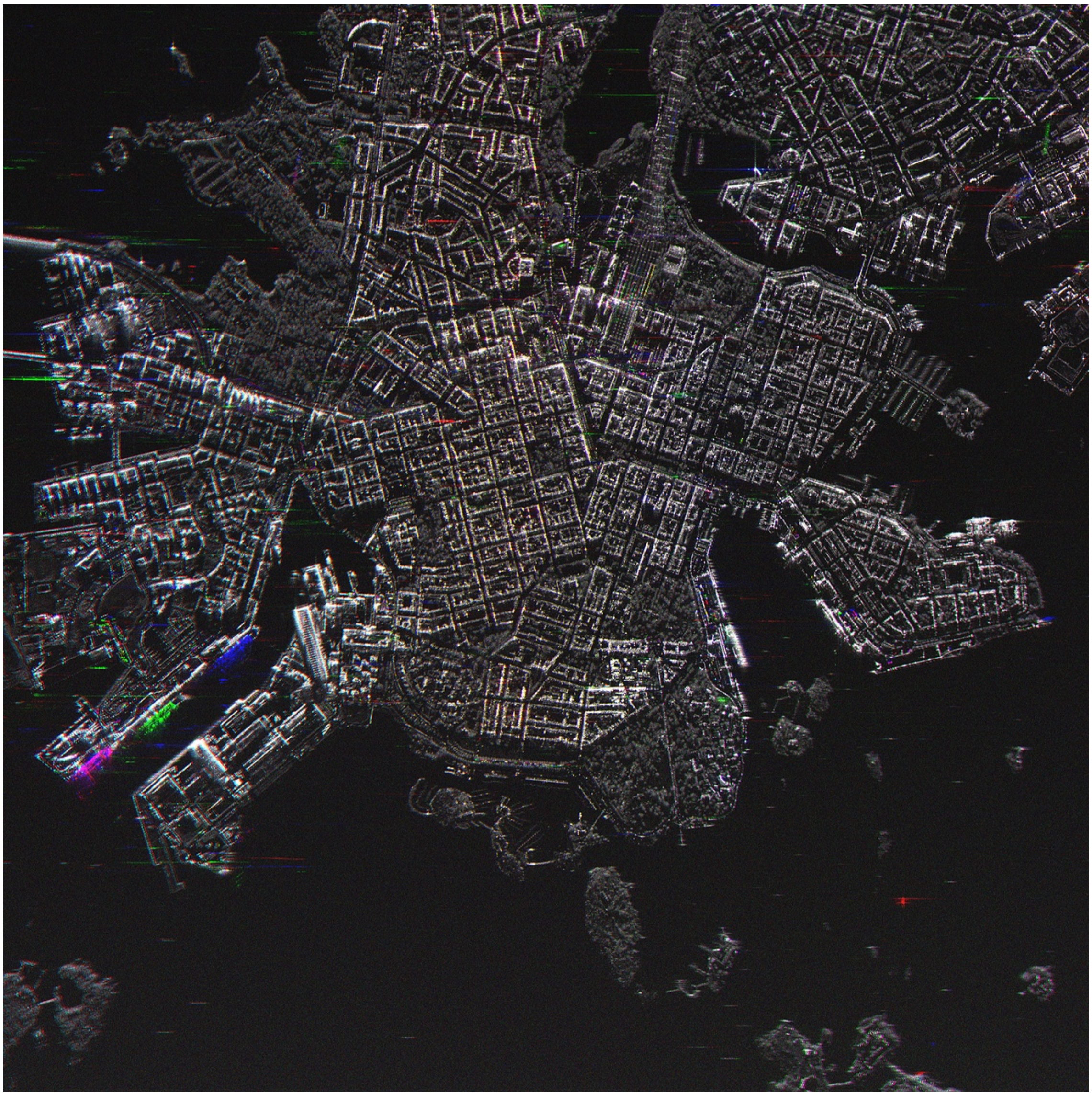

Figure 1: SAR Image of Helsinki (Satellite Data 2023)

The case company offers three types of products: data, solutions, and missions. Data is the raw SAR images that get acquired on demand. They are mostly of interest to intermediary companies, which acquire such data from multiple providers and build their own value-added services. Solutions are value-added services that are built on top of internal and external data. For example, the dark vessel detection service combines SAR data with boat automatic identification systems, allowing detection of unregistered vessels and helping governments curb illegal fishing; or the flood monitoring service tracks floods as they happen and provides a tool for insurance agencies to match the incoming insurance claims against provided data to check the legibility of the claim.

The case company has been growing rapidly over the years, roughly doubling its headcount every year. New teams emerged, existing teams split into smaller and more focused teams, and new offices opened in other countries. As the market matured, the demand for services has been steadily increasing. Recent developments in global politics such as the war in Ukraine and its successful acquisition of the case company's imaging capability made governments realize the need for persistent monitoring (ICEYE Signs Contract to Provide Government of Ukraine with Access to Its SAR Satellite Constellation 2022).

Such growth brings organizational growing pains familiar to every startup. Yeo and Park (2018) defines them as "problems that occur as a result of inadequate organizational development in relation to business size and the complexity of external environments at a given stage of growth". Therefore it is essential to close the gap between existing infrastructure and the infrastructure required to sustain growth.

1.2 Business Challenge, Objective and Outcome

Even though the demand for satellites is increasing, the current processes are not developed to support higher-scale manufacturing. Each satellite is high complexity, high-cost product and involves hundreds of parts that require many assembly steps. Due to the variety of tasks and frequent design changes, a significant amount of work is performed manually.

This results in numerous issues regarding work quality and personnel. Due to inadequate planning, the workload intensity is periodic, where the spikes in workload have to be covered by frequent overtime crunch, which is expensive and severely diminishes morale. A lot of knowledge of minute details is not captured in the documentation and overall over-reliance on collective and individual knowledge is a bottleneck. The clean room is located in an office building, which puts the available workspace and storage space at a premium.

The objective of this research is to recommend improvements for the assembly process and the outcome is assembly process improvement recommendations.

1.3 Thesis Outline and Scope

This study consists of 4 stages to address the challenges described in the previous section. The first stage is the current state analysis of the assembly process. The purpose of this part is to learn and expand on these challenges in a planned, systematic way. The main sources of knowledge for that part are existing documentation and interviews with a diversified set of stakeholders.

The objective of the second part is to search through existing literature on current best practices relevant to the issues discovered in the first part. After that, a first set of recommendations is co-created with the stakeholders. Then the initial recommendations are presented to the stakeholders and based on their feedback, the final recommendations are formed.

This thesis document consists of seven sections. Section 1 is the introduction to the study. Section 2 describes the research plan, research approach, design, data plan and the logic used to create those. Section 3 analyses the current state of the assembly process to guide further research. Section 4 provides an overview of industry best practices and develops a conceptual framework to guide the development of process improvement proposals. Section 5 follows with the creation of initial recommendations for improving the current assembly process. Section 6 analyzes the provided feedback and formulates the final recommendations. Section 7 is the conclusion and self-evaluation.

2 Research Plan

The business context, challenge, objective and outcome were introduced in previous sections. In this section research plan, approach, design; and data plan will be described.

2.1 Research Approach

Sreejesh, Mohapatra and Anusree (2014) defines business research as a systematic and objective process of gathering, recording and analyzing data that provide information to guide business decisions. Two primary methods were considered in determining the most appropriate research approach for this study: qualitative research, and quantitative research. Each of these two approaches has distinct advantages and disadvantages, making it essential to thoroughly assess their suitability in addressing the research problem.

Quantitative research is a method that relies on numerical data and statistical analysis to reach conclusions about the research problem. It requires a large sample size, a defined and rigid research design and consistent data collection methods. While it has good repeatability and prediction power, it may not provide the depth of understanding and context that qualitative research can, especially when studying complex, multifaceted issues (Cooper and Schindler, 2013).

Qualitative research on the other hand focuses on exploring and understanding phenomena in a comprehensive manner. It delves into the experiences, perspectives, and contexts that shape the subject being studied. This type of research is characterized by its flexibility and adaptability, as it allows the researcher to gain a deeper understanding of the nuances involved in the research problem. Due to its exploratory nature, the research design often evolves or adjusts throughout the study. It requires a lot smaller sample size and simplifies data security measures. While it allows a deeper level of understanding of the problem, however, often it lacks the predictive power of the quantitative approach (Cooper and Schindler, 2013).

Applied action research is a research methodology that aims to address organizational issues by combining development and research activities (Kananen, 2013). This methodology utilizes a qualitative research approach that closely aligns with the organization’s natural development workflow to work with people directly involved in the process. The use of structured and semi-structured interviews, workshops and similar data collection methods allows us to gain deeper insight into the actual way the processes work in the case company. The output of the applied action research is a practical and functional solution to improve the operations in the case company which is the reason this methodology was selected over others.

2.2 Research Design

The research for this study was divided into four phases as shown in figure 2. The first stage is conducted by performing a comprehensive analysis of the current state of the manufacturing process, which starts with a review of the existing process documentation. Then a series of interviews were performed with the relevant stakeholders. To minimize disruption to the workflow, the existing weekly meetings and one-on-ones with the technicians and engineers were utilized. The result of the first stage is the summary of the strengths and weaknesses of the current assembly process.

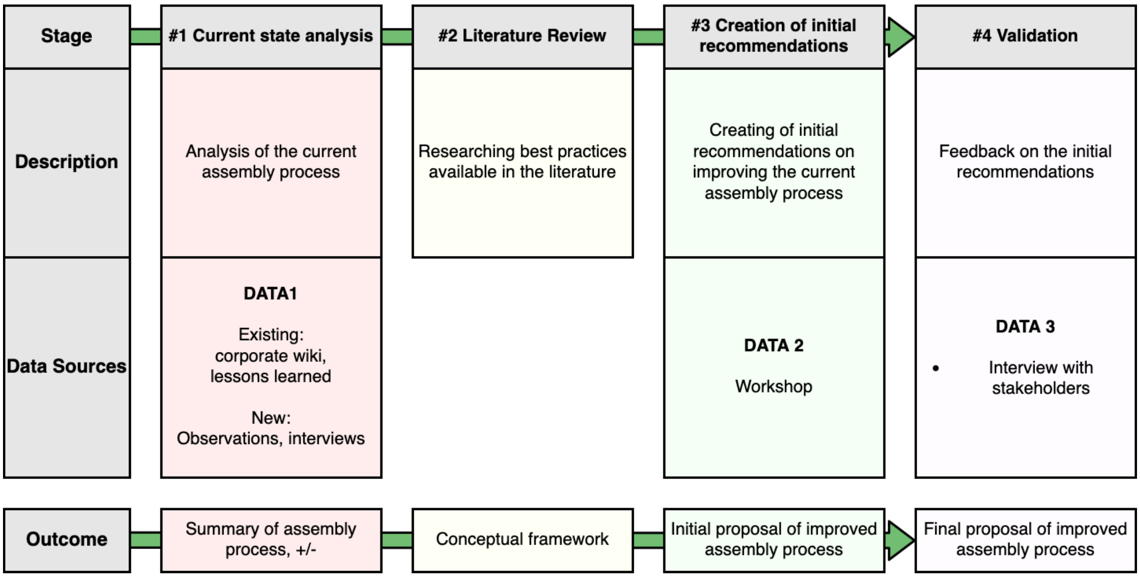

Figure 2: Research Design

After the summary is formed, the second stage is the literature review. The purpose of this stage is to collect and consult with the existing literature and practices to gain insight into probable solutions for the existing issues with the assembly process. The result of the literature review is a collection of insights that forms the conceptual framework of this research.

The third stage builds upon the second stage to form initial recommendations to improve the current assembly process. It distills the conceptual framework of the existing issues in the build process with the help of workshops and individual interviews with the stakeholders. The initial recommendations are tailored to the existing process and aim to improve it over time.

The fourth and last stage is a validation of the initial recommendations. This is done by condensing those recommendations into accessible slides and presenting them to key stakeholders of the process. Then stakeholders formulate the feedback and the initial recommendations are adjusted accordingly.

2.3 Data Plan

This research draws information from a multitude of sources. It is beneficial to get a first impression of the current state by delving into written information: internal wiki system, and process diagrams. However, as work processes evolve and improve, it is often the case that the documentation lags behind. To bridge that gap it is necessary to involve actual rank-and-file employees that are involved in those processes on a daily basis.

Table 1: Data 1 collection — current state analysis

#	Source	Data Type	Topic	Date	Length	Documented
1	Internal Wiki	Document	Missions Team Structure	14.1.2021	1 pcs	–
2	Internal Wiki	Documents	Build and Launch Spacecraft	14.1.2021	12 pcs	–
3	Internal Wiki	Documents	Lessons Learned 2020Q1-Q4	14.1.2021	4 pcs	–
4	AIT Team sync-up weekly meetings	Observations	Process operations	Q1 2021	–	–
5	Director of Missions	Interview	Process operations	11.2.2021	45 min	Field Notes
6	Mission Manager 1	Interview	Process operations	8.2.2021	45 min	Field Notes
7	AIT Engineer 1	Interview	Process operations	29.1.2021	45 min	Field Notes
8	AIT Engineer 2	Interview	Process operations	28.1.2021	45 min	Field Notes
9	AIT Technician 1	Interview	Process operations	3.2.2021	30 min	Field Notes
10	AIT Technician 2	Interview	Process operations	25.1.2021	30 min	Field Notes

There are established channels of communication within the management team as well as between management and employees, primarily through weekly sync-up meetings, steering board meetings, one-on-ones and various project update meetings. These existing channels provided the opportunity to incorporate the interviews with the stakeholders in the already scheduled one-on-one meetings.

The table 1 presents an overview of the first data collected to perform a current state analysis. Despite Covid restrictions, the author was fortunate enough to be able to interview most people in person. Only Mission Manager 1 was interviewed over Zoom, as they normally work remotely.

The internal documents are grouped by topic, Missions Team structure describes the roles and responsibilities of various teams in the Missions Department, which are adjacent to the AIT team. Build and Launch Spacecraft is a set of documents describing top-level processes involved in building and launching the satellite, such as the timing of milestones, reviews, people involved in those reviews, outputs, etc. Lessons Learned is the internal process in the team that is run after every launch to discuss things that went wrong and make an action plan to improve.

Table 2 provides a comprehensive summary of the data gathered for the second data collection, which is used for creating the initial recommendations for process improvement. One thing to note is that “Mission Manager 1” was promoted to be the team leader of the Mission Management team. As AIT Technician 2 and AIT Engineer 1 could not attend the workshop, only one workshop was organized to accommodate a smaller number of participants.

Table 2: Data 2 collection — creating initial recommendations

#	Source	Data Type	Topic	Date	Length	Documented
1	• Director of Missions • TL of Mission Management • AIT Engineer 1 • AIT Technician 2	Workshop	Creation of recommendations	31.5.2021	120 min	Field Notes

The last data collected is shown in table 3. The two interviews were organized separately due to scheduling conflicts.

Table 3: Data 3 collection — validation of initial recommendations

#	Source	Data Type	Topic	Date	Length	Documented
1	Director of Missions	Interview	Process operations	20.7.2021	45 min	Field Notes
2	TL of Mission Management	Interview	Process operations	13.7.2021	45 min	Field Notes

The next section section 3 elaborates on findings presented in Data Collection 1.

3 Current State Analysis of the Manufacturing Process

This section explores the present state of the satellite manufacturing process. It relies on the findings of the Current State Analysis performed according to the process described in section 3.1 and the data collected shown in table 1. As the aerospace industry's early development was stimulated by government agencies, the processes used in the industry are somewhat unique. Section 3.2 and section 3.3 provide an overview of the processes unique to this industry and the necessary context.

Afterward, the overview of the Current State Analysis is provided. This requires a thorough examination of the data collection methods, as well as a discussion of the specific details and challenges encountered during the process.

This is followed by a comprehensive examination of the manufacturing process in section 3.4.1. This section describes various aspects related to the management of the process, including inputs to the manufacturing process, team structure, KPIs, etc and their impact on the output of the process.

The section concludes with a summary of the findings and presents the Conceptual Framework of the study, showing the findings and listing them in table 4. By the end of the chapter, readers should have a clear understanding of the current assembly process, its strengths, weaknesses, and areas that could be improved.

3.1 Overview of the Current State Analysis

This chapter provides an in-depth account of the data collection process for the current state analysis of the satellite manufacturing procedure. The data collection process utilized a variety of methods to gain extensive and varied insights.

Initially, the documentation stored in the internal wiki system was reviewed to get an overview of the process which provided valuable insights into the operational aspects of the manufacturing process's procedures. The wiki served as an extensive repository of information that reflected the organization's institutional knowledge, standard operating procedures, and best practices. It also showed areas where the documentation was insufficient, inconsistent, or outdated, highlighting potential improvement areas.

However, due to the organization's rapid growth, the documentation can not keep up with the pace of process adjustments. Often technicians and engineers find small ways to improve their operations that are not reflected in written sources. Therefore, for a complete and accurate depiction of the process, its participants must be included. The first step is to identify the key stakeholders. Having a good mix of technicians, engineers and managers allow to get a holistic view of the process as multiple key aspects of the process can be examined from multiple angles.

The primary data collection method was semi-structured interviews with key stakeholders. This approach allows for a set of predetermined questions (see appendix 1) to start the discussion and the flexibility to explore topics in greater depth or introduce new ones based on the responses and background of the interviewees. The findings were collected into Field Notes. These interviews were crucial in understanding the nuances of the process, the perceived challenges, the possible improvements, and the dynamics among team members.

In addition, observations were carried out during weekly "AIT sync-up" team meetings. The purpose of these meetings is to communicate organizational changes coming from upper management and answer any relevant questions, get collective input on organizing test campaigns and various team events, and conduct "Lessons Learned" sessions after a launch campaign. Observations made during these meetings provided a perspective on the team's dynamics, the issues they encounter, and the way they tackle those issues.

The combination of these data collection techniques allowed for a comprehensive and holistic understanding of the present state of the satellite manufacturing process. The outcome of the analysis is the summary of strengths and weaknesses of the processes in table 4.

3.2 Introduction to Old and New Space

The old or classic space approach was born in government-managed space agencies such as NASA, ESA and others. Due to the cost of development at the time, reliability became the focus of their philosophy. Due to extreme conditions encountered in space, such as radiation, high-energy particles, extreme temperatures, extreme acceleration and vibration requirements, those agencies adopted a very conservative design approach. Each project has multiple design reviews, and extensive testing at component, sub-system and integrated levels is conducted. Due to this approach, the costs tend to explode. As an example, Envisat, launched in 2002 by ESA has a mass of 8,211 kg and a total program cost of 2.3 billion Euro.

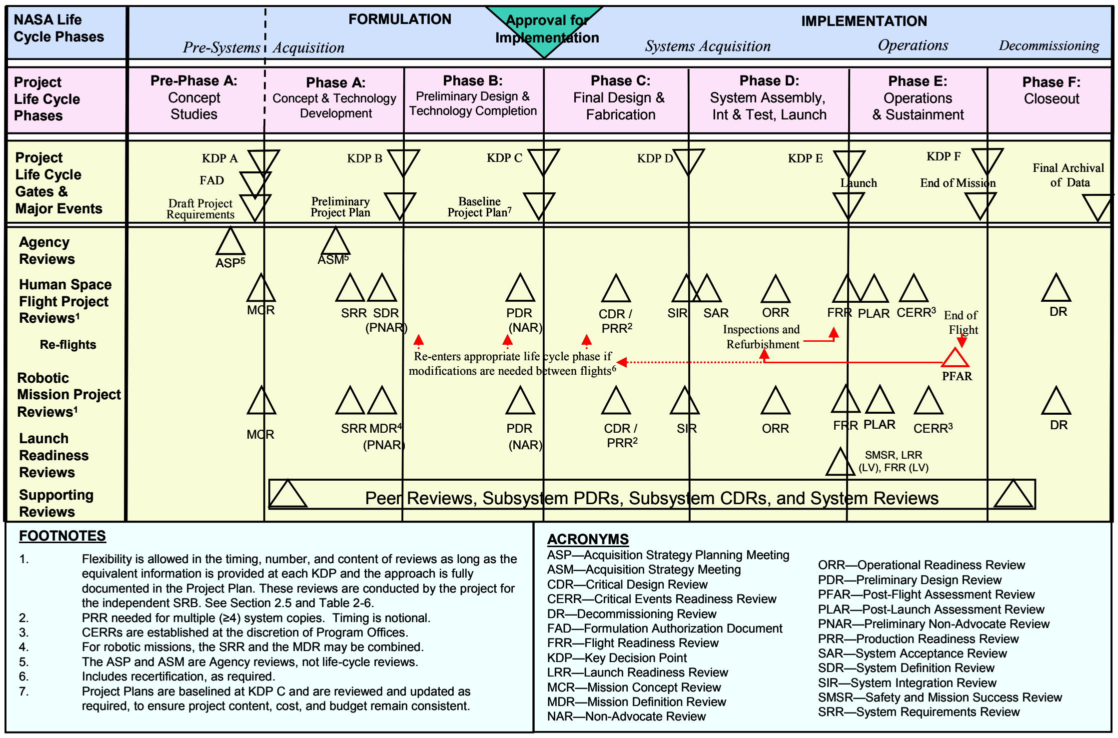

Figure 3: NASA Project lifecycle

A New Space approach was born with the democratization of launch vehicles. Companies like SpaceX and Arianespace were able to design a new generation of rockets and push down the launch price from 40000$ USD to 10000$ USD (citation) to LEO (Low Earth Orbit). This allowed the market to develop a new, smaller type of satellite (usually in the 100-150 kg range (Capella X-SAR 2023) (ICEYE - Earth Online 2023) (Illuminate the World - Umbra 2023)) using off-the-shelf components to do so. It allows greater agility in design, as usual, lead time for automotive components is a matter of days or weeks, not multiple months as is the case with rad-hard components. The cost of automotive components is usually 100 to 1000 cheaper compared to rad-hard ones.

3.3 Introduction to AIT

NASA defines AIT as “Assembly, Integration and Test”, which is a set of activities encompassing the physical assembly of the satellite starting with receiving electrical and mechanical parts and through the process flow until the satellite is launched (NASA, 2013). The purpose of AIT is to serve as a bridge between the design and the operational phases, making sure that what is designed is actually what is sent to space.

This process typically involves several different steps and activities, including:

Assembly: This involves physically putting together the various qualified components of the spacecraft or other system, using tools, machines, and other equipment as needed. This could mean for example applying a conformal coating to printed circuit boards, assembling them into boxes, and applying necessary thermal paste and glue.

Integration: This involves connecting and configuring the various components of the spacecraft or other system, to ensure that they work together properly and function as a single, cohesive unit. This could mean for example installing a payload module (the main reason the satellite is built) onto the bus (the frame and supporting subsystems).

Testing: This involves conducting a series of tests and evaluations to verify that the spacecraft or other system meets all of the required performance and safety standards, and is ready for use in space. Some examples:

- Thermal-Vacuum Testing: Some launch providers require thermal-vacuum testing to be performed. The satellite is put into a vacuum chamber and thermo-cycled. The purpose is to measure the outgassing of various parts of the satellite.
- Vibration: All launch providers require qualification shake (per design) and acceptance shake (per satellite) to be done. The purpose is to simulate the launch environment and test the workmanship.
- Functional: Testing the functionality of the satellite. All sub-systems are tested independently, then a full system test is performed. For example, a simulated orbit environment information could be fed to the satellite, connecting using on-board communication, etc.

It is important to have a well-working AIT process to ensure spacecraft reliability and validate performance before it leaves the ground. It minimizes the risk of mission failure by testing all the subsystems beforehand and finding out design flaws. It also contributes to overall engineering knowledge by propagating hands-on experience so that the next iteration of hardware can be better designed for manufacturing. In essence, an effective AIT process is crucial to the success of any space mission, as it guarantees the spacecraft's readiness for operation in the harsh space environment.

3.4 Description and Analysis of the Existing Process

This section discusses the findings of the current state analysis, which are broken down into strengths and weaknesses, and describes the current state of the AIT process. The previous part introduced the process of collecting information to create a concept of the current state of the company.

3.4.1 The Main Process

The AIT process is located at a junction of multiple interconnected processes, requiring managing multiple process suppliers while still maintaining strict performance criteria and deadlines. Space launches are usually procured roughly 18 months in advance and are subject to specific launch dates determined by the primary customer or are organized as rideshare missions (SpaceX - Rideshare 2023), which restricts the flexibility of launch dates. Failing to meet the launch date brings a loss of over a million EUR in just the launch costs, not counting any potential missed revenue. On the other hand, as the AIT process is positioned close to the end of the Build and Launch Spacecraft process, all the delays accumulated in preceding processes and suppliers are accumulated and the timeline gets compromised. Based on the data collected described in Data Plan, a process map shown in figure 4 is drawn.

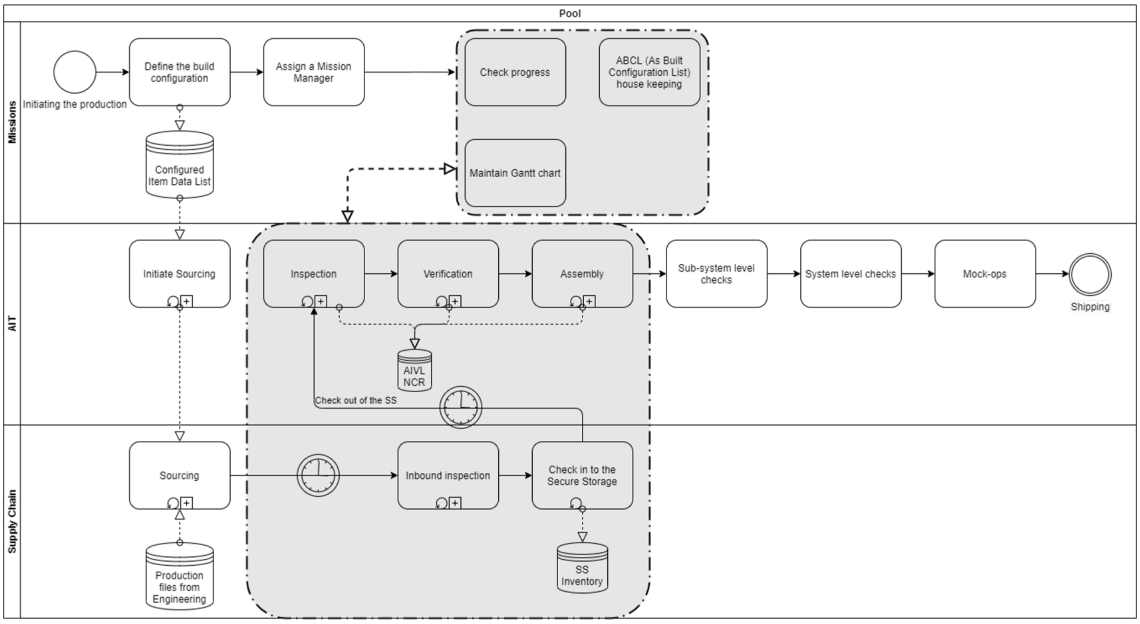

Figure 4: Extracted process map

The main AIT process starts with receiving physical parts. It could be PCBs (Printed Circuit Boards), PCBAs (PCB Assemblies), mechanical parts or harness parts. Usually, harness design is very specific to the design of the system so in most manufacturing enterprises harness manufacturing is done in-house.

The physical parts are received by the Supply Chain team, which does the incoming inspection and updates the necessary ledgers. The parts are stored in Secure Storage, which is a limited-access inventory room. The access is limited as a lot of parts are either under EAR or ITAR licenses which put limits on who can have unsupervised access to them. Often this becomes a bottleneck in operations as every check-in or check-out operation requires the right person to be available.

The actual process for each type of physical item is slightly different, for example, mechanical items are only inspected once, but electronics boards are inspected when first PCB is manufactured, then when PCB is assembled. However, the general idea is the same, first, the item is received, then some kind of inspection is done.

Due to the complexity of manufacturing, the electronics industry has several standards regarding the quality of the manufactured product. For example, for PCBs, it is governed by IPC-A-600, PCBAs IPC-A-610 and for cable harness its IPC/WHMA-A-620 (IPC International, Inc., 2020). Each standard defines various features of the end product and qualifies which ones define the quality and which ones are process indicators. The IPC standards establish 3 quality classes for PCB and PCBA, from class 1 (lowest, cheap general electronics) to class 3 (highest consumer reliability). Note that military, classic space and other industries can also define their own, stricter quality criteria (i.e. MIL-PRF-31032/1 in the USA).

For the mechanical part due to simplicity, the inspection mostly relates to checking critical dimensions, if all the thread inserts are installed correctly and the quality of anodizing. The next step is the verification of the physical part. For harness it usually involves checking the continuity of the connector pins, making sure there are not any unspecified open circuits or closed circuits. For PCBAs, it usually involves a set of tests designed either by engineering or by AIT and is based on design requirements and historical mean values for the measured parameters. Due to the segregation of engineering and AIT teams in different departments, the tests are often not optimized for the AIT process, either due to out-of-date pass criteria, excessive coverage (multiple tests testing a single parameter) or poor documentation. The 2 departments tend to work in silos and engineers often do not get the full picture of how their products are assembled and used.

Whenever an issue occurs during any steps of the AIT process, either its inspection, verification, assembly, or final inspections, an NCR is made, which stands for Non-Conformance Report. It is a process common in many manufacturing fields meant to have a traceable report of non-conformances happening, actions done to isolate the issue and actions done to prevent it in the future.

This is paired with an 8D process which formalizes the problem-solving approach (Divanoğlu and Taş, 2022).

Figure 5: List of the Eight Disciplines (8D) (ASQ, 2019)

One example could be if an aluminium part with an outdated spec was assembled into the system. Then the report could look like this:

0. Plan: Management (team leader) is alerted about the issue, and the decision is to start the NCR process and start creating the report in the ticketing system.
1. Create a team: the technician, who found the problem; the team leader; the QA engineer; the configuration manager; the mechanical engineer
2. Define and describe the problem: During assembly, it was found that the X bracket hole was misaligned by 2mm. In revB of this part, the mounting hole was moved to accommodate new design requirements.
3. Contain the problem: correct part was ordered and assembled
4. Identify, describe and verify the root cause: the design release process was not properly followed and the part drawing was using old dimensions
5. Choose corrective actions: update the drawing

6. Implement and validate corrective actions: the drawing was updated (link)
7. Take preventive measures: update the design release process, organize a refresher training for engineers
8. Congratulate your team

Complimentary of NCR is the ECN (Engineering Change Notice) process. The ECN process is meant to capture and track changes to designs that are already released for use or manufacturing, processes or configurations. It provides a structural way to explain the change, the value it would bring, and the risk analysis in case the change is approved and in case it is not approved, and the impact it would bring on current processes. The process also requires communication changes to all the relevant stakeholders, suppliers, production engineers and floor staff. It is a common process used in the automotive, medical and aerospace industries.

3.4.2 Inputs to the Main Process

The AIT process is occurring during the later stages of development and therefore is a customer of many internal and external inputs and suppliers. This section will describe the various inputs that contribute to the AIT process, highlighting their significance in ensuring a successful transition from the design and manufacturing stages to the final, operational satellite.

As the AIT process encompasses the assembly, integration, and testing of all satellite components and subsystems, it relies heavily on the inputs received from earlier stages of development. These inputs play a crucial role in shaping the AIT process and determining the ultimate success of the satellite mission. Some of the key inputs to the AIT process include:

- Design Documentation: The engineering teams provide design data that helps in identifying the root cause for various anomalies
- Manufacturing Data: The engineering teams provide manufacturing files for the designs that are used by configuration and supply chain teams to procure
- Qualification Reports: Engineering teams provide qualification reports

confirming that the design is suitable to use in specified conditions

- Test Plans and Procedures: The engineering teams prepare and documents test plans used in testing individual units as proof of manufacturing
- Physical products: all the physical components needed to manufacture the satellite

3.4.3 Output

The AIT process plays an important role in the satellite production process, making sure that the final product is ready for launch and can successfully operate in the space environment. This section will focus on the various outputs that result from the AIT process, and describe their importance in demonstrating the satellite's reliability, performance, and compliance with mission objectives.

The outputs generated during the AIT process serve as tangible evidence of the satellite's readiness for launch and provide valuable information for decision-makers, stakeholders, and future satellite development efforts. Some of the key outputs of the AIT process include:

- Test Results and Data: Test results for each unit, subsystem and full system.
- Performance Validation Reports: Similar to test results, but for full assembly to evaluate the performance of the payload and allow the engineering team to perform necessary calibration.
- Integration Records and Logs: Records and pictures of each assembly step of each unit, subsystem and system.
- Issue and Anomaly Tracking Documentation: Aforementioned NCR process to track all the anomalies that happened during the assembly.
- Final Satellite Configuration Data: Full configuration data is required for software and operation teams.

3.5 Findings

3.5.1 Timeline and Task Management

The manufacturing process is managed with the use of Gantt charts, which serve as a tool to illustrate the project schedule. These charts show tasks and milestones on a vertical axis and the dates on a horizontal axis. Gantt chart is a useful tool as it provides an easy visual representation of the state the project is in, and allows assigning tasks to technicians.

Correct use of this management tool highlights delays, resource conflicts and other issues. However, due to the complexity of the tasks involved the Gantt chart grew to an unmanageable size. The web-based tools used were incapable of supporting a project that size, and offline tools such as MS Project were quite expensive and had limited collaboration features, locking the ability to see project status to only managerial staff. As a result, the task of keeping the chart up to date falls solely on the project manager in addition to other responsibilities.

The timeline and task management issues was a prominent topic of discussion with every interview participant in various degree. The technicians and engineers mentioned confusion regarding unclear and always-changing priorities. Due to Covid related global supply chain issues the lead time of components needed for PCB assemblies is uncertain which is reflected in the quality of planning and management of priorities. The workload planning took on cyclical nature, where the work intensity would increase as the deadlines approached. The dull periods later would unfocus the team and exacerbate the problems in planning.

> AIT Technician 1: “We are often unsure about the priorities. It seems like they are changing every day.”

> AIT Engineer 1: “Sometimes we start a task and then we’re told something else is more important. It’s hard to keep up.”

> AIT Engineer 2: “Deadlines are often unclear. We end up rushing to complete tasks at the last minute.”

More managerial participants (Director of Missions and Mission Manager) noticed a communication gap between AIT and other teams in the department. Having weekly-sync ups is found to be insufficient in keeping all the teams updated in such an uncertain environment which caused Mission Management team to be incapable of assisting in removing various roadblocks.

> Director of Missions: “The Gantt chart is overly complex. We need a simpler way to manage tasks.”

> AIT Engineer: “The Gantt chart is hard to use. It’s not user-friendly.”

As all the managers in the Space Missions department came from an engineering background, they often choose the Waterflow approach to manage their projects and Gantt charts to visualize the planning and progress, as this is what is commonly taught in their studies. However, the volume of satellite manufacturing falls in the spot between bespoke manufacturing and mass manufacturing where neither a Project-based nor manufacturing line-based approach is sufficient.

3.5.2 KPIs

During interviews with the Director of Missions and the TL of Mission Management, it was noted that there are difficulties in evaluating the performance of our processes and process improvements. The main process is lacking what is called a key performance indicator. A lack of Key Performance Indicators (KPIs) can make it difficult to evaluate process performance because KPIs serve as critical metrics for measuring the efficiency of a particular process. Without KPIs, organizations struggle to define and communicate their strategic goals and objectives. This lack of clarity can lead to confusion and misalignment of efforts. Furthermore, the organization is initiating the ISO 9001 certification process which requires the implementation of a mechanism to evaluate performance.

3.5.3 Assembly Instructions

An assembly procedure is a set of instructions provided to technicians describing steps, guidelines and best practices to create a fully functioning unit. For a good assembly procedure it needs to specify a set of items:

- Step-by-step instructions for assembling items in the correct order
- Pictures, diagrams or other visual aid
- Quality control checkpoints or Key inspection points

Having good coverage of the build assists in making sure each satellite is built similarly to others. When this is not done, the technicians start relying on volatile tribal knowledge. As a consequence the parts could be assembled wrong, and some important non-obvious pieces could be missed (thermal pads, glue, etc). Assembling without a procedure could cause damage to expensive parts. The misuse of parts could also go unnoticed and only found out during system-level checks, where the cost and labor of replacing units is many times higher.

The construction of a satellite is a complex task that requires a clear, consistent, and updated set of assembly instructions. However, the CSA revealed several issues with the Assembly Instructions that are impacting the satellite manufacturing process.

The most obvious issue was gaps in documentation. Some assemblies were relatively straightforward to assemble, yet challenging to describe in written language with diagrams and pictures, resulting in incomplete documentation. When the assembly was completed or integrated during late hours, the pressure to finish the task leads to the potential for errors sneaking through, resulting in wasted time and effort later in the process.

> AIT Technician 2: “When the instructions are missing, we often have to rely on our own knowledge or ask other people on the team.”

This quote illustrates that in the absence of assembly instructions technicians have to resort to either relying on their experience or asking teammates for help.

This phenomenon, also known as tribal knowledge, is undocumented and informal knowledge that exists within the group and is exchanged through word of mouth and accumulated shared experience. The problem with this form of communication is that tribal knowledge is not consistent, as every person has a different way of understanding, processing and interpreting information. Relying on such knowledge exposes the organization to risks if the key person leaves the team (Ph.D, 2011). In the software world, this is referred to as “truck number”, as in how many people in the organization have critical unique domain expertise (Coplien and Harrison, 2004). In addition, compliance with ISO 9001 requires having procedures and work instructions for every process in the company (Quality Management Systems — Requirements (ISO 9001:2015) 2015).

Another issue is multiple different formats or styles of work instructions. Early on, the technicians would fill up a paper checklist to verify that the correct assembly steps were followed in the right order. Over a few years the processes transitioned towards an electronic (PDF) based checklist, then later to a semiautomated computer process. Since the transition process was gradual there are multiple different types of instructions in use geared towards different checklist types. Occasionally, new better processes would be available and used to perform specific instructions, but as the minute details were still developing, the procedure would not get updated preventing wider adoption.

The third issue is the absence of document approval and the version control process. While the internal wiki system keeps track of all the changes, there is no way to know which changes are approved. Quality Management Systems — Requirements (ISO 9001:2015) (2015) requires a document control and approval process set up to prevent floor staff from using unapproved or outdated instructions. As one of the AIT Engineers noted: “It’s frustrating when we realize we’ve been working with an outdated version of instruction”. Another noted: “We occasionally find ourselves following procedures that have been updated without our knowledge.” Having to rework the assemblies is considered one of 7 types of waste in lean manufacturing.

The last challenge that emerged during interview discussions is the lack of KIPs (Key Inspection Points) in assembly and integration instructions. While unit verification naturally lends itself towards having pass criteria, standardizing this process is more challenging due to the variety of units and methods of assembly and integration. Without provided KIPs the technicians lack a comprehensive understanding of what kind of information needs to be documented. When QA later inspects the output documentation, in some cases they are unable to verify if the subsystem was assembled correctly or not.

3.5.4 The Team

The AIT process requires the close collaboration of several adjacent teams. While mission managers contribute to the overall mission delivery and ensure that processes are followed correctly, the bulk of work is carried out by the AIT team. The team size and structure are determined by the annual amount of missions to be launched and the corresponding workload. However, even for smaller missions that could be potentially fulfilled at the customer's site, there is a lower limit due to the immense amount of specific domain knowledge required to build the satellite. As the team size increases the number of one-on-ones, development plans, task management, training and mentoring increase proportionally. In addition, Kameda et al. (1992) suggests that once the team grows beyond 4 members, the average performance and motivation tend to decline, possibly due to lower perceived contribution to the team effort.

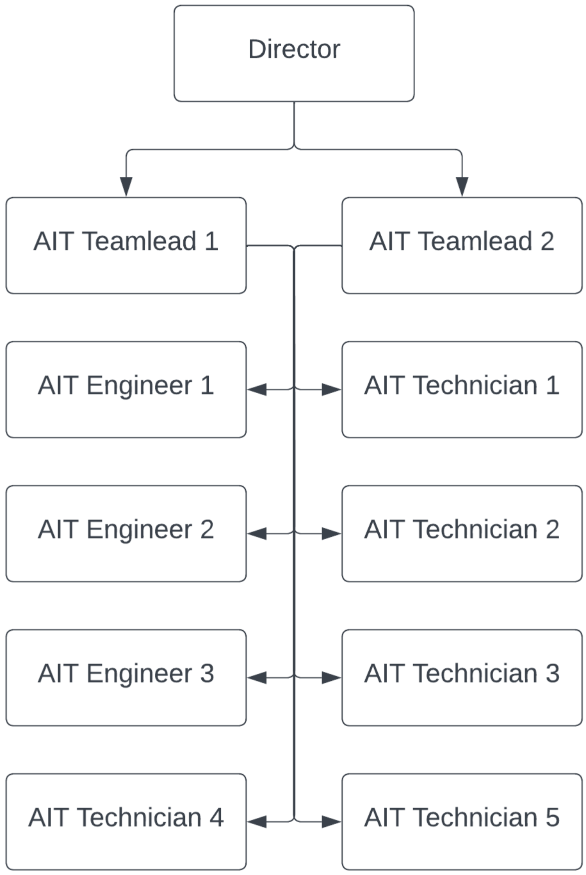

Figure 6: AIT Team structure

In 2021 the AIT team size is 12 people and follows a traditional flat structure (see figure 6). Due to historical reasons, the team is managed by 2 equal team leaders. While it is an unusual team structure, when appropriately managed it can bring several benefits (Thude et al., 2017). As both team leaders come from different engineering knowledge domains, it allows them to have a different perspective on the problem (Denis, Langley and Sergi, 2012). In addition, it distributes the management overhead between 2 people, allowing multiple people to have 1-on-1, adding benefits of different leadership styles and expertise. As the team is yet to be self-directed, having shared leadership provides a backup in case of emergencies or vacations.

Substantial effort was put into the hiring process to achieve a highly resilient and agile team. Focus was put on hiring people with high adaptability and good communication skills. This approach helped shorten onboarding, bringing people up to speed on the tasks they need to do and providing resilience in the AIT process through redundancy in competencies. Good communication skills and a willingness to help and share information contribute to the transactive memory system and overall team cohesion (Huang, 2009).

As part of the ISO 9001 certification, the roles and competencies must be well-defined and documented (Quality Management Systems — Requirements (ISO 9001:2015) 2015) Based on background, education, past work experience and expected scope of work employees have either AIT Engineer or AIT Technician work title. If the position demands narrow specialization, usually in the insourcing roles, the title could be for example Battery Assembly Technician. Having a clear role definition helps employees to maximize their performance and prevents confusion regarding their tasks and expectations (Patel, Pettitt and Wilson, 2012).

A sense of camaraderie in the team helps with the productivity of the manufacturing line by creating an environment that encourages collaboration, communication, and problem-solving. When team members feel connected and respected, they are more likely to be motivated to put in their best effort and work together to achieve the goals of the manufacturing line. A sense of camaraderie can also help to foster a culture of continuous improvement, as team members are more likely to suggest and implement innovative solutions when they have a strong sense of connection and trust in their colleagues. Ultimately, a strong sense of camaraderie can lead to a more productive and efficient manufacturing line.

3.6 Summary of the Findings

In this chapter, the main discoveries and results from the interviews and workshops conducted are brought together. Information has been gathered and compiled from various sources as described in the data plan, allowing for the creation of a clear and comprehensive picture of the findings and their impact. A summary of these findings can be found in the table 4.

Table 4: Strengths and weaknesses

#	Strengths (+) and weaknesses (-)	Sources
1	(+) Strong team morale, high job satisfaction among the AIT team members, clear role definition.	Interviews, Siqni survey
2	(+) Good meeting structure set-up: team sync-ups, status updates, 1-on-1s.	Interviews
3	(-) NCR (Non-Conformance Report) is cumbersome to use. Difficult to extract and aggregate data.	Interviews, lessons learned
4	(-) Gantt charts diverge from reality, overly complex and difficult to manage.	Interviews
5	(-) No set KPI’s makes it difficult to evaluate process improvements.	Interviews
6	(-) Missing procedures for a lot of assembly processes, reliance on tribal knowledge.	Interviews, lessons learned
7	(-) Overly exposed supply chain. Delays and hiccups. Unstructured supplier selection process.	Interviews and meeting observations.
8	(-) The Secure Storage has limited access rights, which disrupts the workflow.	Interviews, team sync-up meeting.

The table highlights eight significant findings. People tend to naturally focus on existing issues, but it is equally important to recognize the two positive findings. Out of six negative findings, only six are considered for this study because findings 7 and 8 involve other teams and therefore are excluded from consideration. The following section investigates best practices available in current literature.

4 Best Practices and Literature Review

In this chapter, the existing knowledge gathered from various sources is examined and a framework for the study is developed. Based on Section 3's findings, a literature search was carried out to address the identified weaknesses. The results were organized into a list of strengths and weaknesses to facilitate the search for suitable ideas and methodologies.

Each of the chapter's section 4 sections discusses significant findings from the literature review. Each section begins with an explanation of a particular idea, concept, or method, followed by a discussion of its relevance to the investigation. At the conclusion, a visual summary of the major discoveries is provided.

4.1 Build Management

Build management encompasses a set of activities associated with the satellite's construction. These activities involve planning the build taking into account all the major milestones and deadlines, task management, people management, resource management, etc. This section discusses the various approaches and methodologies applicable to the topic and how they could be used to address the identified weaknesses.

4.1.1 Build Management Methodologies

The process of building a satellite involves a complex series of interconnected steps, starting from defining the configuration all the way to the launch. This extensive process requires careful planning, collaboration, and implementation to guarantee a successful satellite deployment and operation in space. Due to the complexity of each product and low-volume manufacturing, the lifecycle of each satellite is similar to a project and is managed using various project management approaches.

In the past, the waterfall approach was used in the space industry. The origins of the waterfall method can be found in the 1950s and 1960s, a time when massive engineering and construction projects dominated the field of project management. Winston W. Royce later modified and formalized this approach, introducing a sequential process model that has now come to be known as the waterfall approach in 1970. The concept first became well-known in the software development sector, where it was used as a method for managing and overseeing challenging projects. The method has been improved and changed over time, and a variety of industries have adopted it (Royce, 1987).

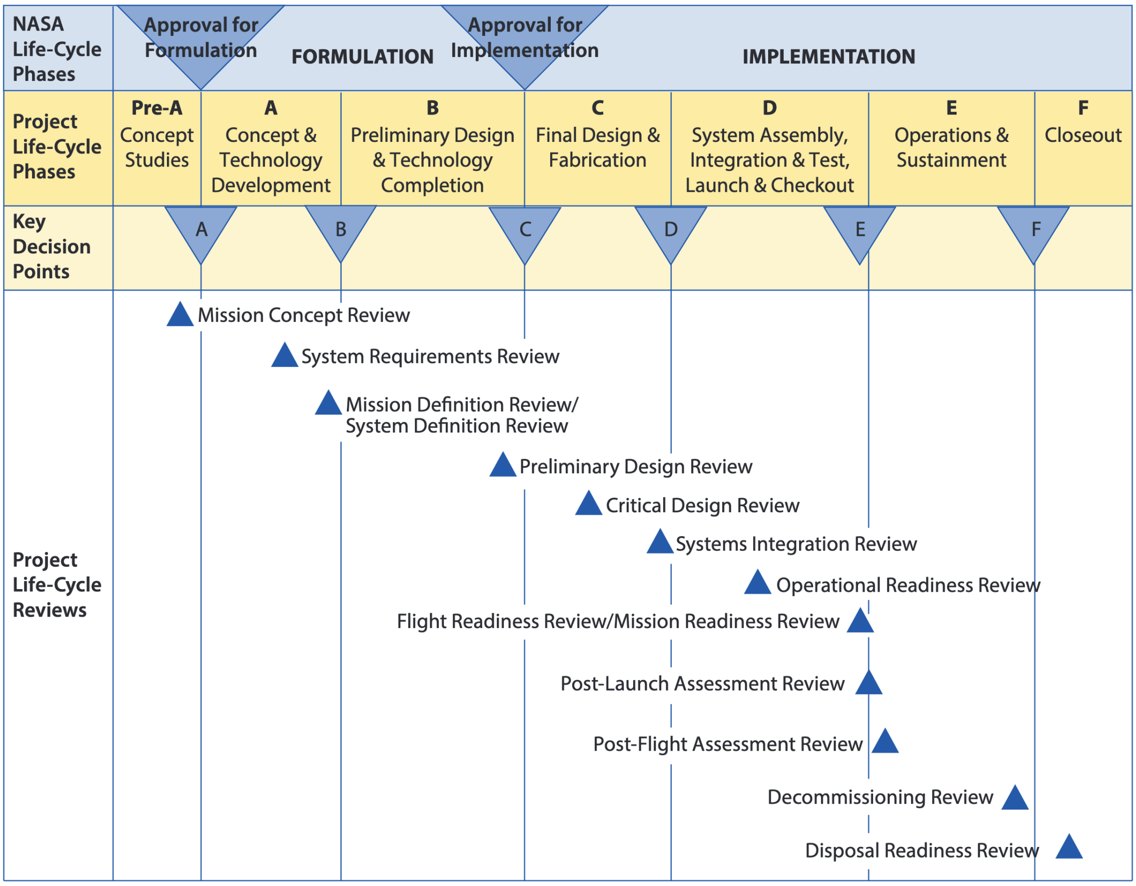

Figure 7: Simplified project lifecycle (Blythe et al., 2014)

However, the waterfall approach has its limitations, including rigidity and inefficient resource utilization. The strict sequence of phases can make it challenging to adapt to changes or unforeseen issues, while the linear structure can lead to periods of inactivity for team members. Additionally, the late start of the testing phase can cause delays and increased costs if significant issues are discovered (Thesing, Feldmann and Burchardt, 2021).

The limitations of the conventional Waterfall methodology in software development and other dynamic project environments contributed to the development of Agile methodologies. The rigidity and inflexibility of the Waterfall approach often caused projects to struggle to adapt to changes in requirements or unforeseen challenges (Reddy A, Bindu C and Baseer, 2015). Project teams needed a more responsive and flexible strategy to manage complex and changing projects. Agile methodologies emerged as a solution to these challenges, offering an iterative and incremental framework that prioritizes collaboration, adaptability, and customer feedback, allowing teams to deliver high-quality products in a constantly changing landscape. Kassab, DeFranco and Graciano Neto (2018) show the Agile approach to be widely used figure 8 and well-liked in the software world across numerous domains.

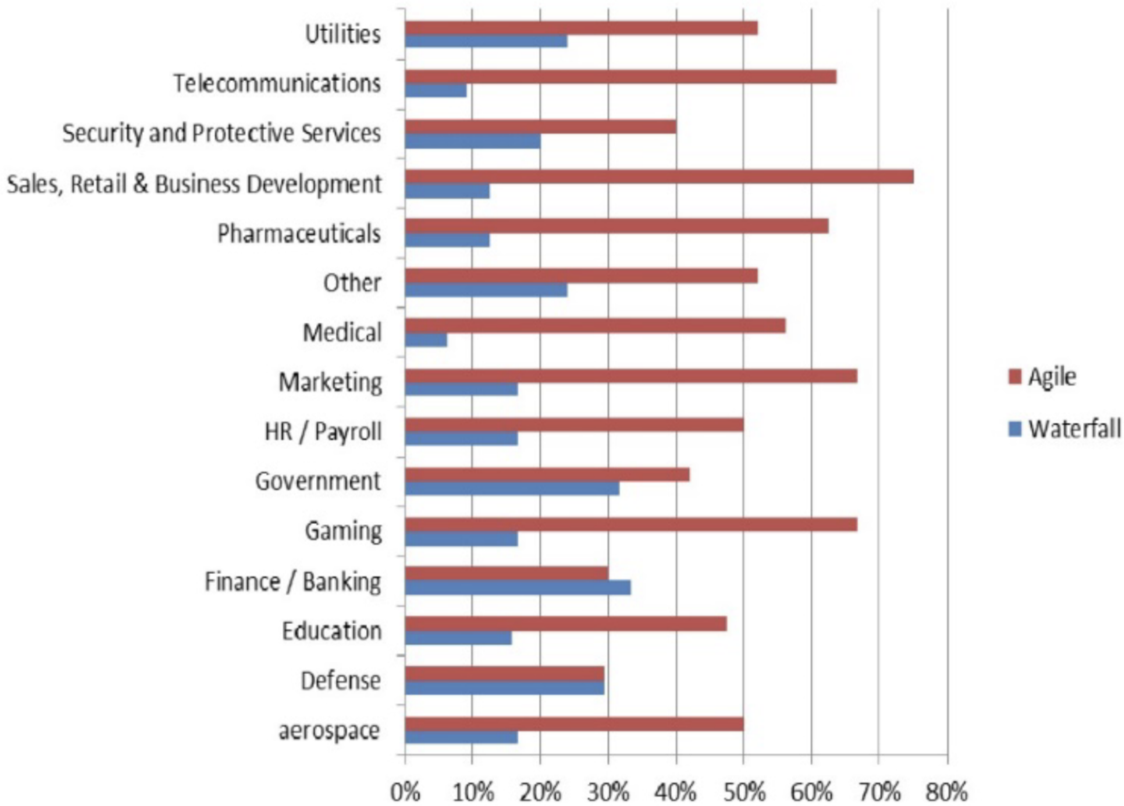

Figure 8: Software development lifecycle employed across industries (Kassab, DeFranco and Graciano Neto, 2018)

Thesing, Feldmann and Burchardt (2021) suggest a number of exclusion and selection criteria for selecting the best approach. Factors such as the project's decomposability, the rigidity of requirements, and criticality may influence whether the Agile method is appropriate or not. In the context of the case company, the top-level requirements are frozen at the beginning of the Preliminary Configuration Review. However, due to the continued volatility of the global supply chain (Newton, 2023) the middle and bottom-level requirements are subject to change. The suppliers face shortages and delays in the component shipments which can trigger changes in configuration or build processes. Additionally, the market pressure from competing companies requires incorporating more subsystems and features on production satellites as secondary subsystems and testing them in orbit.

In Agile methodology, team empowerment is a key factor that can help software development projects succeed. The team needs to be trusted to act independently and decide how best to complete their tasks. Technical and soft skills, such as communication and collaboration, are essential for teams to have to make sound decisions.

When the team is empowered and has the required expertise, they are better equipped to adapt to changing requirements and deliver high-quality software that meets customer needs. Overall, a culture of collaboration, continuous improvement, and autonomy can help Agile teams to succeed. Raza and Majeed (2012) points out mature, properly and formally trained Scrum teams are more likely to extract the full potential of Scrum.

However, Thesing, Feldmann and Burchardt (2021) points out that high-complexity projects with interdependent deliverables, which prevents them from using incremental and iterative approaches benefit more from the traditional approach. Factors such as complicated team structure, number of interfaces between teams, documentation requirements and high visibility of requirements all suggest using the more traditional approach.

In recent years, the hybrid model, which combines elements of both Scrum and

Waterfall, is getting traction as an effective way to manage complex projects. By combining the best parts of both methods, project teams can find a balance between structure and flexibility. This gives them the tools they need to deal with risks and unknowns while keeping track of the project's requirements, scope, timeline, and budget. Batra et al. (2010) demonstrated that both Agile and structured approaches can coexist harmonically within the same organization or the same project. The structured approach provided planning, control and coordination of resources, while agile provided iterative and fast development cycles within that infrastructure, with both approaches complementing each other.

Table 5: Hybrid methodologies (Reiff and Schlegel, 2022)

Approach	Initial phase	Development phase	Final phase
Water-Scrum-Fall	Waterfall - Requirements analysis - Planning	Scrum - Design - Development - Implementation	Waterfall - Integration - Testing
Waterfall-Agile	Waterfall - Requirements analysis - Planning	Agile approach - Design - Development - Implementation	Agile approach - Testing
Hybrid V-model	V-model - User requirements - System requirements - Planning	Scrum - Design - Implementation - Unit testing	V-model - Integration - System testing
Agile-Stage-Gate (Scrum-Stage-Gate)	Stage-Gate for administrative and strategic activities Scrum for operative activities - Discovery - Idea generation - Scoping	Stage-Gate for administrative and strategic activities Scrum for operative activities - Development - Implementation	Stage-Gate for administrative and strategic activities Scrum for operative activities - Testing - Validation - Launch

Reiff and Schlegel (2022) in their work "Hybrid project management – a systematic literature review" analyzed the existing literature on various hybrid project management methodologies and classified them based on the degree and type of integration between traditional project management and agile practices summarized in table 5. The most common is to have the initial phase and final phase kept in the traditional phase to frontload the requirement definition and resource allocation and keep the actual development phase agile. Agile-Stage-Gate differs as the Agile element is present in every phase. The author summarizes various advantages, such as efficiency improvements, flexible response to changes and lower costs. The drawbacks of this approach include the need for additional training, increased administrative load, and higher levels of transparency requirements.

Ahmed-Kristensen and Daalhuizen (2015) explore cases of 4 Danish manufacturing companies and their efforts to adapt the stage-gate model to incorporate Agile processes. Although the specific implementation is varied, several common challenges are presented. Notably, the informal communication within the team improved greatly, however, creating shared understanding became more difficult. To address this issue, the companies implemented various visualization tools and optimized interaction points, such as meetings with key stakeholders.

Krug et al. (2019) developed a method on how to determine the right proportion between Scrum and Stage-Gate. The method of the cross-impact matrix is used to identify breakpoints in different development steps. Then Agile-Fitting is used to calculate how well the step fits for converting to a Scrum process.

4.1.2 Team Structure

Galbraith (1971) defined several types of organizations ranging from purely functional to purely project-based. Functional organizations are divided into functional areas such as engineering, administration, finance, sales, and so on, whereas project organizations allocate resources based on projects that are separate from regular functional structures.

Matrix organizations were introduced to NASA in the 1960s to tackle the increased complexity of the Apollo mission, which at its peak involved over 390 thousand people and over 2 billion parts. The approach took hold in the manufacturing industry due to their ability to improve collaboration, resource allocation, and overall efficiency (Mccarthy, 1980). In this chapter, we will look at the key aspects of implementing a matrix organizational structure in manufacturing settings, as well as the potential benefits and drawbacks of doing so.

Employees in a matrix organization report to multiple managers, typically a functional manager and a project or product manager. Because employees with specialized skills can be easily assigned to various projects or tasks as needed, this dual reporting structure allows for better resource coordination (A Guide to the Project Management Body of Knowledge (PMBOK® Guide) 2017). In a traditional team structure, the team leader functions both as a functional and project manager. As the number of projects grows, the number of employees working on those projects grows as well, which naturally limits how well the size of the team can scale.

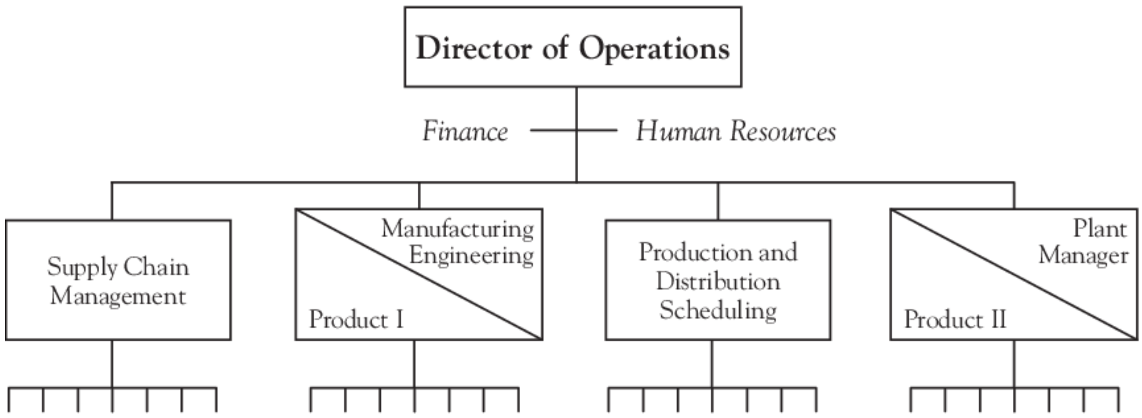

Figure 9: Two - Hat Model Within Operations (Galbraith, 2009)

Clear communication and well-defined roles are required for the successful implementation of a matrix structure in manufacturing. To avoid confusion and ensure that all team members understand their expectations, each manager's responsibilities must be explicitly defined. Regular meetings between functional and project managers can aid in the maintenance of transparency and cooperation in decision-making processes (Burton, Obel and Håkonsson, 2015).

The matrix organizational structure has many advantages, but it also has some drawbacks, such as role ambiguity and increased communication complexity. Implementing the RACI matrix, which stands for Responsible, Accountable, Consulted, and Informed, is one effective way to address these problems.

A RACI matrix is created by listing project tasks or processes on one axis and team members or roles on the other. Designations are assigned to each task or process to indicate who is responsible for completing the task, who is accountable for its completion, who should be consulted before making decisions or taking actions, and who should be informed after decisions or actions have been taken.

RACI Chart	Person				
Activity	Ann	Ben	Carlos	Dina	Ed
Create charter	A	R	I	I	I
Collect requirements	I	A	R	C	C
Submit change request	I	A	R	R	C
Develop test plan	A	C	I	I	R

R = Responsible A = Accountable C = Consult I = Inform

Figure 10: RACI Example (A Guide to the Project Management Body of Knowledge (PMBOK® Guide)–Sixth Edition 2017)

4.2 KPIs

Since the 1980s, there has been an increasing focus on performance management across industries and sectors. This shift has been driven by the desire to improve organizational effectiveness, accountability, and transparency (Neely and Bourne, 2000). Historically management has been striving to find a tool that would allow simplifying existing operation reports into easily digestible data. The value-bringing processes are often complex to evaluate holistically on a day-to-day basis to track the overall trend. A properly aligned measurement system could provide valuable information on whether the processes are achieving the goals. Performance measurements, including KPIs, have become a crucial tool for managers and decision-makers in modern businesses. By providing a snapshot of business operations, KPIs enable managers to evaluate how well their organization is performing regarding its goals (Fraser, 2006). However, developing and aligning KPIs is not a trivial task and many managers fail to do so correctly. Neely and Bourne (2000) estimate 70% of implementations of measurement systems fail.

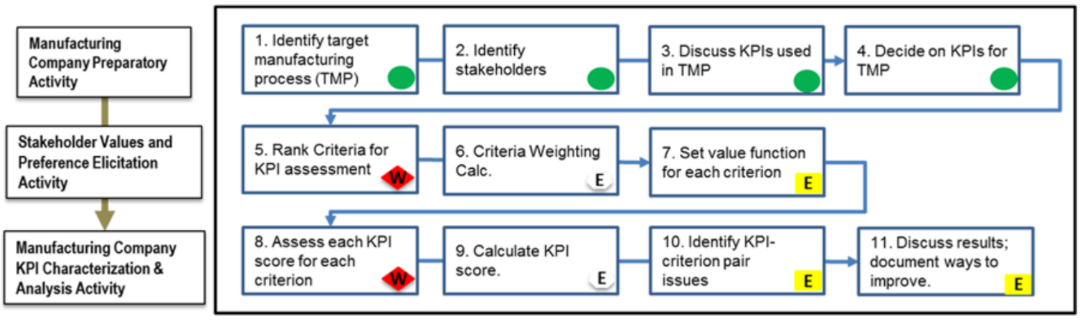

Figure 11: KPI Assessment Methodology (Hester et al., 2017)

Fraser (2006) suggests that companies that excel in their operations, and have a well-established framework for measuring and analyzing their performance can utilize KPIs to improve their core business indicators. Hester et al. (2017) in his work disseminated the factors that help succeed companies in implementing KPIs into 10 step process shown in figure 11. Initially, stakeholders evaluate the relative importance of each criterion listed in table 7, assigning a rank based on their perceived significance. As a result, each criterion gets a value function assigned to it indicating average significance. Afterward, the KPIs are evaluated against the criteria on a scale from “Completely Disagree” (score 0) to “Completely Agree” (score 6) yielding criterion-KPI pairs. Such pairs are evaluated using the assigned value function, and the resulting values are then added to get the KPI Score. Such a method allows to evaluate the KPIs against each other and identify any areas where KPI performance may be lacking.

4.3 Assembly Instructions

Assembly instructions are a crucial component in supporting the technicians in assembling subsystems. Well-designed instructions reduce cognitive load and mentally prepare for tasks at hand. However, as mentioned in section 3.5.3 the workers in the case company struggle with too many instruction styles. Ganier

Table 7: KPI Criteria and Definitions (Hester et al., 2017)

Criterion	Definition
Quantifiable	The degree to which the KPI's value can be numerically specified.
Relevant	The degree to which the KPI enables performance improvement in the target operation.
Predictive	The degree to which the KPI is able to predict non-steady-state operations and is accompanied by a record of the past performance values for analysis and feedback control.
Standardized	The degree to which a standard for the KPI exists and that standard is correct, complete, and unambiguous; also, the more broad the scope of the standard, the better, for example, plant-wide is good, corporate-wide is better, and industry-wide is best.
Verified	The degree to which the KPI can be shown to be true and correct with respect to an accepted standard and has been correctly implemented Note: The verified criterion is zero if no standard exists, but this is an indication that a KPI used without a standard can be a costly problem
Accurate	The degree to which the measured value of the KPI is close to the true value.
Timely	The degree to which the KPI is computed and accessible in real-time, where real-time depends on the operational context, and real-time means the updated KPI is accessible close enough in time to the occurrence of the event triggering a change in any metric affecting the KPI.
Traceable	The degree to which the steps to fix a problem are known, documented, and accessible, where the particular problem is indicated by values or temporal trends of the KPI.
Independent	The degree to which the KPI collection, transfer, computation, implementation, and reporting are performed independently from process stakeholders.
Actionable	The degree to which a team responsible for the KPI has the ability and authority to improve the actual value of the KPI within their own process.
Buy-in	The degree to which the team responsible for the target operation are willing to support the use of the KPI and perform the tasks necessary to achieve target values for the KPI.
Understandable	The degree to which the meaning of the KPI is comprehended by team members and management, particularly with respect to corporate goals.
Documented	The degree to which the documented instructions for implementation of a KPI are up-to-date, correct, and complete, including instructions on how to compute the KPI, what measurements are necessary for its computation, and what actions to take for different KPI values.
Inexpensive	The degree to which the cost of measuring, computing, and reporting the KPI is low.

(2004) states that assembly instruction users encounter three types of problems. First, they need to navigate the document to find instructions aligning with their intentions. Then, they need to understand and apply the information presented in the instructions to complete their task. Unifying the structure and formatting of the assembly instruction leads to a decrease in cognitive load in the first type of problem. Söderberg, Johansson and Mattsson (2014) recommends 5 guidelines to improve assembly instructions.

Table 8: Design of simple instructions (Söderberg, Johansson and Mattsson, 2014)

Guideline	Connected to phase	Description
Structure	Planning	- The structure should be based on a planned procedure of assembly, for examble by the use of HTA (Osvalder et al. 2009, empirical studies). - Support the instructions by adding separate presentations with pictures of the finished product (empirical studies). Depending on the space available in the instruction layout, the separate presentation can be placed either in the same information presenter or on a separate presenter. A separate presentation can also be added with pictures of high complex parts.
Layout	Presenta-tion	- The layout should make it easy to find information and be consistent throughout the instructions (Osvalder Ulfvengren, 2009; Inaba et al, 2004). - The instructions steps should include headings that are clear and consice, intuitive and informative (support the understanding of the task) (Ganier, 2004).
Pictures and text	Presenta-tion	- The instructions should have a high focus on pictures, and text should only be used when pictures are not sufficient (Ganier, 2004). - All pictures should be realistic (Osvalder Ulfvengren, 2009; Li et al., 2013), photographs are to prefer when possible. - In order to be clear the pictures should be big, have high contrast and reduced shadows (Li et al. (2013), . - Text and pictures should only include relevant information (Osvalder Ulfvengren, 2009). Eliminate unnecessary details in pictures. - Differences between similar objects should be highlighted (Clark et al., 2006; Osvalder Ulfvengren, 2009). This could be done by the use of information enhancers like arrows, numbers, measure indicatiors, marking, enlargements etc.

As the case company is progressing towards ISO 9001 certification, the implementation of the Quality Management System (QMS) is one of the top priorities. The key element of QMS is control of documents and information. The Quality Management Systems — Requirements (ISO 9001:2015) (2015) specifies the following: “When creating and updating documented information, the organization shall apply reviews and approval needed for the suitability and adequacy of this documented information.” This requires designing a process and related tools for capturing, reviewing, and releasing documentation used in organizational processes. While ISO 9001 does not specify the layout, books such as Abuhav (2017) provide various guidelines.

4.4 Conceptual Framework

The preceding sections have a detailed overview of improvement ideas discovered to address the issues identified in section 3. The conceptual framework for this study, as shown in figure 12 outlines 3 primary areas of improvement: build management, key performance indicators (KPIs) and assembly instructions. These areas were derived from the findings of the current state analysis and served as the foundation for the creation of initial recommendations. These areas were derived from the findings of the current state analysis and served as the foundation for the creation of initial recommendations.

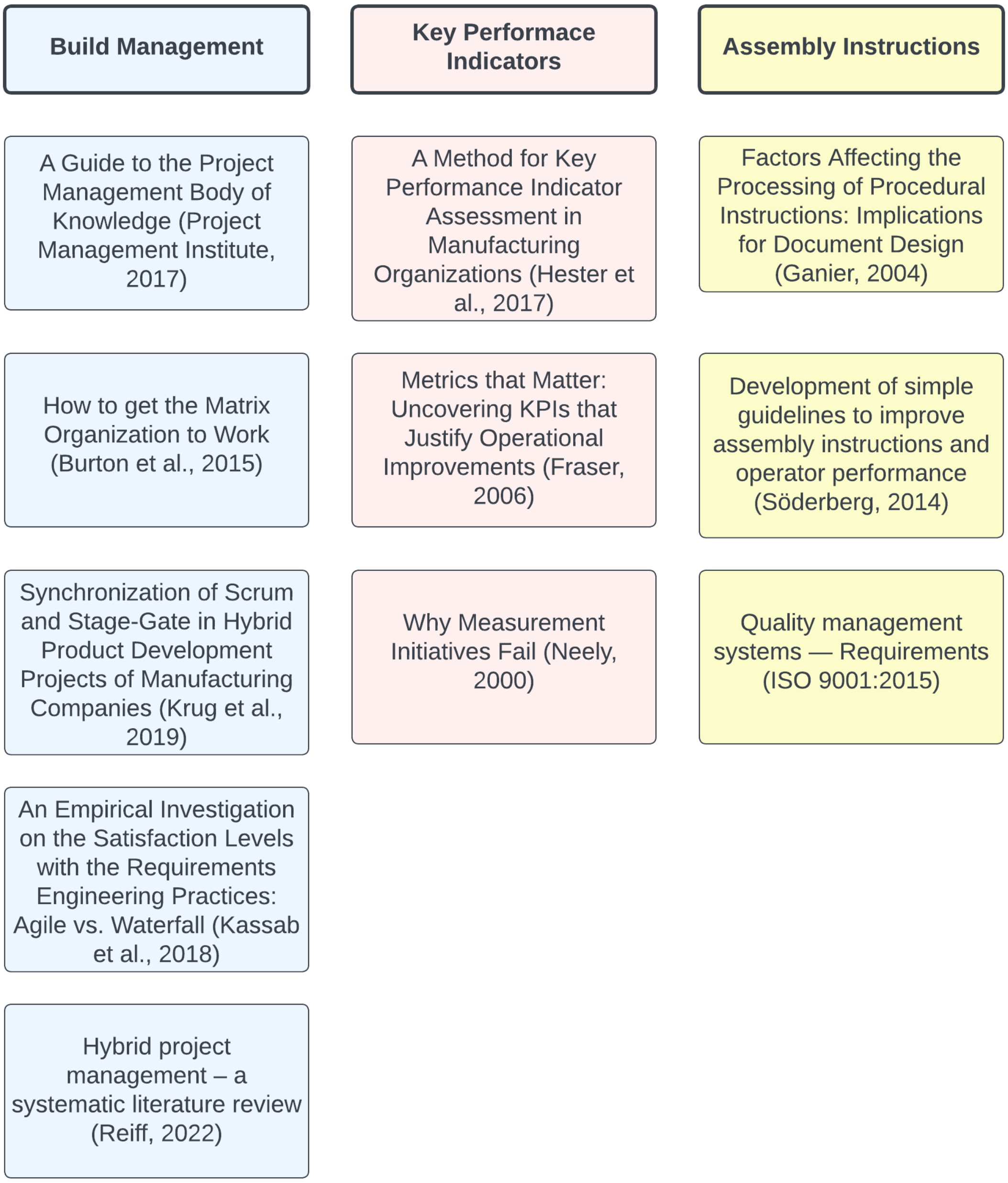

Figure 12: Conceptual framework

The second area — KPIs, describe the guidelines for designing effective KPIs that would benefit the organization. The third area – assembly instructions, combines ideas and techniques for designing assembly instructions that help technicians in accomplishing their tasks with less cognitive load and fewer mistakes.

These areas combined form the conceptual framework of the study and are utilized to create the initial process improvement recommendations described in section 5.

5 Creation of Initial Recommendations on Improving the Current Assembly Process

Previous sections introduced the findings of the current state analysis and the conceptual framework. Section 5 incorporates the results of those sections to create the initial recommendations. The beginning of the section provides an overview of the recommendation creation process. Afterward, each subsection provides a summary of the initial recommendations for each major area of interest.

5.1 Overview of the Initial Recommendation Creation Process

The creation of initial recommendations involved one workshop as described in table 2. The participants were: Director of Missions, TL of Mission Management, AIT Engineer 1 and AIT Technician 2. Similarly to the current state analysis, the participants were selected based on their involvement with the process and also the prior relevant experience pertaining to the identified weaknesses. In particular, the Director of Missions and TL of Mission Management possess extensive knowledge from their previous experience working in larger manufacturing companies which are directly related to challenges identified in CSA. Fortunately, the workshop took place during a relatively quiet period regarding Covid lockdowns and the participants were able to attend in person.

The workshop was structured in 4 parts mirroring the conceptual framework. In the first segment, the introduction, the structure and overview of the workshop are introduced. In each following part, the relevant topic from the conceptual framework is first introduced, then an overview of the extended findings from the current state analysis, followed by preliminary ideas and findings from the literature review and ending with the idea generation phase. At the end of each stage questions and feedback are solicited from the participants to maintain focus on the topic of discussion and address any potential misunderstanding.

Given the active involvement of participants in the manufacturing process in various capacities and dimensions, they were actively engaged in the workshop. The idea generation involved open discussions, brainstorming and evaluation of the recommendations in a free format. All the ideas, comments and suggestions relevant to the creation of recommendations were recorded in the form of field notes as mentioned in table 2.

5.1.1 Build Management

The topic of build management struck a nerve with the participants and sparked a highly debated discussion. Overall the stakeholders acknowledged that the process does not work very well and has issues on multiple levels. With multiple teams involved and numerous interfaces to manage, weaknesses at each interface significantly impact the overall effectiveness of the process.

Table 9: Initial improvement recommendations for build management

#	Focus area	Suggestion
1	Team structure	Delegate build management to a designated position: • Write down the list of responsibilities of an AIT Team Leader • Delegate responsibilities, document in RACI matrix • Define job description
2	Task management	Transition from Waterfall to Hybrid Scrum approach: • Identify major gates and milestones in the process • Define Scrum flow within those gates • Define schedule for Scrum meetings • Develop tools to support the process Develop better scheduling methods: • Separate research on assembly estimation methods

Due to so many interfaces, the amount of management overhead required to maintain the process is high, however, the team still struggles to meet deadlines. In addition, the stakeholders supported the idea of delegating responsibilities for the build management to a designated position. First, this would require writing down the list of all responsibilities of the AIT Team lead and mapping it using the RACI matrix to define the responsibilities of the new position. Once the new position is defined, a decision would be made regarding whether to hire internally or seek an external candidate.

Additionally, participants agreed that the waterfall approach is not flexible enough to support the manufacturing process. The concept of the hybrid Scrum approach was not familiar to the stakeholders, however, they were receptive to the idea. The existing Waterfall can be examined to identify the main gates and milestones. A modified Scrum flow can be established within these gates to promote an iterative tasking process in which tasks are completed in short one-week sprints. Weekly review and planning meetings need to be scheduled to review the progress, eliminate roadblocks and deadlocks, and facilitate transparency and communication. All the existing ticketing frameworks used in software development in the case company support Scrum workflows and require minimal configuration.

The second set of recommendations focuses on improving scheduling methods, particularly assembly estimation methods. Due to poor tasking planning the real-time required to fulfill common tasks is hard to predict due to the low repeatability of the task. The stakeholders shared the notion regarding the poor predictability of assembly tasks. The intricate nature and interdependence of many assembly and testing tasks exacerbate the issues leading to missing deadlines. Unfortunately, the conceptual framework does not cover this topic and it was agreed that separate research is required to identify better scheduling methods. The resulting set of recommendations for the build management is collected in table 9.

5.1.2 Key Performance Indicators

The topic of KPIs was not new to the participants. The ISO 9001 certification requires the implementation of performance indicators (Quality Management Systems — Requirements (ISO 9001:2015) 2015) which is a potential requirement for future customers. Additionally, with good tooling support, well-designed KPIs can provide easy and digestible data to keep track of process efficiency. However, as all the stakeholders started their careers in engineering roles, there were some reservations regarding the implementation of KPIs and the messaging directed to line workers. The TL of Missions shared a notion that once the performance target is measured solely by KPIs, the KPIs cease to be useful as they become susceptible to manipulation. The author later discovered this phenomenon is also known as Goodhart's law originating in his work on the monetary policy of the United Kingdom: "Any observed statistical regularity will tend to collapse once pressure is placed upon it for control purposes". (Goodhart and Goodhart, 1984)

Overall, the stakeholders recognized the need for the implementation of KPIs and converged on a few recommendations. The overall agreement was that an additional workshop would be necessary to facilitate the implementation of the process. As the process does not exist yet, the first step is to collect and define requirements. It was suggested to identify and involve a representative of the operational staff from the beginning of the implementation to get early buy-in, otherwise, the skepticism towards the process might worsen the effectiveness of the implementation.

Table 10: Proposed KPIs during the workshop

#	Proposed KPI	Description
1	Overtime hours	Tracks the quarterly overtime incurred during the build. Good indicator of overall process health.
2	Missed gate deadlines	Tracks the missed gate deadlines.
3	Cost of quality	Costs incurred in maintaining quality standards, such as defects, rework, and resolution of non-conformances.
4	First-pass yield	Percentage of units, such as PCB/A or mechanical parts that pass through the assembly process without needing rework; tracked on per Part Number basis

Once the requirements are defined the schedule for KPI reviews can be established and the necessary IT tools can be prepared. As established in section 5.1.1 the case company has experience with using Agile tools and connecting the data collection and visualization should not be a problem.

However, the question of what KPIs to track is not fully resolved. While some potential higher-level KPIs were proposed during the workshop and are presented in table 10, finalizing the list of KPIs was not in the scope of the workshop. The Director of Missions proposed to conduct a more thorough investigation into the matter to address the question. The summary of all the proposals is collected in table 11.

Table 11: Initial improvement recommendations for key performance indicators

#	Focus area	Suggestion
1	KPI process	Create framework for maintaining consistent KPIs: • Collect and define requirements • Define schedule for review of KPIs • Prepare IT tooling for tracking and visualization of the pertaining data • Initiate KPI process
2	KPI creation	KPI Creation Workshop: • Define stakeholders • Define framework (such as SMART) • Conduct the workshop

5.1.3 Assembly Instructions

As all the workshop participants have worked in the manufacturing process in various capacities, they recognized the importance of improving the documentation process. A GAP analysis was proposed to identify specific areas in the manufacturing process where critical documentation is missing. Stakeholders expressed hope that this analysis would not only provide a foundation for understanding current shortcomings but would also provide a clear roadmap for needed improvements.

The AIT Technician 2 emphasized the importance of a thorough documentation process in reducing the defect rate through improved manufacturing accuracy.

The idea of bringing document and version control requirements has also received broad support from stakeholders. Although the process seems 'heavy', the Director of Missions emphasized the significance of consistency in the document creation, review and release processes. The AIT Engineer related to his sour experience with finding outdated printed instructions and mentioned that having proper document control could avoid costly mistakes. The final proposals are listed in table 12, it was however concluded that the process require the involvement of the Quality Assurance team, which at that point was still in a transitionary state.

Table 12: Initial improvement recommendations for assembly instructions

#	Focus area	Suggestion
1	Documentation process	Create framework for maintaining consistent documentation: • Perform GAP analysis of missing documentation relevant to the manufacturing process • Define requirements for document control • Define requirements for version control
2	Documentation	Improve process documentation: • Identify various types of documentation pertaining the manufacturing process • Design standard templates according to best practices identified in section 3 in collaboration with identified stakeholders • Implement transition schedule

As a result of the active workshop participation, a series of initial recommendations was co-created. These recommendations are intended to address the weaknesses identified in the current state analysis. Next section 6 describes the validation of the created initial recommendations.

6 Feedback on the Initial Recommendations

Section 6 describes the validation of the initial recommendations co-created in section 5. The section starts with a description of the validation process. Then, it delves deeper into the provided feedback and how it relates to the creation of final recommendations. The section ends with a description of the final recommendations, which are then summarized in table 14.

6.1 Overview of the Validation Stage

The validation of recommendations was performed by organizing two separate meetings with the stakeholders described in table 2: Director of Missions and Team leader of Mission Management. The selection of the participants was defined based on their ability to facilitate change and their knowledge and closeness to the manufacturing process. The feedback is required to evaluate whether the initial recommendations have the potential to improve the manufacturing process. Various aspects such as feasibility, effort, and resources were taken into account.

The meetings were organized in person. The structure is similar to the workshop described in section 5.1, first the study premise is reintroduced. As both the participants had prior involvement with the study, the introductory part was rather short. Then the meeting took part in three parts mirroring the structure of the current state analysis. In each part, the relevant topic is introduced by stating the relevant weaknesses identified in the current state analysis. Following that the initial recommendations are presented and the feedback is solicited generating the Data 3 of the study (see table 3). The feedback was recorded in field notes. Based on collected feedback the initial recommendations are adjusted and the final recommendations are generated.

6.2 Feedback Received for the Initial Proposal

As the interview participants were involved in the previous stage of the study, the topics introduced were familiar to them. Despite all the complexities described in the previous section, overall the feedback was positive. The interviewees found the action plan embedded with the recommendations reasonable and achievable. Table 13 provides a comprehensive summary of the feedback received.

Table 13: Suggestion to the initial recommendations

#	Focus area	Initial Suggestion	Feedback
1	Team structure	Delegate build management to a designated position: • Write down the list of responsibilities of an AIT Team Leader • Delegate responsibilities, document in RACI matrix • Define job description	Director: Idea should go forward, however, getting the headcount will take some time. The headcount request process should be initiated ASAP.
2	KPI process	Create a framework for maintaining consistent KPIs: • Collect and define requirements • Define schedule for review of KPIs • Prepare IT tooling for tracking and visualization of the pertaining data • Initiate KPI process	Director: The ownership of the process should be transferred to the upcoming Quality team.
3	Documentation process	Create framework for maintaining consistent documentation: • Perform GAP analysis of missing documentation relevant to the manufacturing process • Define requirements for document control • Define requirements for version control	TL: The GAP analysis should be done periodically or as a part of the lessons learned process.

Regarding the proposed team structure, the participants felt the proposed plan is sound and ready to be executed. Implementing elements of a matrix structure into the team seems feasible and well-researched and is proven in the case company's software teams. However, the director shared his concerns regarding the additional headcount this would require as the final approval falls into the responsibility of the Vice President. The headcount request process requires a set of documents to initiate and a long period of time, so the director suggested initiating it as soon as possible.

Building up the notion of the KPI process ownership, initially raised during the initial recommendation creation workshop, the Director suggested transferring the ownership of the process to the Quality Assurance team. At the moment of the interview, the Quality Assurance team was undergoing reorganization to be more integrated with manufacturing and operations. It was also noted that the risk management process was not fully established, which is a necessary process for the ISO 9001 certification (Quality Management Systems — Requirements (ISO 9001:2015) 2015).

Regarding the documentation process, the Team Lead of Missions proposed to make the GAP analysis process either periodic or tie it to the lessons learned process. This should prevent the gaps in documentation from accumulating and improve overall confidence in written instructions.

The rest of the improvement ideas remained unchanged. The team leader of Missions showed interest in the task management framework and proposed collaboration as similar tools could be useful in his team as well.

6.3 Final Recommendations

Following the current state analysis and the extensive literature review, initial recommendations were created.

The final proposal was created based on the feedback received in section 6.2 from the selected stakeholders and collected in table 14. The initial set of recommendations was amended by three suggestions highlighted in **bold**.

Table 14: Final improvement recommendations

#	Focus area	Suggestion
1	Team structure	Delegate build management to a designated position: • Write down the list of responsibilities of an AIT Team Leader • Delegate responsibilities, document in RACI matrix • Define job description • **Initiate the headcount approval process**
2	Task management	Transition from Waterfall to Hybrid Scrum approach: • Identify major gates and milestones in the process • Define Scrum flow within those gates • Define schedule for Scrum meetings • Develop tools to support the process Develop better scheduling methods: • Separate research on assembly estimation methods
3	KPI process	Create framework for maintaining consistent KPIs: • **Transfer the ownership of the process to the Quality Assurance team** • Collect and define requirements • Define schedule for review of KPIs • Prepare IT tooling for tracking and visualization of the pertaining data • Initiate KPI process
4	KPI creation	KPI Creation Workshop: • Define stakeholders • Define framework (such as SMART) • Conduct the workshop
5	Documentation process	Create a framework for maintaining consistent documentation: • Perform GAP analysis of missing documentation relevant to the manufacturing process • **Establish regular schedule for the GAP analysis** • Define requirements for document control • Define requirements for version control
6	Documentation	Improve process documentation: • Identify various types of documentation pertaining the manufacturing process • Design standard templates according to best practices identified in section 3 in collaboration with identified stakeholders • Implement transition schedule

The first adjustment addresses the headcount approval issues. As the process requires several steps and multiple documents and approval, the stakeholders urged to start the process sooner to finalize the hiring before the end of the year.

The second adjustment is about transferring the ownership of the KPI process to the Quality Assurance team. The team is undergoing a major reorganization and in the future will be closely integrated into major functions of the organization. Having all processes related to ISO 9001 under the umbrella of the Quality Assurance team should provide consistency and concentrate the knowledge within the team.

The third adjustment refers to the initial GAP analysis of the existing documentation. By implementing a scheduled review of the documentation on a consistent time interval the non-conformance creep can be avoided.

In conclusion, the final recommendations present the outcome of this study. By addressing various facets of the manufacturing process these recommendations aim to improve the various aspects of satellite manufacturing. However, it’s not the end of the journey, but rather the steps in the right direction. In the end, these improvements should be considered as part of an iterative process, always open to refinement and development. The most significant aspect of this approach is its emphasis on continuous learning and adaptation. It is believed that the company can incorporate this philosophy further into its culture, embracing change and continuous improvement as fundamental to its mission.

7 Conclusion

In this final section, the overall summary of the study is provided, encompassing key findings of various stages and insights. The implications of the study for the case company are examined, providing insight into the resources required to continue the process and a possible action plan. Afterward, the thesis evaluation is provided to elaborate on how the selected research approach influenced the study outcomes. The section ends with closing words describing the significance of the topic to the case company.

7.1 Summary

The objective of the study was to propose recommendations to improve the manufacturing process of the case company. The case company is going through a phase of rapid expansion and the processes are not keeping up, causing issues with the workforce and quality of the product. The outcome of the study is a set of recommendations aimed to improve the weaknesses found during the current state analysis.

The study was conducted using applied action research using qualitative data-gathering methods which allowed to get useful data with smaller sample sizes. The first stage was the current state analysis where the manufacturing process was examined through available documentation and a series of interviews with subject matter experts on different aspects of the process. The outcome of the analysis is a list of strengths and weaknesses of the manufacturing process. The second stage was a literature review steered by the findings of the first stage. Examination of best peer-reviewed practices led to the creation of the conceptual framework encompassing the focal points of the literature review. The third stage is the co-creation of the initial recommendations with a group of stakeholders. The fourth stage was a validation of the initial recommendations by stakeholders and the creation of the final recommendations, the outcome of the study.

The current state analysis was performed by a series of interviews with manufacturing process users and stakeholders. The findings were listed in two groups: strengths and weaknesses. Three of the weaknesses were selected for further study based on severity and the ability of this study to influence it. The three weaknesses were: build management, KPIs and assembly instructions. The literature review was based on research on the identified three weaknesses. Identifying the seminal works in the field and how they are connected to the newer studies allowed to create a conceptual framework for the study. The conceptual framework includes the best practices available to address the identified weaknesses. This allowed to organize the workshop, where together with the stakeholders the initial recommendations were co-created. Later the initial recommendations were validated by the stakeholders, whose feedback allowed to create the final recommendations.

7.2 Managerial Implications

The final recommendations collected in table 14 contain the action plan. However, the actions described in the action plan cross over to multiple adjacent teams. Therefore the first step is to organize an initiative encompassing all the affected teams to bring all the relevant team leaders and directors into a meeting room. The three main areas are independent of each other and can be improved on in parallel. However, the topic of build management is critically important and the hiring process should start immediately. The most important outcome is that the author has the buy-in from his immediate manager, the Director of Mission, to facilitate the changes described in the action plan.

7.3 Thesis Evaluation

This section discusses the evaluation of this thesis through the prism of validity, reliability, logic, and relevance. It critically examines the strengths and weaknesses of the study to better appreciate its value and potential areas for improvement.

7.3.1 Validity

The study's validity is strengthened by the use of multiple data sources. It mitigates the risk of single-source bias by combining information from multiple types of sources, such as written documentation, interviews and workshops. However, there are still some issues that could affect the study's validity. Due to reliance on free-form discussion and because of the author's proximity to the issue and superior rank over some of the interviewees, the information is subject to bias. The qualitative approach relies on the interpretation of field notes which are also vulnerable to personal bias.

7.3.2 Reliability

The study's reliability is supported by the use of a consistent set of interview questions and careful documentation of field notes. There are, however, some limitations. Because the study relies on free-form discussion and the author's working relationships with stakeholders, a different researcher attempting the study may not produce the same results. Furthermore, as a result of the case company providing services to intelligence and governmental agencies; and due to increased attention from unfriendly governments, a lot of previously non-confidential information has become highly sensitive. As a result, the resulting lack of transparency prevents another researcher from replicating the results of the study.

7.3.3 Logic

The study followed an action research design, preventing it from falling into many pitfalls. The process started with investigating the manufacturing process of the company, identifying weaknesses, researching literature to find best practices to address the weaknesses, creating the recommendations, validating the recommendations and adjusting them to get the final recommendations.

7.3.4 Relevance

The study is highly relevant because it addresses a wide range of issues that the case company is currently experiencing. The study provides valuable insights by focusing on these critical areas, which can be used to improve the efficiency and effectiveness of the company's manufacturing process.

7.4 Closing Words

While it was a fun project that lasted way longer than initially planned, eventually, it still had to come to an end. The study produced a set of recommendations grounded in the research method. While it is not without limitations, the outcome of the study holds significant value for the case company, providing a clear path for future improvements. What is more important is that this study opens the door for the culture of continuous improvement in the case company. I am grateful for the opportunity given to me by the case company and by Metropolia AMK. This experience has not only increased my understanding of the processes I interact with daily but also improved my understanding of various research approaches.

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1 Current State Analysis Interview Questions

1. Can you describe your primary responsibilities? Are they documented?
2. What specific tools, equipment, or technologies do you frequently use in your role, and how do they assist you in performing your tasks effectively and accurately?
3. How do you manage your daily tasks?
4. How does your work get verified?
5. How do you communicate or collaborate with other teams?
6. What kind of training or development opportunities has been provided by the company?
7. Can you share an example of a challenging situation or problem you have encountered while performing your work and how you resolved it
8. What in your opinion are the main areas of improvement?