TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

NEW PRODUCT IMPLEMENTATION IN FLIR SYSTEMS ESTONIA OÜ

UUE TOOTE JUURUTAMINE ETTEVÕTTE FLIR SYSTEMS ESTONIA OÜ NÄITEL

MASTER THESIS

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Tallinn 2021

(*On the reverse side of title page*)

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DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

THESIS TASK

Student: Kristo Vossi, 192576

Study programme, main specialty: Industrial engineering and management

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Thesis topic:

New product implementation in FLIR Systems Estonia OÜ.

Uue toote juurutamine ettevõtte FLIR Systems Estonia OÜ näitel

Thesis main objectives:

1. Propose and carry out a plan for the implementation of a new dual-spectrum fixed mount security camera to volume production
2. Develop and build a production line for the product with efficient resource and space usage in mind
3. Evaluation of the product implementation project

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Formulate thesis topic and structure	31.01.21
2.	Literature review and company introduction	07.02.21
3.	Initial data analysis	07.03.21
4.	New product implementation	31.03.21
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PREFACE

The thesis was initiated by the author, Kristo Vossi, who works in FLIR Systems Estonia OÜ as a mechanical engineer. One of the reasons for choosing this topic was that the project covered in the thesis started right before the thesis topic needed to be selected with a planned launch date right before the submission date. Another reason for choosing this topic was that the author was selected as the project leader for the project and the particular project is a good example of multidisciplinary product implementation, as well as covering many topics learned during the masters degree studies.

I would like to thank my colleaguese for helping me along the way, especially Meelis Bergmann, who is the plant manager in FLIR Systems Estonia OÜ, for providing guidance and being the company side supervisor. I would also like to thank Kristo Karjust for being the supervisor from the university side.

Keywords: NPI, electronics, LEAN manufacturing, production line set-up, project management

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List of abbreviations and symbols

BOM – Bill of materials

CER – Capital expenditure request

COGS – Cost of goods sold

DVT – Design validation test

EMEA - Europe, the Middle East and Africa

ESD - Electrostatic discharge

EVT – Engineering validation test

FOV – Field of view

FPY – First pass yield

GTC – Global trade compliance

IEC - International Electrotechnical Commission

IP67 - Ingress protection rating according to IEC 60529 standard

IR – Infrared

IRFPA - Infrared focal plane array

LEAN - A philosophy or a strategy that utilizes a set of practices to minimize waste in order to improve an enterprise's performance

LOB – Line of business

LWIR - Long Wave Infrared

MAC - Media access control

MOH – Material overhead

MWIR - Mid Wave Infrared

NIR - Near Infrared

NPI – New product introduction

OH - Overhead

PCBA - Printed Circuit Board Assembly (PCBA)

PDS - passive data structure

PVT – Production validation test

POE – Power over ethernet

R&D – Research and development

REACH - Restriction of Chemicals

RoHs - Restriction of Hazardous Substances

SWIR - Short Wave Infrared

TPS - Toyota Production system

UAS - Unmanned aerial solutions

VSM – Value stream mapping

WAF - Web application firewall

WIP – Work in progress

INTRODUCTION

FLIR Systems Inc. (FLIR) is the world leader in the field of designing and manufacturing thermal imaging infrared cameras. FLIR offers a diversified portfolio that serves a number of applications in government & defense, industrial, and commercial markets. Their products help first responders and military personnel protect and save lives, promote efficiency within the trades, and innovate consumer-facing technologies. FLIR has business units in over 150 locations worldwide, including in Estonia, where about 180 of the 4200 total employees work at.

FLIR Systems Estonia OÜ, with a factory in Tallinn, serves as a manufacturing unit in the corporation, being one of the largest in the corporation. FLIR Systems Estonia OÜ mainly producing thermography cameras, marine electronics and surveillance cameras. In order to maintain, as well as strengthen its position within the corporation having well set up and efficient operations is key, both concerning the existing product lines and during the planning and introduction of new ones. This thesis takes a look at the implementation of a new dual-spectrum security camera into production.

The goals of this thesis are to propose and carry out a plan for the product implementation, develop and build a production line for the product, and evaluation of the product implementation project.

The first chapter of the thesis focuses on giving an overview of the company and its product portfolio to give the reader a holistic view of the context of this work. The second chapter is concerned with reviewing the research on the topics of thermal imaging, lean manufacturing and use of original design manufacturer (ODM) services in electronics manufacturing to give an overview of the theoretical background for carrying out the work in this thesis. The third chapter introduces the product this thesis is focused on, as well as the set-up of the implementation project in general. In this chapter the requirements for the implementation will be analysed and a budget for the project set based on the requirements. The fourth chapter is where most of the actual work for the product implementation takes place. This includes creating a detailed project time plan, reviewing the product design with a focus on function and manufacturability, as well as creation of the production line design. Also covered in this chapter is setting up the traceability of production process, design of test stations, fixtures, and assembly aids as well as the selection of equipment. As a result of this chapter a production line set-up is developed and built. The final chapter focuses on the technical and economical calculations and analysis of the project.

The appendices include the project time plan Gantt chart, the project line budget overview and the factory layout drawing. The graphical material section contains drawings of equipment designed during this thesis.

1. COMPANY OVERVIEW

1.1 FLIR Systems Inc. Overview

FLIR Systems Inc. (FLIR) is a US-based electronics manufacturer headquartered in Arlington, Virginia mainly known for it’s leadership in the infrared camera industry. FLIR offers a wide portfolio of products that serves a number of applications in government & defense, industrial, and commercial markets. Their products help first responders and military personnel protect and save lives, promote efficiency within the trades, and innovate consumer-facing technologies. FLIR has business units in over 150 locations worldwide, including in Estonia, where about 180 of 4200 total employees work at. FLIR is publicly traded company listed on the NASDAQ and has a market cap of approx. 4.8B USD [1].

The company’s operations is split between two main operating segments: Industrial technologies consisting of Components line of business (LOB) and Solutions LOB and Defense technologies consisting of Unmanned integrated systems LOB and Sensors LOB. Industrial technologies operating segment develops, manufactures and services cameras, camera cores, related software and other offerings to create thermal, industrial, and other types of imaging system solutions. Products in this segment include:

- Cameras for building / electrical / mechanical inspecion;
- Thermal cameras cores;
- Machine vision cameras;
- Firefighting cameras;
- Commerical Unmanned aerial solutions (UAS);
- Security cameras;
- Intelligent transportation systems.

Some of the applications can be seen below in figure 1.1.

Figure 1.1. Applications of industrial segment [2]

Defense technologies operating segment develops and manufactures solutions for enhanced imaging, advanced surveillance, classification and suppresion of chemical, biological, radiological, nuclear and explosives (CBRNE) threats for global military, law enforcement, public safety and other government entities. Products in this segment include:

- Airborne systems;
- Unmanned solutions;
- Integrated systems;
- Border surveillance;
- Maritime systems;
- Radiation and explosives detectors;
- Chemical-biological threat detectors [1].

Some of the defence applications can be seen below in figure 1.2.

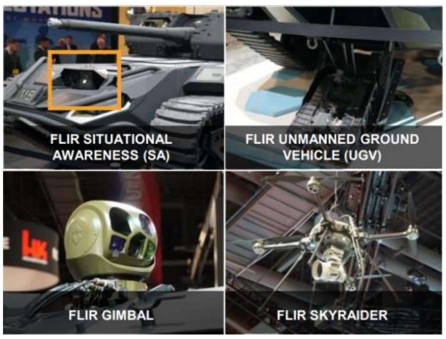


Figure 1.2. Defence applications [2]

Financial highlights for 2020 full year were a revenue of $1924 million, compared to $1877 million for the year prior, with a gross profit of $947 million, marking a gross margin of 49.2%, consistent with the year prior. Operating margin for 2020 was 16.5% compared to 14.5% in 2019. The industrial technologies segment accounted for revenues of $1156 million compared to $1092 million, representing a $64 million or 5.9% increase year-over-year. The operating income for the segment was $344.4 million compared to $276,2 million in the year prior. Segment operating margin increased to 29.8% from 25.3% in the prior year.Defense Technologies revenues for the year of $767.6 million decreased by $27.3 million, or 3.4% compared to the prior year. Defense Technologies segment operating income was $168.5 million, compared to $196.6 million in the prior year. Segment operating margin decreased to 21.9% from 24.7% in the prior year [3].

1.2 FLIR Systems Estonia OÜ overview

FLIR System's Tallinn factory serves as a manufacturing unit in the Solutions LOB, mainly producing volume segment products, reporting to, and working closely together with FLIR's Reasearch and development (R&D) unit and production unit in Täby, Sweden. Tallinn factory is one of the largest factories in the corporation. A picture of the factory can be seen in figure 1.3. Today FLIR System Estonia OÜ operates in a new 4300 m² facility built in 2014, designed with special requirements electronics manufacturing sets in mind, such as tight control on electrostatic discharge (ESD), humidity and dust. [4]

Figure 1.3. FLIR Systems Estonia OÜ production facility [4]

Currently FLIR Systems Estonia employs around 180 people. Activities in Tallinn factory include:

- Product industrialization;
- Assembly and testing;

- Material planning and purchasing;
- Shipping to sales units or distributors;
- Printed Circuit Board Assembly (PCBA) Production;
- Aftersales support for Europe, the Middle East and Africa (EMEA) region.

Products produced in Estonia are mainly handheld infrared cameras, security cameras and marine electronics. Products manufactured in Tallinn can be characterized by a relatively high level of vertical integration, which means that the production process involves manufacturing of the PCBA's in-house, assembly of optical components and detectors in-house, as well as calibration and final assembly of the cameras. [4]
Some of the products made in Tallinn can be seen below in figure 1.4. In 2020 FLIR Systems Estonia OÜ produced over 220 000 devices, 100% of which was exported [5].

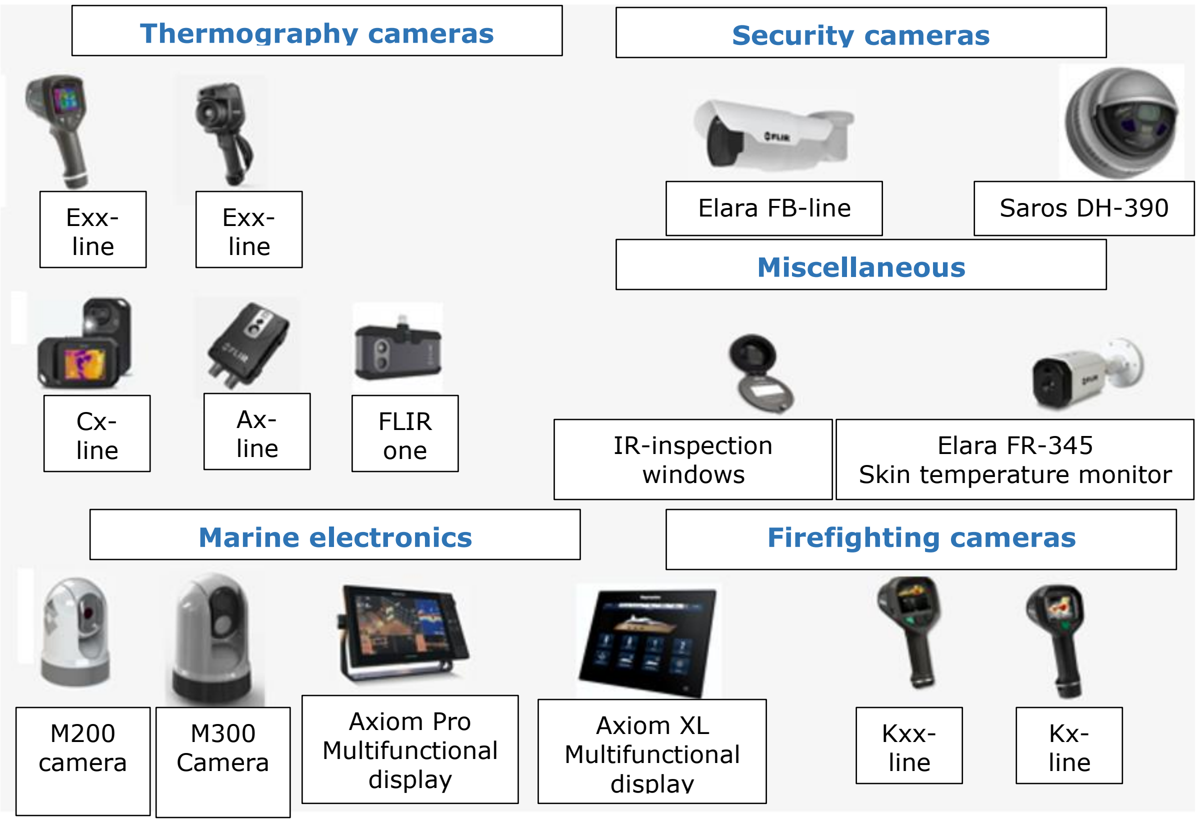


Figure 1.4. Products in FLIR System Estonia's factory [4]

From financial standpoint the company is doing well, having reported a revenue of €81 million in the year 2020 compared to €64,3 million in the year prior. Operating expenses for 2020 were €67 million, 90,5% of it being accounted to material and services costs, finished and unfinished goods inventory. Personell costs for the year were €4,5 million or 6,1% of the revenues. The net earnings for the year were €7,02 million representing a 9% operating margin, compared to €6,45 million and 10% in the year prior [5].

1.2.1 Production engineering organisation

Production engineering organisation is involved with day-to-day production support and new product introduction. The team is split between Tallinn and Täby facilities consisting of approximately 30 engineers and project leaders, the main specialties of the engineers in this organisation include mechanical engineers, production engineers, software engineers as well as production technicians. The team works closely together with R&D and supply chain teams across the world, as very often the products are developed elsewhere than the site of production. For introduction of new products a standardized toll-gate (TG) model is used on most projects, which splits the intruduction project into 6 stages, the completion of each stage should be evaluated by a steering commitee, if every action in a certain stage to be completed is done and the project can move forward or not. These TG stages are:

TG0 is the idea to project preparation stage**:** The purpose of this phase is to verify that all relevant information is in place and sanity checked for a start of pre-study. Project preparation inputs usually are: Ideas, Assignment (Specification) or Road-map item(s). A viable production concept is available, which will fit with current production, produce sufficient yield and good price/performance. The cost of deploying the concept has been estimated and is reasonable.

TG1 is the pre-study phase. The purpose of the pre-study phase is to, from a technical and commercial viewpoint, assess the feasibility of ideas for the development of new products, enhancement of products in production or the phasing out of existing products. A fairly detailed production concept is available. Most of the technical unknowns and uncertainty in terms of cost has been resolved and are now known, Risks are understood and mitigation plans are in place.

TG2 is the Planning stage. The purpose of the planning phase is to define and describe the project in detail, and in this way to prepare for a successful implementation. During the planning phase, technical areas are to be addressed and more closely investigated in order to form a base for an effective implementation. The project goals should be settled, a detailed time schedule including clear milestones should be prepared, internal and external resources should be booked, the project organization should be set up. We have a detailed production concept. Number of fixtures needed, what needs to be implemented in production traceability software, pallets and test schemes, benches needed etc. are all described in detail. No physical equipment need to be produced at this point.

TG3 is the Execution stage**.** The purpose of the execution phase is to reach a level of implementation where there is an acceptable chance to reach required level. Sales managers can then start to prepare for market introduction with volumes according to the Master Plan. Major investments in production or major purchasing of material can be made. The production concept has been prototyped using physical prototypes. All parts of the production system have been tested and validated to some extent.

TG4 is the Launch preparation stage**.** The purpose of the launch-preparation phase is to be ready for the start of market introduction. Orders can now be accepted with a confirmed delivery date. The prototypes have been iteratively improved until they reach pre-series ready status. The designs and systems should be ready for ordering of production equipment and/or deployment in volume production. The pre-series is successfully produced with yield and issues at a manageable level before null-series.

TG5 is the Handover stage**.** The purpose of the handover stage is to prepare the for production to take over the ownership of the product. In this stage work most of the issues with the product and production line should be solved. Instructions and production equipment should be documented. The null-series has been produced and verified for acceptable yield. Knowledge is transfered to the production management teams. After this stage most engineering resources are reassigned to other projects.

2. LITERATURE REVIEW

2.1 Infrared Thermal imaging overview

This sections goal is to give the reader a short overview of the technology behind thermal imaging which is an important component of the product covered in this thesis, as well as the other uses of this technology.

2.1.1 Fundamentals of thermal imaging

Thermal cameras are passive sensors that capture the IR radiation that is emitted by all objects that have temperature above absolute zero. All items consist of atoms that are in constant, with higher energy atoms vibrating more frequently. The vibration of charged particles generate electromagnetic waves. The rise in temperature of an object correlates with an increase in the speed of the vibration, and thus an increase in spectral energy. Due to this, all objects are continually emitting radiation at a rate with a wavelength distribution dependant upon the temperature of the object and its spectral emissivity, $\varepsilon(\lambda)$. Radiant emission is typically treated in terms of the concept of a blackbody. A blackbody is an object that absorbs all incident radiation and, conversely, consistent with the Kirchhoff's law, is a perfect radiator. The total radiation received from any object is that of the sum of the emitted, reflected and transfered radiation. Objects that aren't blackbodies can absorb only the fraction $\varepsilon(\lambda)$ of blackbody radiation, and the remaining fraction, $1- \varepsilon(\lambda)$, is either transmitted or, for opaque objects, reflected. A thermal image arises from temperature variations or differences in emissivity within a scene [6].

Infrared radiation lies between the wavelengths of visible light and microwave. The IR spectrum is divided in the following ranges:

- Near Infrared (NIR) with a wavelength of 0.75 μm to 1.4 μm;
- Short Wave Infrared (SWIR) with a wavelength of 1.4 μm to 3 μm;
- Mid Wave Infrared (MWIR) with a wavelength of 3 μm to 5 μm;
- Long Wave Infrared (LWIR) with a wavelength of 8 μm to 12 μm [7].

A diagram of the positioning of infrared radiation in the electromagnetic spectrum can be seen below in figure 2.1.

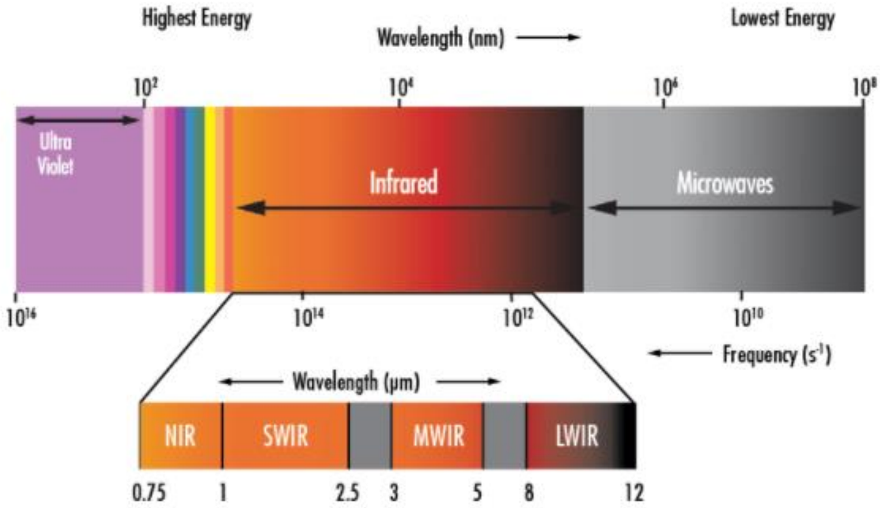


Figure 2.1. Electromagnetic spectrum [8]

For the application of thermal imaging the main wavelengths used are the mid-wavelength and long-wavelength since objects in temperature ranges from 190 K to 1000 K emit radiation in these spectral ranges [7]. MWIR and LWIR spectral bands differ considerablity with respect to background flux, scene characteristics, temperature contrast, and atmospheric transmission with diverse weather conditions. Factors which favour MWIR applications are higher contrast, better clear-weather performance, higher transmittivity in high humidity, and higher resolution due to optical diffraction being three times smaller. Factors which favour LWIR applications are superior performance in fog and dust conditions, winter haze, higher resistance to atmospheric turbulence, and lower sensitivity to solar glints and fire flares [6].

2.1.2 Camera and detector types.

Infrared cameras can be made either as scanning devices, capturing only a single point or a row of an image at a time, or using an array, as a two-dimensional infrared focal plane array (IRFPA) where all image components are captured at the same time with each detector element in the array. Today IRFPA is the dominant technology, as it has no moving parts, is faster, and has higher spatial resolution than scanning devices.

The detectors used in thermal cameras are usually of two types, photon detectors or thermal detectors. Using photon detectors the absorbed electromagnetic radiation is converted directly into a change of the electronic energy distribution in a semiconductor by the change of the free charge carrier concentration. Thermal detectors convert the absorbed electromagnetic radiation into thermal energy causing an increase in the detector temperature. The electrical output of the thermal sensor is then produced by a corresponding change in a certain physical property of material, for example the temperature dependent electrical resistance in a bolometer. The photon detector generally works in the MWIR band where the thermal contrast is high, making it very sensitive to small differences in the scene temperature. The main limitation of this type of detector is its need for cooling. Uncooled thermal detectors have been developed with two main types of detectors - ferroelectric detectors and microbolometers [7].

2.1.3 Use of infrared imagers

In the field of R&D thermal imagers are used for capturing and recording thermal distribution and variations in real-time, allowing engineers and researchers to see and accurately measure heat patterns, leakage, dissipation and other temperature factors in products, processes and equipment. Some of the uses of thermal imagers in the field of R&D include:

- Medical thermography – Used as a diagnostic technique for visualizing and quantifying changes in surface temperatures for example for vascular evaluation, tumor detection, muscle strain assesment as well as locating a source of bleeding;
- Industrial R&D – Used for studying a product's characteristics such as heat dissipation and thermal characteristics;
- Non-destructive testing – Using thermal imaging internal defects can be detected through target excitation and observation of thermal differences on target surfaces being able to detect voids, delamination and water inclusion in composites;
- Thermal signature analysis – used to measure a targets apparent infrared brightness as a function of wavelength and revealing the appearance of a target to sensors, used in the design of vehicle sensors and camoflage systems [9].

In Industrial sector thermal imager applications are used for non-invasive monitoring and diagnosis of both electrical and mechanical systems which allows for early detection of issues and enables condition-based maintenance (CBM) [10]. Some specific examples in this field include:

- Building inspection – used to carry out non-invasive inspections this allow for evaluation a condition of a building, being able to visualize energy losses, find leaks and moisture, detect electrical faults, detect cold bridges and much more [11];
- Inspection of electrical systems – Used in the case of both high and low voltage installations thermal imaging allows for identification components with increased

temperature due multiple reasons such as corrosion or loosening of connections allowing for repairs to be planned ahead of time [10];

- Inspection of mechanical installations – Thermal imaging allows for the inspection of mechanical systems such as motors or conveyors belts where problems such as lack of lubrication, misalignment or overheating can be identified by detecting the increased heat associated with the kind's of problems [10].

In the field of public safety and surveillance thermal imagers are used for:

- Detection and tracking of humans – Thermal cameras are useful for surveillance and detection of intruders due to their ability to not be dependant on the wheather conditions as can be the case with visible imagers. The use of thermal imaging also expands the ability to implement machine vision classification as humans can be detected base on the temperature of a region, after which the objects can be further classified by shape, increasing the accuracy of the system [7];
- Intelligent traffic solutions - In transportation management, planning, and road safety, collecting data for both motorized and non-motorized traffic is important. Collecting vehicle data was traditionally limited to manual data collection or inductive loops at fixed locations, nowadays vision-based monitoring systems are used. Contrary to systems using visible spectrum imaging, the use of thermal imaging allows for the system not to be affected by environmental factors such as lighting, shadows and weather conditions, which is really important due to the fact that these kinds of systems are required to operate 24/7. In addition to data collection these systems also allow for improving the flow of traffic, detect accidents and traffic jams on highways, tunnels and railway tracks [12];

2.2 Use of ODM and OEM services in electronics manufacturing

During the last few decades, the growing demand of electronics and computer products has made way to a new kind of manufacturing firms in Asia, the so-called original design manufacturers (ODMs), most notable examples being Flextronics, Quanta, and Compal. These companies provide design, manufacturing, and other value-added services to original equipment manufacturers (OEMs) [13]. The goal of this section is to give a short overview of the trends of outsourcing design work in the electronics manufacturing industry, its benefits and downsides. The reason for including this section is because contrary to usual process of doing design work in-house, the product to be implemented to production in this thesis utilizes ODM services for parts of the design and manufacturing processes.

Nowadays OEMs are under pressure to constantly bring new products to market in rapid succesion. This is especially true in the electronics and computer industry, where product life-cycles have shortened significantly—it is unseen for a consumer electronics OEM to introduce a new product model every six months. To stay competitive, OEMs must be capable of efficiently managing their product development processes to meet the time-to-market and time-to-volume targets. Because both design of the product and manufacturing are performed by ODMs, the ODM model offers opportunities to utilize concurrent engineering and design-for-manufacturability. Collaboration between design and manufacturing is a common challenge in the traditional contract manufacturing (CM) model. This has the potential to generate large cost savings for production as well as shortening the time-to market for OEMs' products. It is said that 70% of a product's manufacturing cost is determined in the design process With concurrent engineering, design, development, manufacturing and many more functions are integrated to reduce the total time required to bring a new product to the market. Utilizing design-for-manufacturability leads to product designs that are more cost efficient to manufacture [13].

One of the issues with outsourcing design is the reduction of product differentation. Since the ODM market is dominated by a limited number of large suppliers, it is inevitable that competitors end up outsourcing to a common ODM. OEMs are becoming increasingly worried about their outsourced work being used to serve competitors. To ease the concerns, ODMs often setup separate divisions to trade with OEMs independently. However, inter-company resource sharing may not be completely eliminated. Because the products designed by ODMs are often highly commoditized therefore there can be a huge benefit from sharing resources and knowledge across products of different OEMs [13].

Another concern with using ODM services is that ODMs can be in time develop enough capabilities in both management and engineering of a certain product type that may want to pursue creating an own-brand strategy, by which becoming a competitor to the OEMs.

Due to high competition OEMs are inclined to release new products very often, which can mean that companies are unable to uncover all potential quality issues. In order for an OEM-ODM relationship to succeed, both of the parties need share responsibility for the quality of the product and make efforts to improve the quality, however in the end, the OEM is responsible that the product lives up to the customers expectation so if this cooperation is not good, the companies can be off-put from using ODM services [14].

2.3 LEAN Manufacturing methods used in FLIR

This section gives an overview of theoretical background to the manufacturing management techniques and philosophies used in FLIR in order to ensure the processes are effective end-to-end, space and resources are used effectively. Using these techniques in the recent years, FLIR Systems Estonia OÜ has managed to free over 500 m^2 of floor space, reduced overhead and material overhead by 30% as well as increasing overall efficency which has enabled growth of 30-40% year-over-year.

Lean manufacturing can be defined as a philosophy or a strategy that utilizes a set of practices to minimize waste in order to improve an enterprise's performance. Lean manufacturing originates from the Toyota Production system (TPS), which focused on reducing waste in all aspects of the production process, utilizing a number of tools such as just-in-time (JIT), cellular manufacturing, Value stream mapping (VSM), kanban, 5S, kaizen, etc [15].

The goal of Lean Manufacturing is to eliminate all waste occurring in the enterprise. This enables the company to shorten the time between ordering and sending the finished goods to the client, increase in productivity as well as a reduction in manufacturing costs. As a part of the TPS, Taiichi Ohno, the Chief Engineer at Toyoto listed seven types of waste [16]:

- Over-production – Which means to unnecessarily produce more than is required or producing it earlier than it is needed. Over-production increases the risk of obsolescence, increases the risk of producing wrong items and increases the chance of having to sell those items at a discount or scrap them;
- Defects – In addition to physical defects which directly add to the costs of products sold, this may include errors in documentation, provision of incorrect information about the product, missed delivery date, production to wrong specifications, use of too much materials or creation of unnecessary scrap;
- Inventory – Inventory waste is defined as having unnecessarily high levels of raw materials, works-in-progress and finished products in stock. Unneccesary inventory leads to higher inventory financing costs and higher material overhead costs;

- Transportation - Transportation includes any movement of materials that does not provide value to the product, such as the movement of materials between workstations. The goal is to design the production so that the output of one process is immediately used as the input for the next process. Movement of work in progress or materials between processing operations results in longer cycle times, inefficient use of labor and space and can also lead to production stoppages;
- Waiting – Waiting is idle time for workers or machines, this can be caused by bottlenecks or unbalanced production flow on the factory floor. Waiting results in a significant costs as it increases overhead costs and depreciation costs per unit of output;
- Motion – Motion includes any type of unneeded physical movement or walking by workers which diverts them from carrying out value-adding work. Some examples of these kinds of unneccessary movements include looking around for a tool or a component, unnecessary or difficult physical movements such as lifting or reaching for something, which could stem from poorly designed workplace ergonomics;
- Over-processing – Over-processing means carrying out more processing on the product than what is demanded from the customer, this could be in terms of product quality or features – such as polishing or other surfacing operations on areas of a product that won’t be seen by the customer [17].

Value stream mapping (VSM) is a tool widely used by companies. VSM is a visual method of presenting material and information flow in the production system. A value stream map shows all of the tasks carried out in the process, starting with the purchase of raw materials and ending with the delivery of finished products to the customer. This analysis allows a company to identify all kinds of waste and directions for further action in order to eliminate them [16]. An example of a value stream map can be seen in figure 2.2.

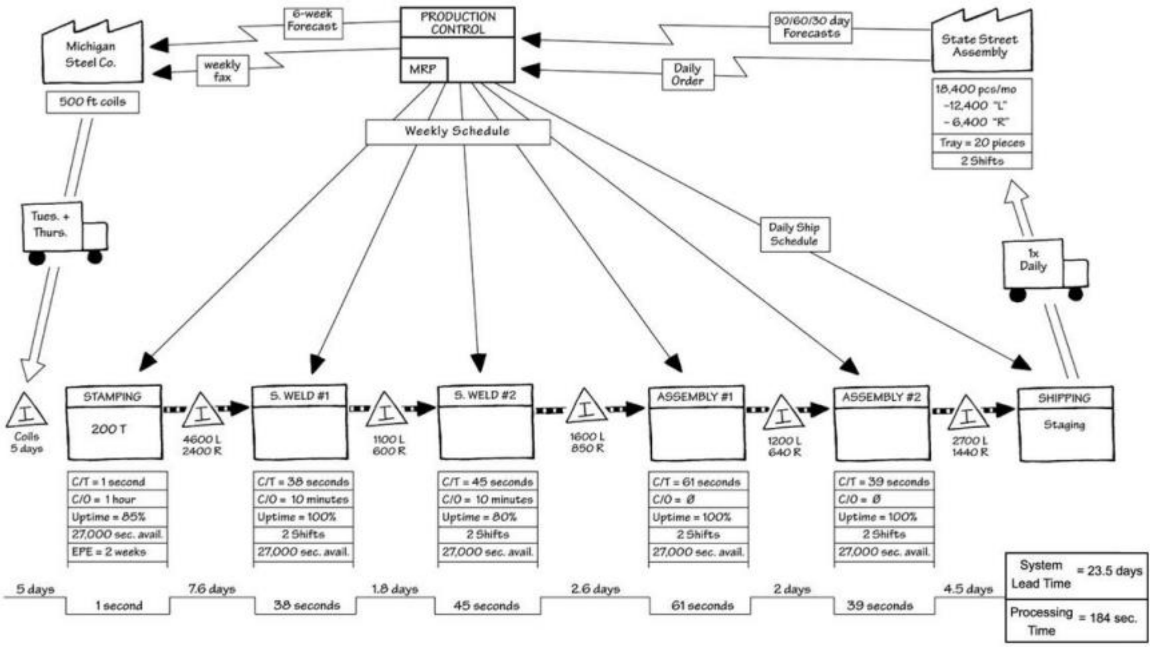


Figure 2.2. Value stream map [18]

5S method is another method used for improving production processes. 5S is a method of creating a sustainable culture which preserves a clean and efficient workplace; a method for clearing all excess components and tools from the workplace and organizing the important items such that they are easy to find, use, and maintain. The name 5S is derived from the first letters of five Japanese words which mark 5 particular stages of the method. These stages are explained as following:

- Seiri (sort) – elimination of all the items that are unnecessary for doing the job. This step is conducted mainly to decrease inventory, and to better the use of working space;
- Seiton (set in order) – rearranging and selecting a suitable place for all the tools in the workstation. This step is performed in order to reduce unnecessary traffic an employee must performed when searching for tools, also eliminating the errors in quality of products resulting from mistakes made by having the tools properly so the wrong tool cant be used;
- Seiso (shine) – cleaning and maintenance of the workplace with an aim of creating a standard of proper cleanliness, identifying and eliminating the causes of pollution;
- Seiketsu (standardize) – determining the rules for repetition of the first three stages of 5S. This stage defines the responsibilities of the involved employees and creates instructions which supporting the execution of the previous steps.

- Shitsuke (sustain) – making sure the process will be followed in the future as well as creating an audit process. It is a difficult and long stage, because it forces a change in the habits of both production workers and management [16].

Benefits of 5S include the ability to improve the safety and ergonomics of a workplace, reduces the time spent on searching for things leading to time being spent on things that actually create value. It is also an useful tool for strengthening the employees a sense of ownership in relation to the workplace as the system allows for visual control, exposion of problems and it instills discipline in following the standard work [16]. An example of the 5S method being utilized in FLIR System Estonia's service department can be seen below in figure 2.3.

Figure 2.3. 5S method in action

Standardized work is a method used in Lean Manufacturing for the improvement of work and increasing the sustainability of production processes [1]. Standardization means homogeneous operations, or tasks by all workers. This allows to carry out all manufacturing steps in the same way, in the same order and time, and at a consistent cost. Standardization also assumes continuous development of working standards, so as to adapt to the constantly changing customer demands [16].

Kanban system is a tool of lean manufacturing that seeks to achieve minimum levels of inventory at all times. The word Kanban stands for visible record or a sign in Japanese. General, Kanban refers to a signal of some kind, in the case of manufacturing, it refers to Kanban cards. The Kanban system relies on a customer demanding a part from the supplier of the part. The customer of that part can be an actual consumer of a finished product (external) or the production personnel at the next station in a manufacturing facility (internal). Similarily, the supplier can be the worker at the preceding station in the production flow. The premise of Kanban is that material will not be produced or moved until a need for it is signaled by the customer. [19]

An example of simple Kanban System implementation is 3-bin system for components supplied by an outside supplier where one bin is on the factory floor, one bin is in the warehouse and one bin is at the supplier’s site. The bins contain removable cards with the product details and other relevant information. When the bin on the factory floor is depleted, the empty bin and its card are returned to the warehouse. The warehouse then replaces the empty bin from the factory floor with a bin from the warehouse and then sends the empty bin with its card to the supplier. The supplier then deliveres it’s full bin to the factory warehouse and the supplier keeps the empty bin.

3. INITIAL DATA ANALYSIS AND PROJECT PLANNING

3.1 Thermal security camera portfolio

The product in the focus of this thesis belongs in the thermal security camera segment, which currently has 11 different cameras with various specifications shown in figure 3.1. The cameras in this segment feature two main mounting types: the fixed mount cameras, which means the camera will be set up to a fixed position of view, and the pan-and-tilt cameras, which allow for the camera's view to be altered by moving the positioning of the camera. The cameras in this segment also feature either single-spectrum or dual-spectrum variants, which means the cameras either only have an infrared sensor or both the infrared and visible light sensors. Cameras in this segmented are mainly used for perimeter security in a professional setting, examples include construction sites, car dealerships and critical infrastructure etc.

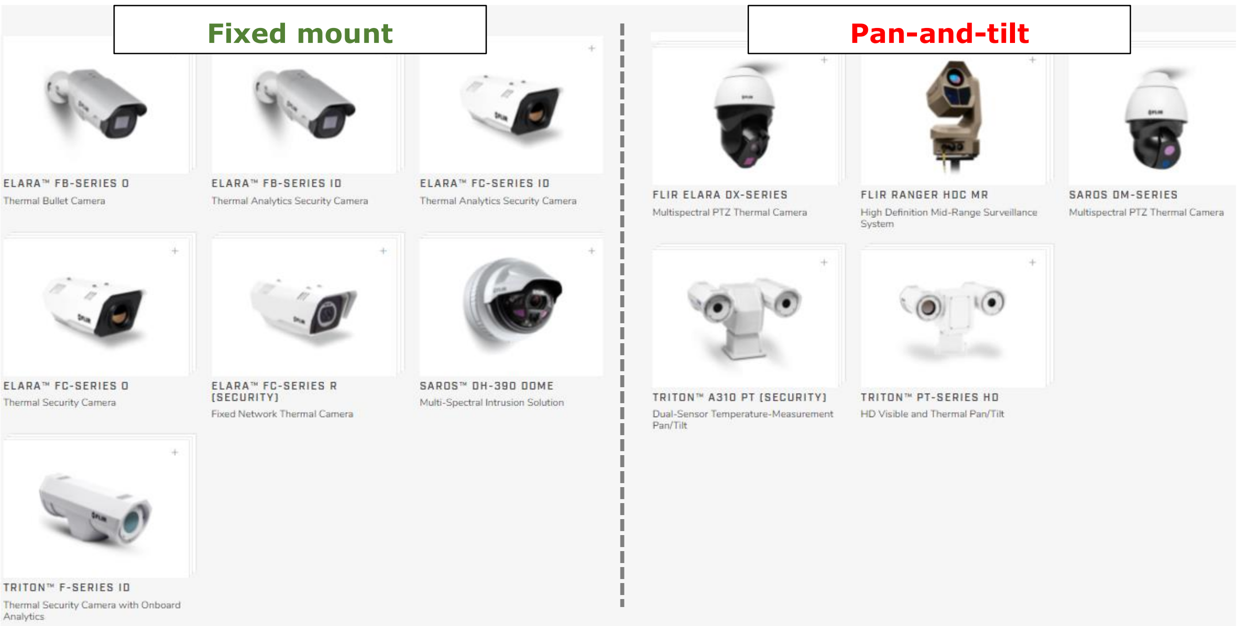


Figure 3.1. Thermal security product portfolio [20]

3.2 Product overview

The Triton™ FH-Series is FLIR's new generation of fixed thermal security camera. Simple installation, new 17um sensors, high-performance processor for VA and lower COGS provide a purpose-built solution for the perimeter security market. FH-

Series integrates industry-leading thermal imaging with 4k visible imaging to provide a detection solution optimized for all environmental and lighting conditions. Intrusion analytics running on both the thermal and visible streams can be scheduled to take advantage of visible imagery in daytime and thermal imagery at night. The product can be seen in figure 3.2. From the standpoint of FLIR Systems Estonia OÜ the product is important because the projected annual revenues for manufacturing this camera is approximately 6 million dollars or nearly 5 million euros amounting to nearly 7.4% annual revenue growth.

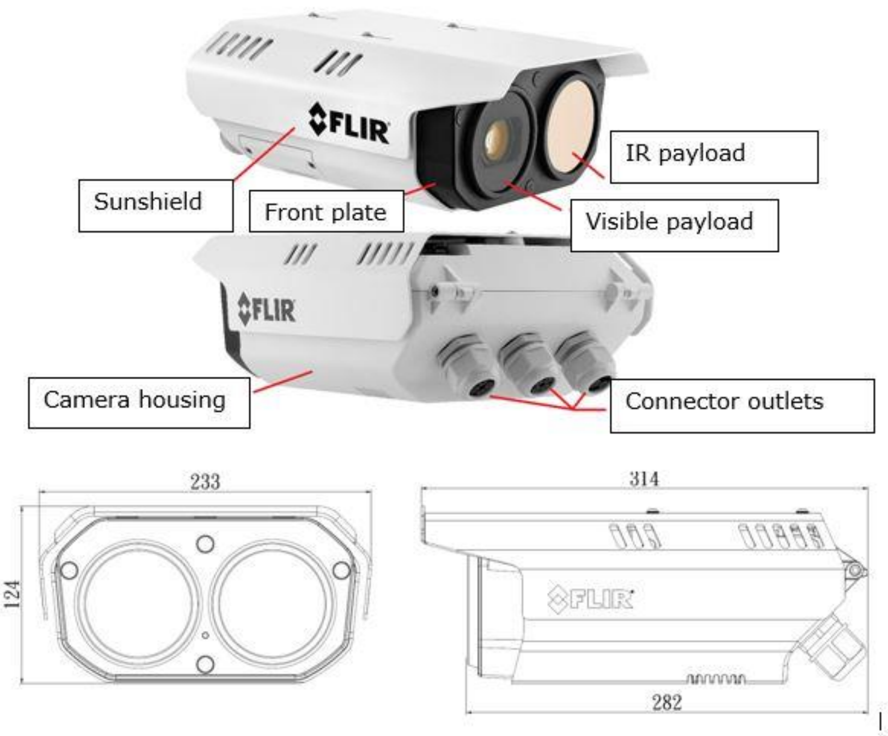


Figure 3.2. Triton™ FH-Series camera

Market justification With improvements in video analytics technology and low-light imagery, visible cameras are increasingly being used for detection and classification of targets during daytime and in optimal lighting conditions. Thermal cameras are more effective in low-light and inclement weather, but visible cameras offer information that thermal cameras cannot provide such as color, facial features, license plate recognition, etc. Since visible and thermal cameras have different strengths, it is becoming increasingly common to see them installedside-by-side to cover all environmental conditions and to collect forensic video. The downside of this approach is that the infrastructure cost of installing two cameras is much greater than the cost of installing one accounting for the price of both the cameras themselves as well as the supporting hardware. All this sets the stage for hybrid cameras that have both thermal and visible camera in a single package.

The Triton FH camera is targeted specifically at the perimeter security market, particularly for critical infrastructure applications. Per the market data and projects below (table 1.) from IHS Markit, the fixed thermal security camera market will stop growing and go into a state of decline starting in 2022, with more customers opting for "Dual Head" cameras instead of fixed thermal cameras [21].

Table 3.1. World market for thermal cameras by camera type [21]

Revenues ($M)	2018	2019	2020	2021	2022	2023	CAGR 18 - 23
Fixed	216.1	226.4	233.8	234.7	227.4	213.3	-0.3%
		4.8%	3.2%	0.4%	-3.1%	-6.2%	
PT / PTZ	68.3	78.1	90.7	106.8	127.2	153.2	17.5%
		14.3%	16.2%	17.8%	19.2%	20.4%	
Dual Head	41.2	44.7	48.9	53.8	59.5	66.0	9.9%
		8.5%	9.3%	10.1%	10.5%	10.9%	
Radiometric	17.8	20.0	22.7	26.1	30.4	35.9	15.1%
		12.1%	13.6%	15.1%	16.5%	18.0%	
Total	**343.2**	**369.2**	**396.0**	**421.4**	**444.6**	**468.4**	**6.4%**
		7.6%	**7.3%**	**6.4%**	**5.5%**	**5.4%**	

Source: IHS Markit **© 2019 IHS Markit**

Ten configurations sold as 10 different models are available, set apart by different visible camera modules with different field of view (FOV), focal length and F-number configurations, as well as differing IR-core's corresponding with each visible camera set-up. An overview of the product configurations can be seen below in Table 3.2.

Table 3.2. Product configurations

Model	FOV	Focal Length	F/#
369	69° x 56°	9 mm	F1.4
324	24° x 18°	13 mm	F1.0
313	13° x 10°	25 mm	F1.1
669	69° x 56°	9 mm	F1.4
644	44° x 36°	13 mm	F1.0
625	25° x 18°	25 mm	F1.1
617	17° x 14°	35 mm	F1.1
612	12° x 10°	50 mm	F1.2
610	10° x 8,2°	60 mm	F1.2
608	8,6° x 6,6°	75 mm	F1.1

Optical performance related parameters include some of the following:

- Sensor type: 4k IMX 334 1/1.8 CMOS;
- Continuous E-zoom to 4x;
- Latency < 0.6 s [22].

Radiometric performance related parameters:

- Detector type and array format: Long-Life, Uncooled VOx Microbolometer, 640 × 512, 320 x 256 array;
- Radiometric accuracy +/- 10°C or +/- 10%;
- Sensitivity (NedT) <25mK @ 25°C F# 1.0;
- Full frame rate or <9hz [22].

General parameters include some of the following:

- Network protocols: IPV4, HTTP, HTTPS, UPnP, DNS, NTP, RTSP, RTCP, RTP, TCP, UDP, ICMP, IGMP, DHCP, ARP, IEEE 802.1X, FTP/SFTP, NAS Samba, NAS NFS;
- Weight: < 5 kg's;
- Input voltage: 12-30 VDC, 24 VAC, POE 802.3bt (<60W).

Environmental requirements set specifications on the product's use conditions and the requirements to reach the set performance. Some of the requirements include:

- Ingress protection (IP) 67 rating – per IEC 60529 the product must be dust-tight and protected against temporary submersion under water [23];
- Operating temperature -40 to +70°C;

- Corrosion resistance tested according to MIL-STD 810G 1000-hour salt spray test [24];
- Humidity: 0-95% relative;
- Resistance to shock according test criteria set in IEC 60068-2-27;
- Resistance to vibration according test criteria set in IEC 60068-6-64 [22].

Legal requirements and certifications are concerned requirements and certification processes set by some countries and institutions that a product must conform to or pass in order to be sold in those markets. Some of the requirements The product must conform to include:

- Designed according to EU harmonised standard in order to be CE-marked [25];
- Compliant with FCC Part 15 (Subpart B, class A) concerned with radio frequency (RF) devices contained in electronic-electrical products;
- Restriction of Hazardous Substances (RoHs) compliance which restricts the use of specific hazardous materials found in electrical and electronic products;
- Restriction of Chemicals (REACH) which establishes procedures for collecting and assessing information on the properties and hazards of substances [26];
- Compliant with UL 60950-22 and International Electrotechnical Commission (IEC) 60950-22 standards which are concerned with information technology equipment to be installed outdoors;
- Compliant with IEC 62368, which is an Audio/video, information and communication technology equipment safety requirements standard. In addition to that the product must be listed with UL to bear the UL-marking.

Project organisational structure involves many different functions all around the globe. The project management and product architecture design is carried out by the R&D team in Isreal. Software development is spread between two sites, with the Belgium's team implementing video analytics solutions and Spain's team doing more general software encompasses multiple FLIR sites around the world with different functions being spread around as well as involving a supplier as an ODM and sub-assembly manufacturer. Structure diagram for the different project parties can be seen in figure 3.3.

The project's launch and product mangement is being lead by FLIR's fixed mount security R&D team in USA. The project design, i.e design of firmware. The ODM is located in Taiwan and is tasked with developing the mechanical design, PCBA design and manufacturing as well as manufacturing the components and doing some of the assembly. A team in Sweden is supporting the project with global trade compliance

(GTC) analysis, sourcing operations as well as some engineering support related to IR calibrations and production software development. Estonian factory is leading the industrialization efforts and is the site of final assembly of the product.

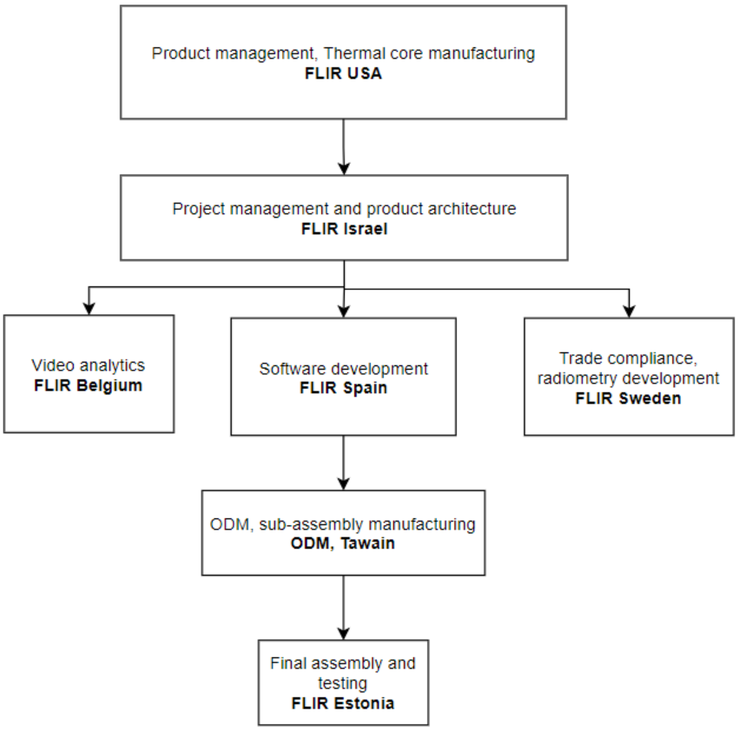


Figure 3.3. Project organisational structure

Roles involved in the project team from Tallinn factory include the following:

- Project leader – Responsible for coordinating the product industrialization project from manufacturing side with all of the accompaning administrative work. Planning of the production line concept and leading the implementation of that. In the case of this project the author of the thesis was carrying this role;
- Supply chain planner – Responsible for creating production BOM's, securing materials, as well as setting up the necessary processes in enterprise resource planning (ERP) software.
- Software engineer – Responsible for development of test and traceability applications. Set-up of computers and auxiliary equipment
- Mechanical engineer – Responsible for analysing the assembly process for manufacturability and quality issues. Design of equipment such as jigs, fixtures and other assembly aids to improve the process. In the case of this project the author of the thesis will also fill this role.

3.3 Production requirements analysis

Capacity requirements are concerned with the ability of the factory to be able to produce necessary amount of products in a set time. Particular requirements include:

- Yearly volume: 3000 pcs;
- To be produced in one 8-hour shift per day.

Factory layout requirements are requirements set to the production line and its placement in the factory. These requirements include:

- Minimal floor space usage;
- Modular design in order to be able to increase number of workplaces in cases of demand increases.

Global trade compliance requirements must be followed since FLIR is a US-based technology operating with IR detectors, some of which are classified as dual-use technologies which means that the technology could be used for both commerical and military applications, all FLIR subsidiaries must follow US export regulations. These regulations dictate the need to analyze all components for potential controlled technology, limit the export of controlled products to certain countries such as Syria, Iran, North-Korea, Sudan and Cuba, as well as requiring tight traceability of controlled technology. Main regulation in question is the Export Administration Regulations (EAR) enforced by the US Bureau of Industry and Security as well as the European Dual-use trade controls. [27]

Traceability requirements are concerned with being able to know the origin of components and for example the manufacturing dates as well as making sure no operations in production have been skipped. Requirements set on the production process traceability are the following:

- In production both the visible and IR module serial number's must scanned and tracked;
- Test results must be linked with a product's serial number and written in a database, a packing serial number can not be created for units with failed tests.

Other requirements are general requirements that stem from quality management practices and requirements from partners. These requirements include:

- Quality management according to ISO 9001:2015 quality management standard;
- Environmental management according to ISO 14001:2015;

- The sales packaging must conform to UPS packaging standards which includes durability requirements such as the need to be able to withstand a drop of 1 meter. In addition to that the packaging must be recycleable.

Cost of camera - Target for average cost of goods sold (COGS) of 2200 USD between all models.

3.3.1 Test and calibration scope

A lot of testing is carried out during the sub-assembly manufacturing at the ODM's site, however some things some tests can only be carried out on the final product, such as the alignment of the modules for the two spectrums used in the camera as well as all the functions concerning the IR-module as the IR-module will be assembled in camera, therefore it can not be tested beforehand. In addition to that, some functions previously tested by sub-assembly manufacturer need to be verified as the components will be disassembled and shipped separately. Some of the main tests to be included in Tallinn are described below.

Boresight alignment test is concerned with verifing and setting in place the boresight between the visible and IR sight in order for the video analytics to sync up between the two spectrums.

Core test ensures all of the main features of the camera are working as intended. Functions covered in the core test include:

- Window heaters test;
- Light sensor test;
- Day/night test IR cut;
- Thermal camera functioning;
- Non-uniformity correction (NUC) function testing of the shutter;
- Radiometry reading;
- All temperates sensors read;
- On/off for fan.

In addition to the previous the assembled cameras will need to pass a leakage test to ensure the product is compliant with IP67 requirements.

3.3.2 Assembly scope

Tallinn will receive the camera housings in a semi-assembled form with all the PCBA's, the fans and the connectors assembled at the supplier's side. The visible module will also come pre-assembled. Thermal core will need partial assembly as well as being assembled into the thermal payload. Both the visible module and the thermal payload will be assembled to the front cover, along with the window heaters. The front assembly will then be attached to the housing assembly along with all cables being connected. The last addition to the assembly is the sunshield which will be mounted on the top side of the camera housing. A schematic of the main assembly steps can be seen below in figure 3.4.

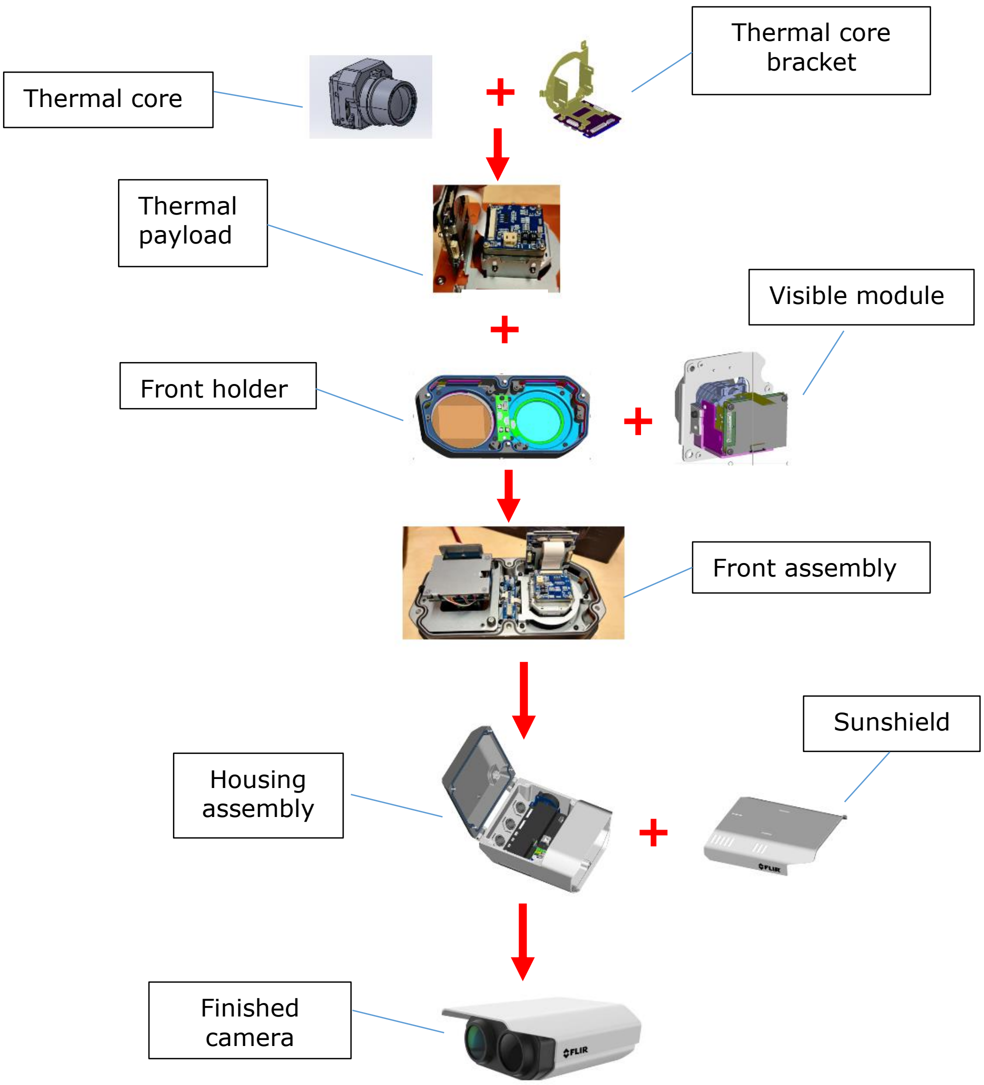


Figure 3.4. Assembly scope diagram

3.3.3 Production line budget analysis

For the industrialization and set-up of production line for this product an estimate of the work needed to be carried out created and broken down to production modules. Based on previous experience in combination with educated guesses, components of each production module was estimated, consisting of machinery and equipment, furniture and fixtures, computer equipment and software as well as other capitalizable costs. In addition to that the amount of work for setting up each of the modules as well as the general project leader activities were estimated. The whole budget breakdown can be seen in appendix 1.

For the industrialization and set-up of production line for this product an estimate of the work needed to be carried out created and broken down to production modules. Based on previous experience in combination with educated guesses components of each production module was estimated, consisting of machinery and equipment, furniture and fixtures, computer equipment and software as well as other capitalizable costs. In addition to that the amount of work for setting up each of the modules as well as the general project leader activities were estimated. The total cost for the product industrialization was estimated at 164702 dollars.

In total, the amount of work to be done was estimated at 1062 hours with a total cost of 54683 dollars with a manhour cost of approximately 51 dollars. The largest contributor to the working hours was the estimate of project leader spending around 280 hours on coordinating the implementation. Followed by that the second most time consuming bit of work was creating the station for camera module’s alignment, estimated at 80 hours, mainly for mechanical engineering and set-up.

From hardware side the largest contributor to the budget was yet again the visual alignment station at approximately 57 thousand dollars. The preferred plan for this station was to develop the solution in-house in order to keep the costs low, however since the company has limited experience with this kind of equipment as a back-up this estimate was based on the cost of buying a ready-made high-end solution as well as the surrounding costs, if designing the station in-house wouldn’t be possible.

4. NEW PRODUCT IMPLEMENTATION

4.1 Project time plan presentation

The industrialization project kicked off in summer 2020 with first major activities starting in mid-autumn 2020 after receiving the first engingeering validation test (EVT) series prototype units. The main milestones for the industrialization project are the Design validation test (DVT) series production in the start of april 2021 and the Production validation (PVT) series in mid-june, latter of which marks the start of volume production. For the project timeline management the „Advanced roadmaps" plugin in Atlassian JIRA software was used. As a baseline the project toll-gate model was followed, which has documented a collection of steps that need to take place in each of the project stage and they are generally very similar across projects. The main tasks to be taken were described in JIRA tasks and split between two main categories – Production line planning and project leader activities, both of which were set up as *Epic's* in JIRA and contained appropriate tasks. In addition the two major test series were created as *Epic's* as well. The Gantt chart for the project timeline can be seen in appendix 2.

The production line breakdown consist of activities related to the bring-up of the production line, for example the design of equipment and fixtures. This stage started in december with the design of a boresight test station and encompasses a number of activities up until the start of the PVT-series in june. The production line module is further broken down into production flow set-up including for example the production flow concept development, assembly line design and flow balancing. Another important breakdown of this module is the new product introduction activities module containing activities such as requirements management, review of drawings and ordering of equipment. One of the main activities in this segment also include the building of boresight verification station which was one the first activities started with a plan to finish it by the end of march. The last breakdown element is assembly fixture design.

The project leader module contains tasks relating to management of the project as well as the general administrative work required for the project to be implemented sucessfully. This module contains activities such as production planning, securing of resources, defining the test scope and much more. From timeline side this module takes place from the start of the project up until the products launch to volume production.

4.2 PRELIMINARY DESIGN AND MANUFACTURABILITY ANALYSIS

Since most of the product cost is incurred already in the design phase it is very important to disover potential problems as early as possible. For verifying the product design goals and specifications have been met it was decided to produce an engineering validation test series of the cameras. The EVT series consisted of a total of 10 early prototype cameras, encompassing each of the product configurations that were analysed stakeholders from multiple functions of engineering involved. This section focuses on the mechanical design and manufacturability of the product. This includes the general usability of components, cosmetics, serviceability, accessibility and ease of assembly.

From design perspective one of the first issue found was that the electrical grounding of the camera was insufficient therefore it was decided that an additional grounding screw would need to be added. Another issue was that the service hatch hinge would not move smoothly when the sunshield is attached due to the additional weight, due to this an alternative hinge was decided as necessary. In addition to that copper heatsink of the PCBA was found to have too high risk of corrosion so a nickel coating was proposed as a solution. From cosmetic standpoint it was found that the internal components were visible from the visible module’s cover window so it was decided that the shape of the outline would need to be modified.

From manufacturability standpoint the issues included visible module adjustment screw that was very hard to adjust due to it having a small threaded head for adjustment as well as breaking during adjustment. To combat this the screw head shape was changed, as well as the diameter and material of the bolt. Another issue concerned the thermal adapter rings which all have very similar geometry, therefore they are difficult to tell apart and carry a risk of the wrong one being assembled. For this model number were added on the rings. On the carrier board the cables were found to have a risk of disconnecting so the use of tape in assembly was proposed. Other manufacturability concerns included visible module springs being hard to hold in position during assembly for which guide surfaces were decided to be added, as well as narrow lens being hard to assemble, for which the bracket was decided to be modified.

From serviceability standpoint it was found that the power panel connector panel and fan connectors are difficult to remove so minor design changes were proposed. A summary of issues identified on the EVT units with respective corrective measures are brought out in the table 4.1 below.

Table 4.1. Issues identified in EVT units

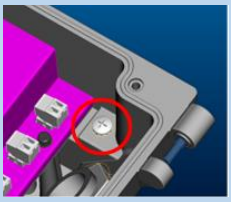
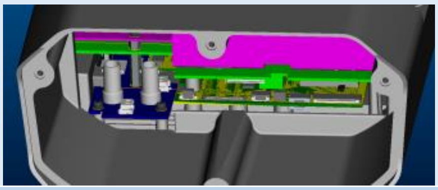
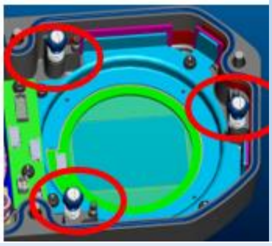
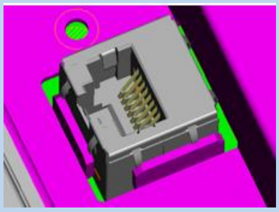
No.	Problem description	Countermeasure
1	Insufficient grounding	Add ground screw near the AC power connector 
2	Hinge torque too low when the sunshield is attached. 	Check with supplier for another hinge.
3	Corrosion risk on the copper heatsink 	Add nickel coating
4	Internal components visible from the visible module window 	Change black outline shape from rectangular to circular. Add mylar sheets.
5	Visible module adjustment screw difficult to adjust by hand 	Change screw head from round to hexagonal to be able to adjust using a tool 
6	Visible module boresight adjustment screw breaks easily 	Increase screw diameter. Change the screw material to stainless steel.

Table 4.1. Issues identified in DVT units, continued

No.	Problem description	Countermeasure
7	Thermal adapter ring difficult to tell apart between models 	Add text indication for model number
8	Risk of cables disconnecting on carrier board and power board 	Add tape on wires. Add a clip for the coaxial cable
9	Visible module springs difficult to position during assembly 	Add a guiding surface
10	Ultra narrow lens model bracket difficult to assemble 	Modify bracket for easier assembly
11	Cosmetic cover difficult to remove, due to RJ45 connector side spring collision. 	Add wall on the cover to avoid ethernet connector side spring to get stuck on the cover. 
12	Fan connector difficult to repair if necessary  	Move fan connector from bottom side to top side.

4.3 Production line design

4.3.1 Production flow concept

The production process starts off in the warehouse with receiving of the components from two main suppliers. The components need to be unpacked and placed in ESD-safe Kanban boxes which are then transported to the assembly area using trolleys. In the production line, the first step involves scanning the barcodes of applicable components (such as the visible and thermal cores) for traceability of the products, from then on the IR-modules are assembled into IR payloads, after that the cores may need to be focused.

The next subassembly is the visual module assembly into a payload, from there both the visual and IR core meet up and are both assembled into the front cover with other components such as the window heaters.

The next step is to upgrade the firmware of the camera, this involves connecting the PCBA's in inside the camera housing to a computer and running an update sequence, after this is done the camera front cover assembly gets connected with the PCBA's of the camera housing and the camera is booted up for the first time, at this time the screws of the front assembly are not tightened.

The next process of the assembly the camera housing with connected payloads moves on to the boresight station, where the front assembly gets attached in a fixture on top of a pan-and-tilt unit, using the pan-and-tilt units control software the sight of the thermal camera gets aimed at the center of a target placed a few meters away. Once the aim is set, the movement of the pan and tilt unit gets locked and the view of the camera gets set to visible camera. Then the process of aiming the crosshair to the middle of the target is repeated for the visible camera, only this time this is done mechanically through adjusting screws on the visual module to align it with the IR sight. After this is done the camera module moves on to the final configuration and functional test station, where the main functions of the camera are tested using an automated test sequence. Once this is done, Front assembly of the camera can be attached to the camera housing using screws, in addition to that the sunshield gets assembled.

From there the fully assembled camera is left to warm-up for 15 minutes in order to reach expected operating temperature so the calibrations can have an accurate set-up. Once the camera has reached temparature, SFFC and gain calibration is done on the camera using reference blackbodies.

Completion of all the previous steps marks the end of the assembly process for the product. The cameras move back to the warehouse to be packed in the sales packaging and are then sent off to the customers. A flow chart of the production flow can be seen below in figure 4.1.

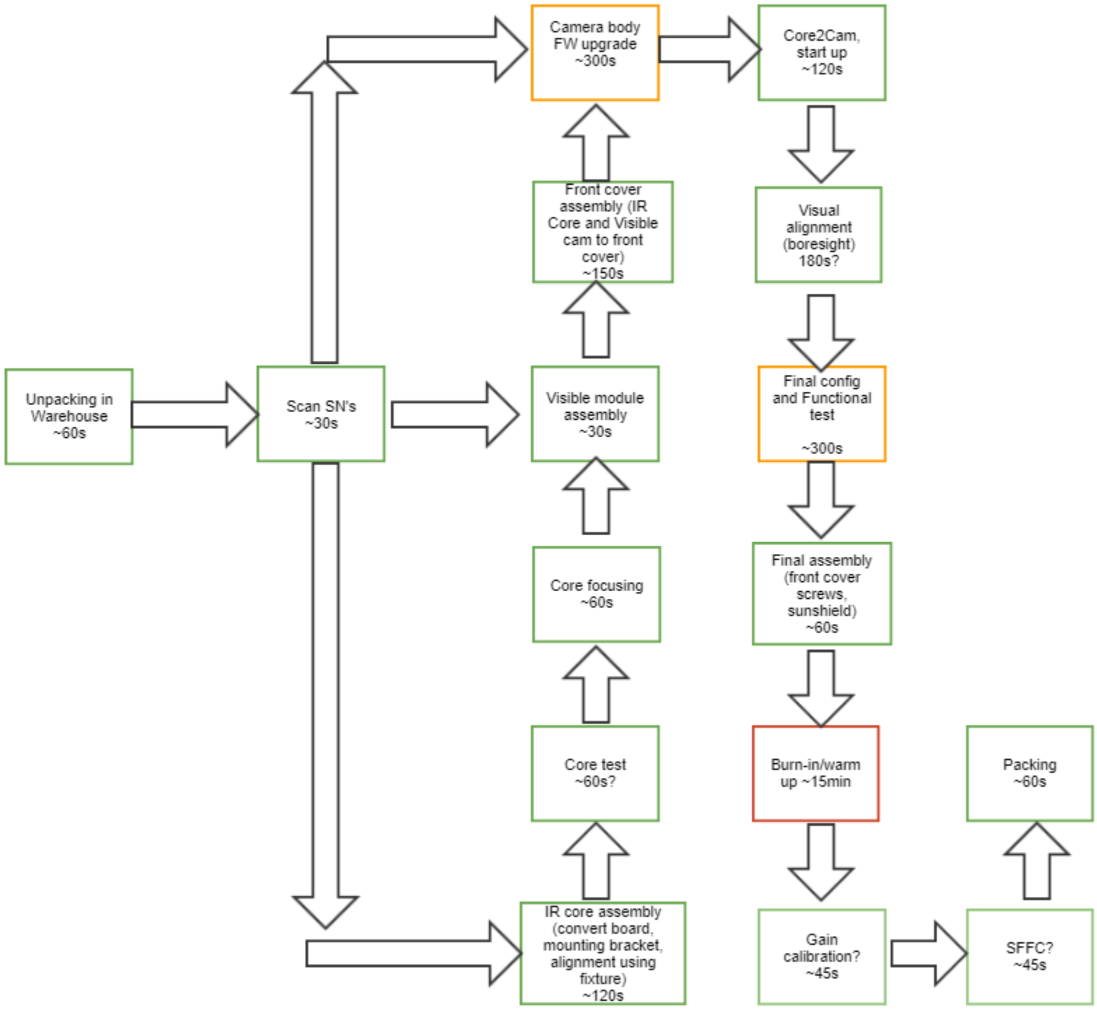


Figure 4.1. Production flow concept

Assembly station breakdown

Based on production flow concept the operations with regard to logical sequences of operations, equipment needed for operations as well as rough timing estimates the operations got grouped to 5 working areas – the incoming materials warehouse where components are unpacked, first assembly station relating to the optics payloads and related testing, second assembly station where the main assembly of camera and leakage testing takes place, the third assembly station which is dedicated to testing and calibration. The cameras are packed in a separate station which is located in the warehouse. Another aspect to consider in the case of the particular product is the comparetively large size of the product, which means the assembly station need to be spread out in order to accomodate the storage of all these components in production. The breakdown of operations between these stations can be seen below in figure 4.2.

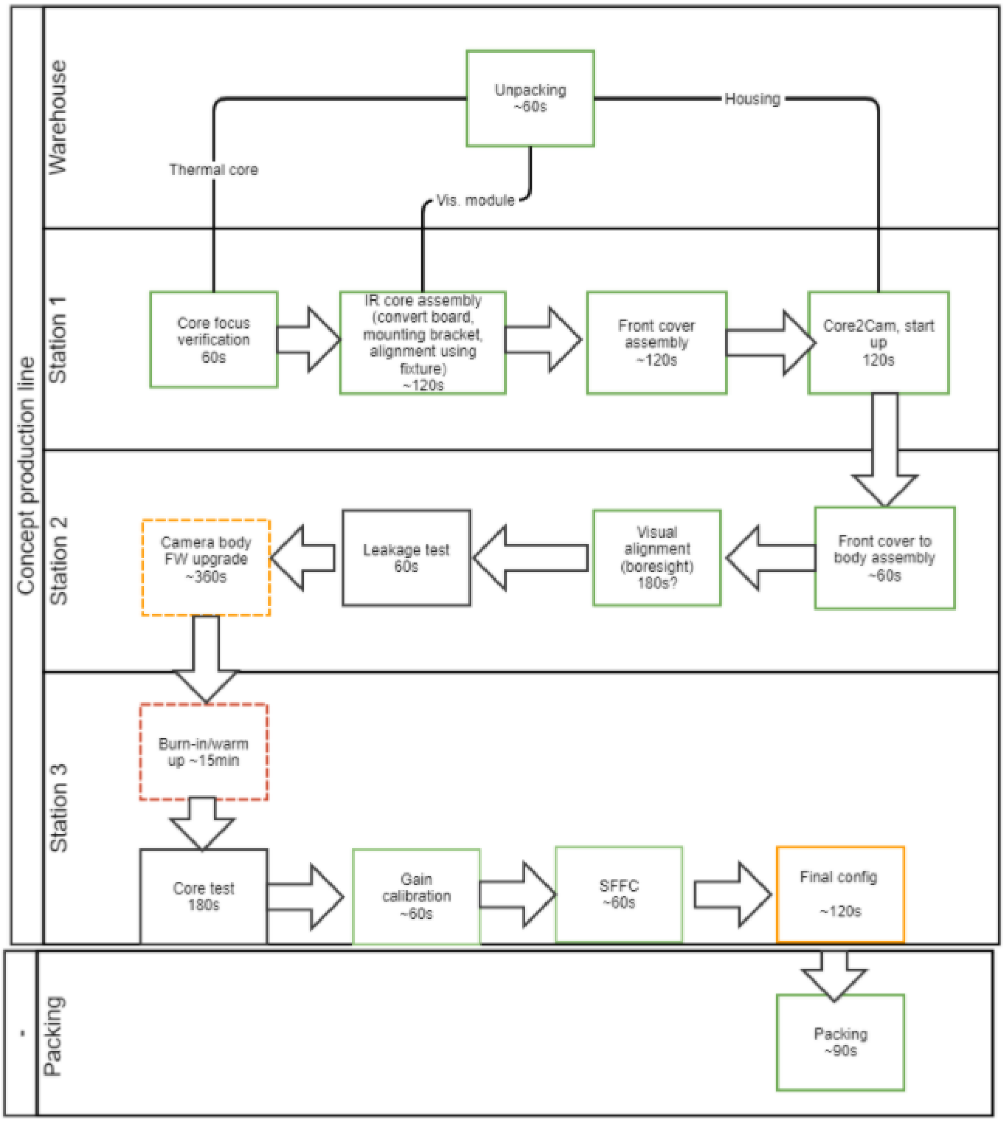


Figure 4.2. Production line concept

Documenting the production flow and steps like shown in the previous figures is also important as an input for quality management point of view since compliance with ISO 9001:2015 management requires well-established processes.

4.3.2 Initial need for operators

Based on an annual volume forecast of 3000 units, assuming the factory works for approximately 48 weeks per year when accounting for vacations, holidays and downtime, a productive time in shift of 7.5 hours we can find out that based on these numbers in order to satisfy the volume requirements a takt time of 36 minutes is required, which means that every 36 minutes one camera needs to be produced. Takt time requirements for different time periods can be seen below in table 4.2.

Table 4.2. Volume requirements calculation

Requirement type	Value
Volume forecast (units)	3000
Weekly requirement (units)	62,5
Daily requirement (units)	12,5
Hourly requirement (units	1,6667
Takt time (min)	36

Based on assembly stations defined previously, as well as the estimated timings, a table for the total cycle times for the assembly as well as the lead times can be compiled (Table 4.3.). The indicators we are going to take a look at are the following:

- Process time - The time it takes to complete a task at each workstation is known as the process time;
- Line balance loss (LBL) quantifies the loss of productivity due to unbalanced workstation processing times. The formula for LBR is the following:

$$LBL = \frac{n * Tmax - \sum Ti}{n * Tmax} \quad (4.1)$$

  Where *n* – total number of workstations;

  T_{max} – cycle time of the longest operation;

  T_i – cycle time of station [28].

- Lead time (LT) which describes the period of time which is needed for the product to be completed on the assembly line. The equation for lead time can be expressed as following:

$$LT = c * (K - 1) + Tk \quad (4.2)$$

  Where *c* – cycle time;

  K – total number of workstations;

  T_k – load time of last station [29].

In our case the lead time is mostly equal to the cycle time of a particular station, since only one unit is worked at a time in a specific workstation.

Table 4.3. Timings and line balancing

Workplace	Operation	Operation Time (s)	Lead time, station (min)	Station process time (min)	Comment
Warehouse	Unpacking	120	2	2	Not included in efficiency calculations
Station 1	IR core asembly	120	7	7	
	Core focus	60			
	VPC module to core	60			
	Front cover assy	180			
Buffer 1	Firmware upgrade	360	6	6	Can run multiple in parallel
Station 2	Core2Cam, start-up	120	6,5	6,5	
	Visual alignment	180			
	Front cover to body	30			
	Leakage test	60			
Buffer 2	Burn-in	300	15	5	3 in parallel
Station 3	Gain cal	60	8	8	
	SFFC	60			
	Final assembly	60			
	Final configuration and core test	300			
Packing	Packing	150	2,5	2,5	Not included in efficiency calculations
Total		2220	47	37	

It can be seen that the total working time for the planned assembly line is approximately 2220 seconds or 47,5 minutes with the largest bottleneck in the need for the camera to warm up for 15 minutes before calibration can take place. In order to combat this, 3 cameras will be connected in parallel, making this bottleneck more manageable. Overall we can see that the whole process has a lead time of 47 minutes, brought down to approximately 37 minutes cycle time by adding capacity to the burn-in step.

For finding the number of operators needed to satisfy the capacity requirements we also assume a pessimistic first pass yield (FPY) rate of 75% for the test series so we assume 25% of the cameras need be run through the process a second time. What we also consider is the loss from balancing, for this we take a look at the three assembly stations as well as the „Buffer" stations and their total operations durations in relation to the longest operation. From formula 4.1 we can calculate the line balance loss:

$$\%LBL = \frac{n*Tmax-\sum Ti}{n*Tmax} = \frac{5*8-(7+6+6{,}5+5+8)}{5*8} = \frac{40-32{,}5}{40} \approx 18{,}75\%$$

From this we see an approximate loss of 18,75%. Putting all this together we end up with a cycle time of roughly 60,71 minutes so about 59% of the takt time requirement, which means 1.6866 ≈ 2 workers on the line would be needed to satisfy the requirements if we were to run the line at a consistent, full capacity. However we do have to take into consideration, that there are periods where there are a lot of orders and then there are periods without any orders so to account for these fluctuations the line will be designed for 3 workers plus one worker in warehouse and packaging.

For foreseeable risks of the production flow the largest risk for variability of production station times can be seen in the visual alignment station due to this station requiring the worker to evaluate and adjust the payloads manually therefore there can be a large increase or decrease in the process time both due to variation of component quality as well as the workers skill level, possiblity creating a new bottleneck in that assembly station. Another operation from the same assembly station that could pose a risk is the leakage testing, where the camera assembly is tested for ingress protection. If an unacceptable risk is identified there some disassembly and re-running is neccessary, therefore considerably extending the station time. In order to combat these risks the production flow will be tested and measured during test-series and based on the finding there some stations can be placed elsewhere or additional capacity added.

4.4 Traceability of production process

WAF/PDS is a Java-based production software solution that is in place in FLIR. WAF/PDS stands for web application firewall / passive data structure. This solution is the central repository for all things related to production process traceability. The system includes web-application based modules which are specific to a product and the operation performed. The main functions of this system include:

- Traceability - keeps track of which hardware components are mounted to an assemby, for example the IR-unit, core, lens or camera and also containing information regarding which steps in production process it has gone trough (which WAF applications), result of test and measurements.
- Installation/Update of software and configurations - updates installed software if needed, installs the right configuration for the camera model, installs configurations and torrent scripts for production and calibration;
- Calibration and measurement - aid when calibrating compass, adjusting camera angles, measuring laser effect, measuring and calibrating lens transmission;
- Test - runs BIT and other hardware function tests;
- Production flow aid/control - helps operators by checking that the right lens is mounted, that all ordered items are packed using weighing method. Checks that the right serial number is printed on the label.

For traceability of components and assembly operations the critical components will arrive bearing labels containing the supplier's serial numbers both in numerical form as well as a barcode or QR-code, components part number, information regarding the production date of the components and for the housing sub-assembly the power ratings and media access control (MAC) adresses for the product. Upon starting assembly the barcodes or QR-codes will be scanned using a handheld scanner and contained information read and put it into the PDS database. The scanner chosen for this is a Datalogic QuickScan QD2430 [30]. Three main components need to be tracked – The thermal core, the visible module and the camera housing assembly, information regarding these components together with results from various tests will be contained in the PDS database and based on the right component combination a camera model serial number will be generated from a pre-reserved number range ledger. This serial number along with the cameras top-level part number and power and networking information, product markings and country of origin will be automatically generated into a final label. This label, along with the suppliers label can be seen in figure 4.3 For the printing of this label thermal transfer printing technology will be used with the aid of a Brady BBP12 label printer [31].

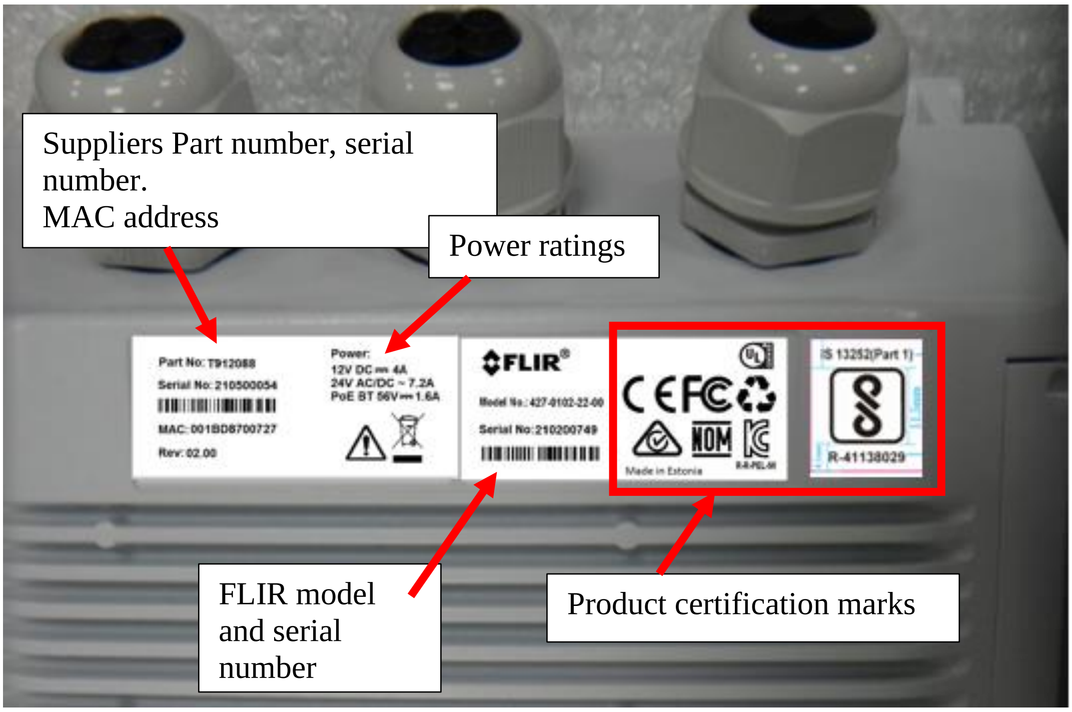


Figure 4.3. Product labels for traceability

4.5 Test stations and fixtures design

Boresight station is one of the key pieces of equipment in the production process of this product. In order to align the sights of the visible and infrared payloads a jig is nessecary due some of the optical modules having a focus distance of upwards to 300 metres, which means performing the adjustment indoors is not possible so equipment to perform this work needed to be designed.

For the design of this station a couple of requirements and assumptions were set:

- The station shall use collimating lenses in order to reduce the focus distance to <0.1 metres;
- The station must able to be used across all of the lens models which means that the selected lenses must be selected on the basis of the lens with the longest focus distance;
- The targets shall be enclosed with the distances of the two lenses being equal to the distance of the two modules in the camera;
- The station must have adjustability in order to align the visible modules crosshairs with a target;
- The front assembly must be fixed securely to the adjustment mechanism in order to avoid shift while doing the manual alignment;
- Sufficient room behind the station in order to allow for access with tools;

- The station must have a frame for holding it in place during the operation.

Based on the set requirements a station was designed. This jig consist of a two collimating lenses – one traditional lens for the optical module and one made out of germanium for the IR-module. These lenses allow for the adjustment to be made at much smaller distances, in the case of the particular jig the targets for respective modules are located inside the same enclosure as the lenses. The visible target is a simple bullseye printed on paper whereas the IR target is a metal target heated by a thermoelectric heater covered by a plastic spacer with a small aperture to target upon. The enclosure of the jig and the apperance of the targets from the camera's point of view can be seen below can be seen in figure 4.4.

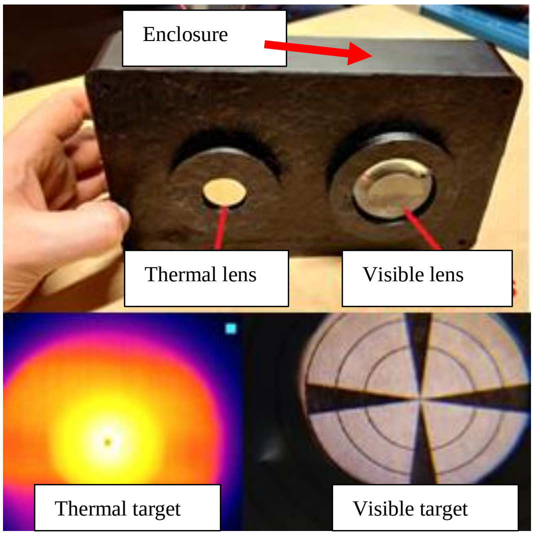


Figure 4.4. Boresight jig enclosure with view from camera

For securing the front assembly during the alignment process a holding fixture was designed as such that the front holder is seated exactly in the holder fixture. For the movement mechanism the use of a pan and tilt actuator was decided as this will allow for precise control of the adjustment process while providing sufficient stability during the adjustment process.

The boresight adjustment process is carried out by first mounting the camera front assembly into a holding fixture (shown in figure 4.5) which is itself mounted ontop of a pan and tilt motor usually used for controlling the movement of a security camera.

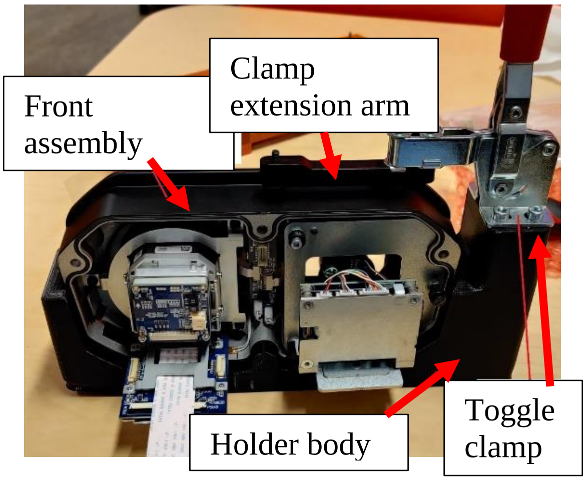


Figure 4.5. Front assembly fixture

For both the boresight jig as well as the pan and tilt unit a frame is built from Minitec profiles. After the camera has been securely mounted using the fixture the worker looks at the visible module stream on a computer screen and using the web interface of the pan and tilt unit to rotate the position of the front housing to match the centre of the visible pictures centre with the target bullseye’s centre. After this is done the pan and tilt unit is locked in place and the video on the screen will be switched to the IR stream. Now using the adjustment bolts on the infrared payload the IR sights centre is matched with the thermal target. The station with all the components put together can be seen in figure 4.6.

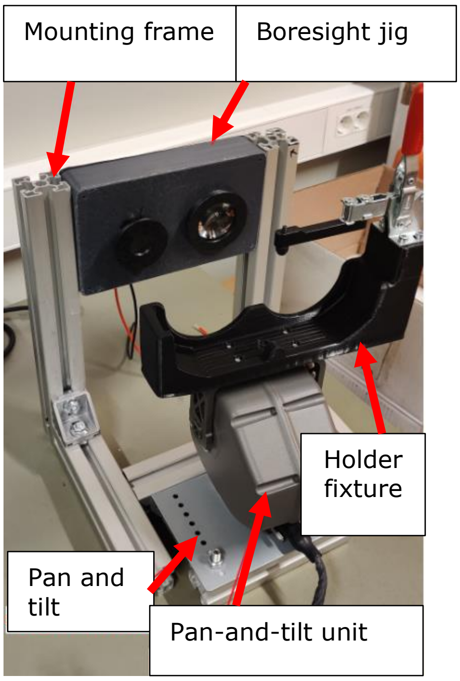


Figure 4.6. Boresight station assembly

Verification of thermal cores to be assembled into to the camera must take place in order to ensure they are in focus and if found not to be, the focusing to be carried out. Similar to the boresight station this process can not be carried out indoors due large focus distances seen in some lens configurations, therefore a similar set-up utilizing collimating lenses would need to be designed. For the design of this station some requirements were set:

- The station must utilize the thermal target section seen in the boresight section for the target except for the target which shall have more distinct shapes as target for easier focusing;
- The thermal core must be able to be fixed securely in order to be stable during the focusing process. The holder must be able to fit all thermal core models;
- The distance from the edge of the lens to the target lens must be large enough to fit all of the lenses;
- The thermal core holder and the target assembly must be fixed together in order to avoid misalignment during the process.

Based on previous a station was created which compromises of a thermal core holding fixture, tools to adjust the lens for focusing, a collimating lens for the narrow FOV lenses as well as a heated target.

The camera cores will be mounted into the fixture (figure 4.7) and secured in place, a video, power and communication adapter will be attached to thermal core and the core connected to a computer where analog video stream will be broadcasted. For the wide field of view lenses a collimating lens is not required since the focus distances are much smaller, but for the narrow field of view the focusing distances can be upwards to 300 metres, therefore on these the collimator is required. A worker will look at the video on the screen and evaluate whether the picture is focused or not, if focusing is found to be required the the focus will be adjust either by using a specialized focus tool on the wide FOV models, or on narrow FOV models by untightening the lens locking ring and adjusting the focus by rotating the lens barrel by hand.

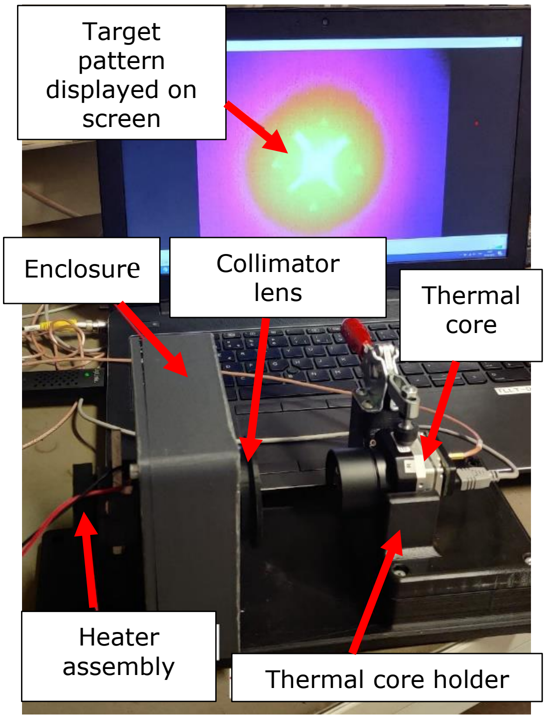


Figure 4.7. Focusing station

Leakage testing is required in order to assure the camera's compliance to IP67 dust and water tightness standard. The testing will take place after the front assembly has been attached to the camera housing i.e when the enclosure of the camera is achieved. For this testing a specialized leakage testing instrument will be used, the test method being a vacuum based differential pressure measurement. The tester chosen for this application is a Nolek S9 lite leak test instrument which can be seen below in figure 4.8. [32]

Figure 4.8. Nolek S9 lite [32]

The testing process will be carried out by attaching a vacuum hose through the camera housing's cable gland using which a vacuum is created within the housing after which there will be a short stabilization period followed by a measurement period and finally a repressurization stage. In the measurement stage the instrument will measure pressure difference between the camera enclosure and the reference volume for a pass or fail based on a set threshold, which will be indicated by either a green or red light on the measuring instrument. A graph of measurement sequence can be seen in a figure 4.9 below.

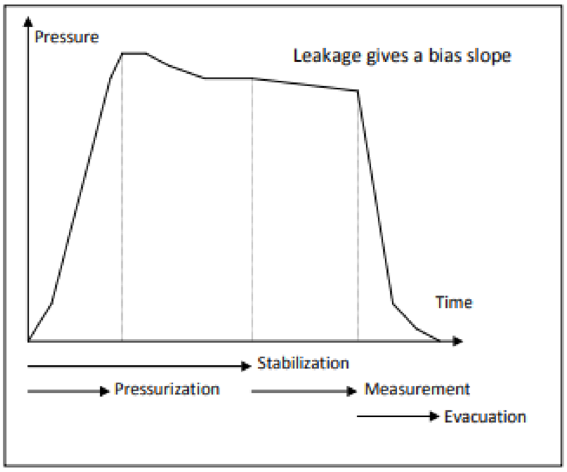


Figure 4.9. Leak measurement sequence [32]

4.5.1 Assembly aids design

In order to aid the workers perform the assembly operations and to increase the repeatability of work a number of assembly fixtures and tools will be designed. These tools and fixtures include holders for components, specialized tools for specific operations as well as jigs to aid with material handling. Most these tools will be designed in-house based on feedback from production workers with a predominant method of fabrication being fused deposition modeling (FDM) 3D-printing to allow for rapid iterations and to shorten the lead times. For fixtures that require higher accuracy and durability machined plastics, mainly utilizing Acetal Copolymer (POM-C). For the design of the fixtures the 3D-models of the component will be utilized in order to be able to generate perfect fit for the components and providing secure placement.

An example of one of the more critical fixtures is the thermal core positioning jig used to assemble the thermal cores to the mounting bracket at a specific position which differs from core to core. This fixture can be seen in figure 4.10.

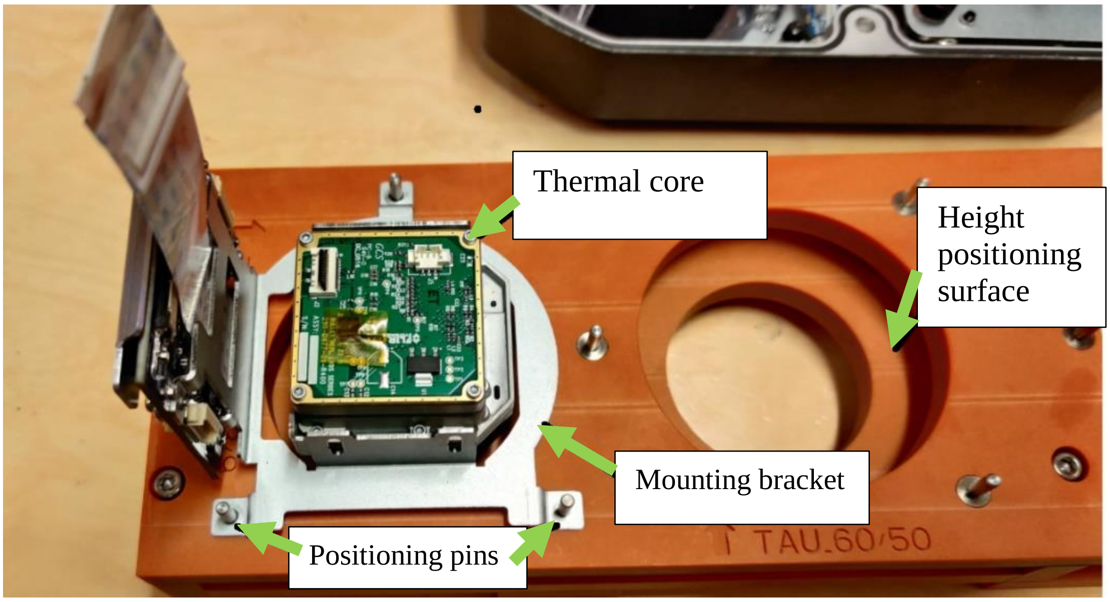


Figure 4.10. Thermal core mounting jig

The fixture features three sockets with specific depths correseponding with the particular thermal core to be mounted, surrounded by positioning pins. The assembly starts with one of the three mounting bracket models being placed onto the positioning pins of the socket, the alignment of the pins also providing an error-proofing method as the holes on the bracket only line up with the right socket's pins. Next the thermal core is inserted in the socket where the sockets inner surface is designed such that the core is mounted in the correct height an the thermal core can be fastened onto the mounting bracket. After this the jig also acts as a holding fixture while a convert board is assembled onto the thermal core.

Other fixtures prepared include mainly holders for various components in different manufacturing stages for example the holder of front assembly seen in figure 4.11, which is used to hold the front plate securely in place while the payloads get assembled into it.

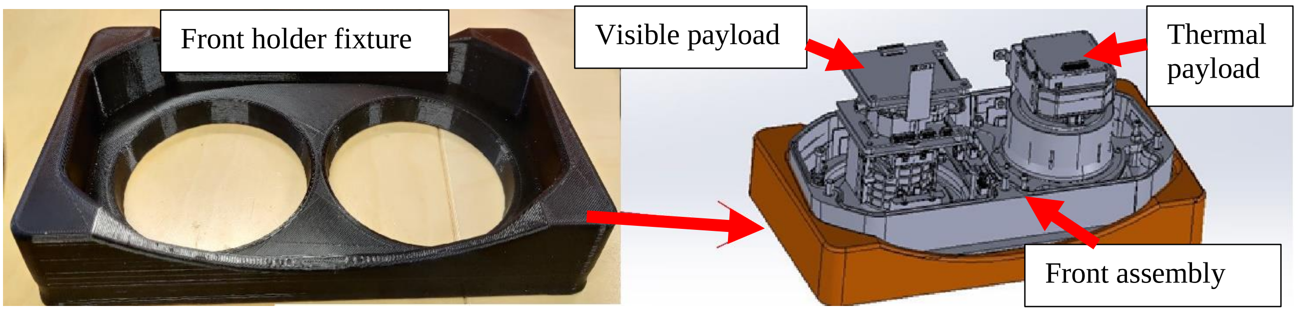


Figure 4.11. Front assembly holder

Another example of holding fixtures is a universal holder for each of the thermal cores used while mounting an interface module to the thermal core before the focusing step. This fixture features a raised platform with a slot for sliding the thermal core into as to not require the worker to hold the core in hand while tightening the screws. This fixture can be seen in figure 4.12.

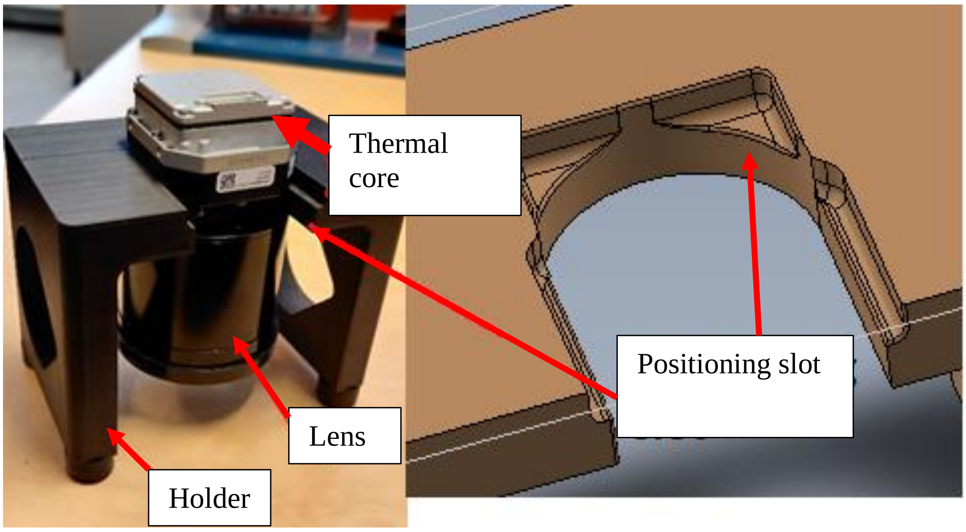


Figure 4.12. Thermal core holder

An alternative type of fixture designed is a a trolley for the camera housing seen in figure 4.13 for moving the components around the assembly table between operations since the camera housing is quite large in size as well as weighing around 3 kilograms so not having to lift this component around all day long considerably increases the working conditions of the worker and avoids workplace related injuries. The trolley consists of a large holding body moulded according to the geometry of the camera housings and roller wheels which are screwed straight to the holding body. The holding body is designed so the housing sits in the trolley slightly tilted upwards, making it easier for carrying out assembly operations such as attaching the front assembly to the housing which would otherwise have to be carried out at a horizontal angle.

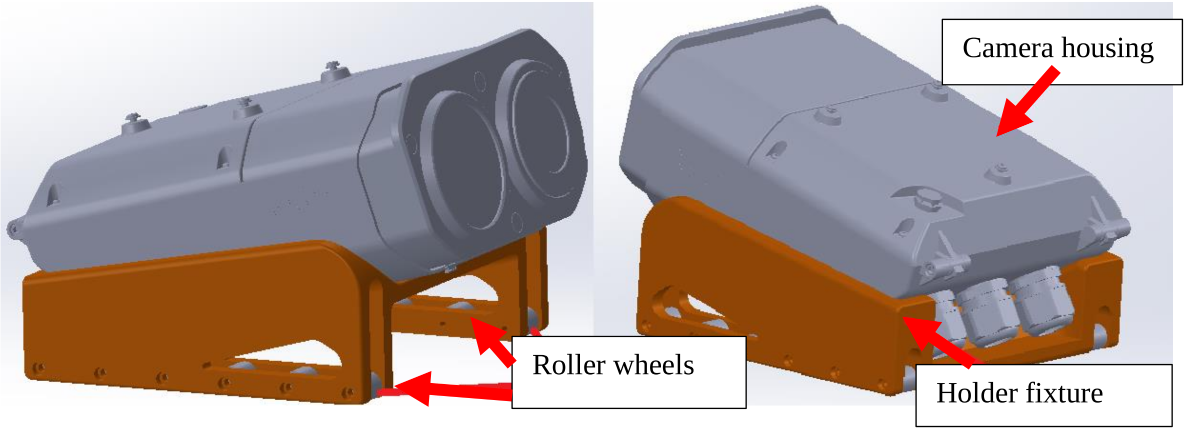


Figure 4.13. Trolley for camera housing

4.6 Screwdriver selection

Since the main type of operation carried out in Estonian factory is mechanical fastening it is important have the correct tools for the job. The screwdrivers must be torque-controlled, be able to calibrated, be ESD safe and must be ergonomic to use.

For the selection of screwdrivers each of the fastening operations and fasteners types were analysed with regard to importance of the particular operation, i.e the need to have a controlled torque setting as well as the accessibility of assembly. A list of fastening operations was created which can be seen below in table 4.4. Based on the above mentioned criteria 3 types of tools were assigned – Hand tools or a spanner for operations that require precise manual adjustment, calibrated electrical screwdrivers for operations that require controlled torque values and finally operations that use electrical screwdrivers, but where the assembly torque is not that important, so non-calibrated equipment can be used and both the initial cost of investment as well as the ongoing maintenance costs in the form of quarterly calibrations can be avoided.

Table 4.4. Fasteners list

Screw	Description	Operation	Tool bit	Tool type	Torque
T912083	Clamp Screw	Boresight fine adjustment	SL1.2	Hand driver	N/A
T912082	Adjustment Bushing	Boresight rough adjustment	-	Spanner 8 mm	N/A
T912080	Set screw	Visible module set after boresight	Hex 1.5	Hand driver	0,29 Nm
T912079	steel boss	Thermal lens (75 mm)	5 mm socket	Torque controlled screwdriver	0,48 Nm
T912078	M3x11L	Thermal Lens	PH1	Torque controlled screwdriver	0,19 Nm
T912077	M3x8L P+W	Thermal Lens	PH0	Torque controlled screwdriver	0,19 Nm
T912076	Screw (M1.6x12L)	Convert board for thermal core	PH0	Torque controlled screwdriver	0,19 Nm
T912075	Screw (M3x8L P+W)	Thermal core bracket	PH2	Torque controlled screwdriver	0,48 Nm
T912097	Screw (M4x10L Torx10)	Sunshield	T10 (security)	Torque controlled screwdriver	0,78 Nm
ZM82-0140173G	M4x18	Housing hatch	T10 (security)	Torque controlled screwdriver	0,78 Nm
SCHS M1.6 X 0.35 X 6 mm L	M1.6x8	VPC module/Thermal core cover	Hex 1.5	Electric, non-controlled driver	N/A
ZM82-0140173G	M4x18	Front assembly mounting	T10 (security)	Torque controlled screwdriver	0,78 Nm

For the torque controlled screwdrivers products by Kilews were chosen from their DC brushless low to medium torque series. The reason for choosing these screwdrivers is that the brushless motors offer a long lifespan and maintenance free durability, a stable torque output as well as an ergonomic design so they are well suited for electronics assembly. In addition to that screwdrivers from that series offer a large adjustable torque range which means that the same model of screwdriver can be used on most of the assembly operations, reducing the set-up time and providing a consistent performance. For screws T912075, T912077, T912079 and M4X10L_T10 the SKD-BN519 screwdriver seen in figure 35 was chosen. The screwdriver offers a torque range of 0,29-1,86 Nm at a rotation speed of 700 to 1000 RPM. More parameters of the SKD-BN519 screwdriver can be seen below in figure 4.14.

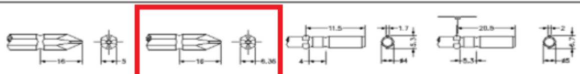
MODEL		SKD-BN512L	SKD-BN519L	SKD-BN512LF	SKD-BN517LF	SKD-BN512P	SKD-BN519P	SKD-BN512PF	SKD-BN517PF
Input voltage(DC)		DC 24V OR 32V							
Power Consumption		55W							
Torque	(kgf.cm)	1.5-12	3-19	1.5-12	3~17	2-12	3-19	2-12	3~17
	(Lbf.in)	1.33-10.44	2.57-16.46	1.33-10.44	2.57~14.78	1.77~10.44	2.57-16.46	1.77~10.44	2.57~14.78
	(N.m)	0.15-1.18	0.29-1.86	0.15-1.18	0.29~1.67	0.2~1.18	0.29-1.86	0.2~1.18	0.29~1.67
Repeatable Torque Accuracy (%)		±3%							
Torque Adjustment		Step less							
Unloaded Rotation Speed (r/min)±10%	HI	1000	1000	2000	2000	1000	1000	2000	2000
	LO	700	700	-	-	700	700	-	-
Screw Size Dia (mm)	Machine screw	1.6~3.0	2.3~3.5	1.6~3.0	1.6~3.0	1.6~3.0	2.3~3.5	1.6~3.0	1.6~3.0
	Tapping screw	1.6~2.6	2.3~3.0	1.6~2.6	1.6~2.6	1.6~2.6	2.3~3.0	1.6~2.6	1.6~2.6
Weight (g)		520							
Length (mm)		245							
Model of Torque Fixing Ring		KC-6C、KC-6S							
Power controller		SKP-32B-60W (BN6PIN)		SKP-BE32HL (BN6PIN)		SKP-32B-60W (BN6PIN)		SKP-BE32HL (BN6PIN)	
Signal Controller		KL-SCBSN							
Model of Suspension Rack		KH-4、(& KC KH-2)							
Bit Type		 HEX 5mm,		HEX 6.35mm		Ø4mm,		Ø5mm	

Figure 4.14. Kilews SKD-BN 500-series specifications [33]

For the power controller the SKP-32B-60W controller was chosen as this controller is compatible with various different models of screwdrivers. For the drive type a 6,35 mm hex drive was chosen as this is the most common driver bit type, making it easy to find bits. In addition to that balancers and suspensions racks were chosen for the screwdrivers and for the M4X10L_T10 screw a pistol grip will be attached as the operation will take place at a horizontal level.

For the T912076, T912077, T912078 screws a lower torque range is necessary so for this a Kilews SKD-BN210L screwdriver was chosen. This screwdriver offers similar characteristics as the BN519L screwdriver at a lower torque range of 0,1-0,98 Nm. Similar to the BN519L this screwdriver will also utilize the SKP-32B-60W power controller and the 6,35 mm hex drive. Additional specifications for the BN210L driver can be seen below in figure 4.15.

MODEL		SKD-B203L	SKD-B207L	SKD-B210L	SKD-B203LS5	SKD-B203LS6	SKD-B203LS7
Input voltage(DC)		DC 24V OR 32V					
Power Consumption		25W					
Torque	(kgf.cm)	0.2~3.5	0.5~7	1~10	0.2~3.5	0.2~3.5	0.2~3.5
	(Lbf.in)	0.18~3.01	0.44~6.10	0.89~8.67	0.18~3.01	0.18~3.01	0.18~3.01
	(N.m)	0.02~0.34	0.05~0.69	0.10~0.98	0.02~0.34	0.02~0.34	0.02~0.34
Repeatable Torque Accuracy (%)		±3%					
Torque Adjustment		Step less					
Unloaded Rotation Speed (R.p.m))±10%	HI	1000	1000	1000	500	370	230
	LO	700	700	700	350	260	160
Screw Size Dia (mm)	Machine screw	1.0~2.3	1.4~2.6	1.6~3.0	1.0~2.3	1.0~2.3	1.0~2.3
	Tapping screw	1.0~2.0	1.4~2.3	1.6~2.6	1.0~2.0	1.0~2.0	1.0~2.0
Weight (g)		330					
Length (mm)		185					
Model of Torque Fixing Ring		KC-13C、KC-13S					
Power controller		SKP-32B-60W					
Model of Suspension Rack		KH-5					
Bit Type		HEX 6.35mm			Ø 4mm		

Figure 4.15. Kilews SKD-BN200-series specifications [34]

For the non-controlled electrical drivers Panasonic EY 7410 LA2S Cordless Screwdrivers (figure 4.16) [35] were chosen due to previous experience with these particular drivers in the company, providing good value for money, ease of use as well as exellent durability.

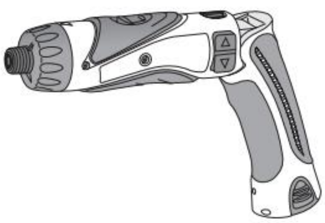


Figure 4.16. Panasonic EY 7410 LA2S [35]

4.7 Production layout design

For choosing an area where to put the assembly stations for this product the factory layout was taken a look at for finding areas where sufficient free space would be available for the assembly stations. An important criteria for choosing the location of the assembly stations is the goal of minimising the distance of internal logistics due to this product and it’s components are relatively large in size, therefore fewer components and assembled cameras can be fit into Kanban’s of the assembly station, resulting in more frequent component replenishments being needed, so having the assembly station being located near the component warehouse as well as the outgoing goods warehouse is key. Another thing to consider is that the assembly line of this product doesn’t have a dependency on any other production equipment, for example the calibration conveyors used on some other products, which usually means that the assembly stations need to be near the equipment it is dependant on, therefore there is more flexiblity with the placement options in the case of this product. Three potential areas were identified, which can be seen marked with red boxes with numbers 1, 2 and 3 respectively on in the factory floor plan (Appendix 3). First two of the potential areas are located in the main assembly area which is a clean room with tight requirements on cleanliness and humidity to reduce the effects of electrostatic discharge (ESD) damages to electronics components.

Due to the cleanliness requirements the packing of the assembled cameras are done in a separate area, historically this was done in the left side of the facility in a dedicated area for operations that dont have as tight requirements on cleanliness, but recently these stations were moved to the components warehouse for improved material movement.This packing area however, is at full capacity at the moment so the non-clean production area will have to utilized once again for packing. The first two assembly areas would be located right near the component's warehouse with a door to the warehouse right by, so the movement of components to the assembly area would be rather efficient, however considering the movement from assembly stations to the packing station, overall distances covered would be much longer. In the case of the third potential assembly area the assembly station would also be placed in the non-clean production area alongside the packing station meaning the area is right by the outgoing goods warehouse. The downside of the third choice is that this area doesn't have an as tightly controlled environment as the first two. However, due to this product's components arriving in partly assembled state, most of the PCBA's are enclosed, as well as not having optical assemblies that require very clean assembly, therefore it was decided that assembly in area other than the clean room could be considered. The material flow for each of the proposed assembly station placement options is shown in figure 4.17, where the blue line represents the location 1, red line location 2 and green line the flow of location 3. It can be seen that the longest amount of movement is required from option 2 where the components move to the far right end of the factory meanwhile the packing materials have to be moved to the other direction amounting together to approximately 350 meters of distance covered. The options number one and three have similar amount of movement for the components of approximately 180 metres, however in the case of the first option the paths of components and packing materials are different so accounting for that the total movement path for the first option is approximately 240 metres which means from the material flow standpoint proposed option number 3 is the most efficient.

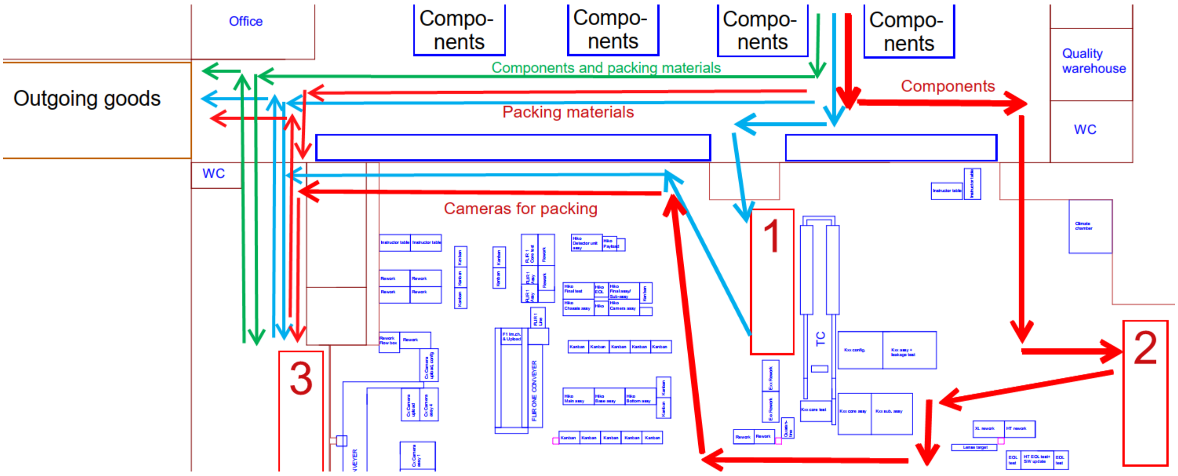


Figure 4.17. Material flow optimization

Considering the material flow and the independence from other production equipment it was decided that the most optimal location for the assembly station would be the area number 3.

Since the production line has no dependancies on other production equipment and the number of stations is small a simple serial assembly line structure will be used so the production can be set up for one-piece flow with minimal buffers for some operations. One-piece flow means that parts are moved through operations from step to step with no work-inprocess (WIP) in between either one piece at a time or a small batch at a time [36]. The proposed assembly line would consist of three assembly stations and one packing table with materials being loaded from the rear of the assembly table, utilizing a three-bin kanban system. A concept of the proposed layout can be seen below in figure 4.18.

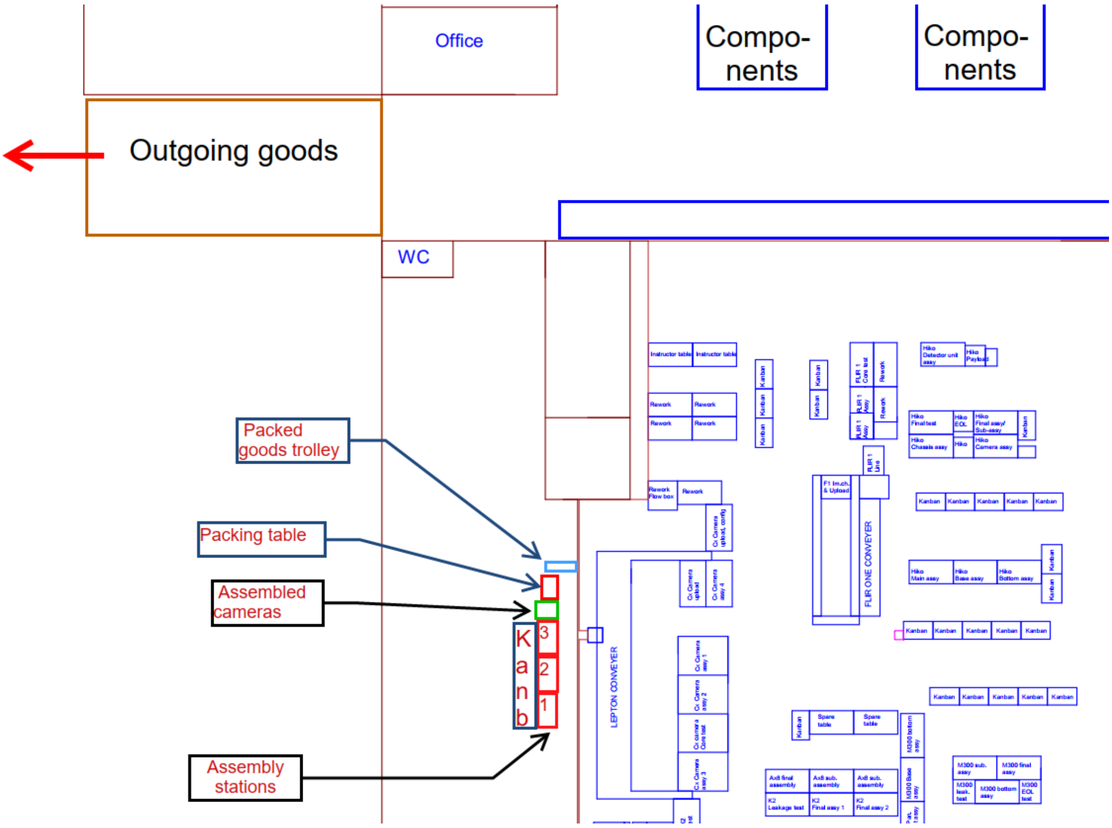


Figure 4.18. Assembly station layout

4.8 Production line set-up

For verification of the production line concept a temporary production line was set up. The line consist of three stations described in the previous chapters and follows the same structure. Where possible equipment left over from end-of-life production lines were used, such as in the case of worktables and chairs in order to save costs as in the the future, once the concept has been verified, dedicated stations will be built for the product according to the specific requirements. By building the stations for a particular purpose it is possible to create a workstation which is more ergonomic and efficient for the worker, as well as being able to use less floor space compared to standardized workstation solutions available on the market. The general layout of the assembly line can be seen in figure 4.19.

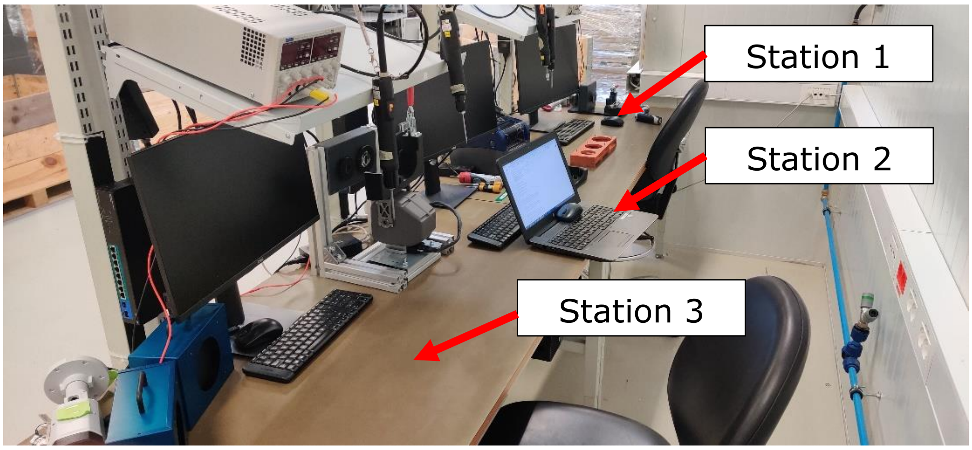


Figure 4.19. Assembly line

The first assembly station is where the assembly featuring both the IR-core and the visible module gets assembled. The work in the station start off with the labels of both the thermal core and visible module being scanned for the serial numbers using the handheld label scanner, the information from there will be written in WAF/PDS and and a label generated for the next assembly station. After this the thermal core is verified for being focused, if necessary adjusting that using the focus station. For powering the focus stations heater assembly, a laboratory power supply unit is used. For both the label scanning and focus verification a standard PC set-up is used for interface. If the thermal cores are focused a thermal payload can be assembled using the thermal core and a combination of handheld eletric screwdrivers and torque wrenches present in the workstation. After this both the thermal and visible payloads get assembled into the front assembly using the front assembly fixture and electrical torque-controlled screwdrivers selected in a previous chapter. A picture of the set-up of assembly station 1 can be seen below in figure 4.20.

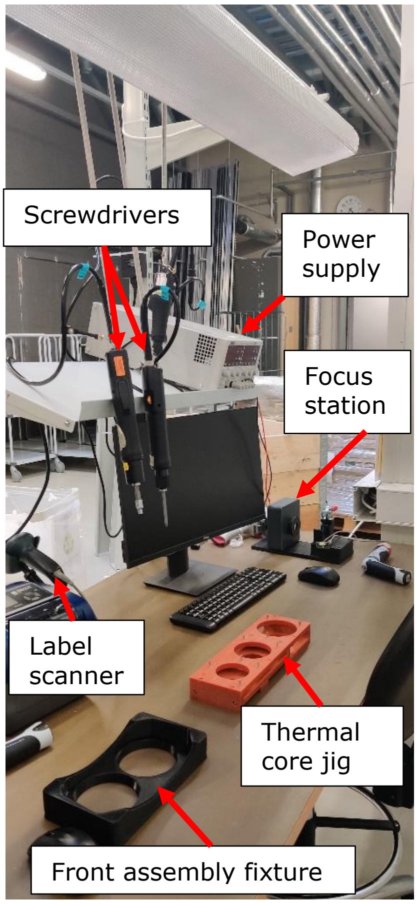


Figure 4.20. Assembly station 1

In the second assembly station the boresighting of the visible and thermal payloads takes place, as well as the assembly of front assembly to the camera housing and the initiation of firmware upgrade process that takes place between the second and third assembly stations. A picture of the second assembly station set-up can be seen in figure 4.21. This station features a label printer for printing the labels generated in the previous station based on the scanned data from visible and thermal modules, the boresight alignment station, screwdrivers for adjustment of alignment and assembly of the front assembly to the camera housing, as well as auxiliary equipment such as a standard PC set-up and networking and power equipment. For communications and powering of both the cameras itself as well as the pan and tilt unit a combination of power over ethernet (POE) injectors and a network switch is used so the whole set-up can easily be managed from a single computer. The computer is an interface for controlling the movement of the pan and tilt unit used for the boresight station. Similar to the focus station a laboratory power supply is used for powering the heater assembly of the boresight station. Missing from the picture of this station is the leakage tester that had a delay in shipment therefore it will have to be set up at a later time.

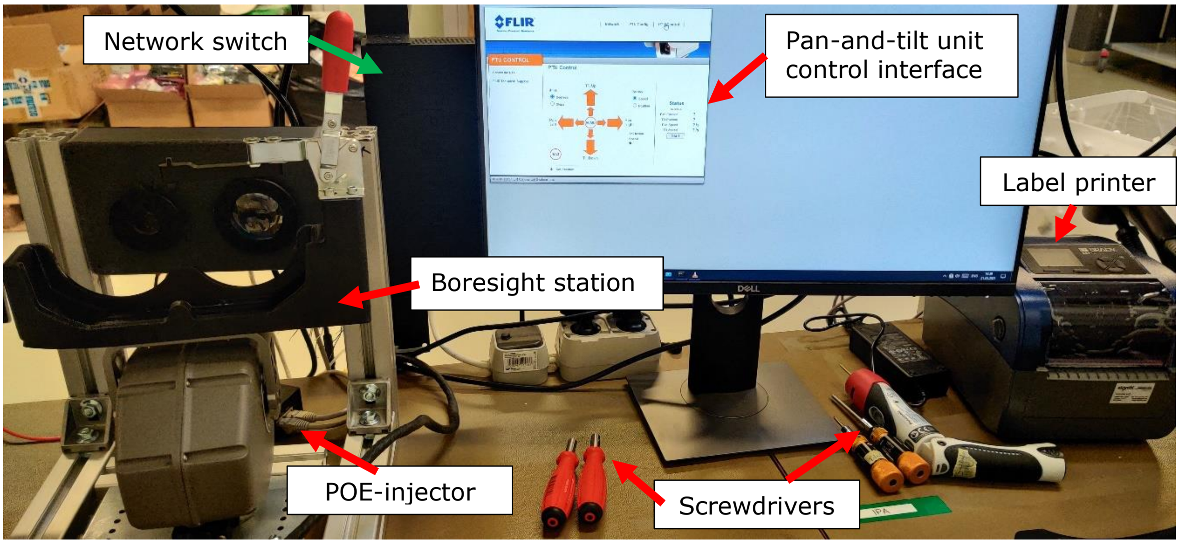


Figure 4.21. Assembly station 2

The third assembly station is mainly concerned with the testing and calibration of the cameras as well as the assembly of the final component – the sunshield, to the camera. The set-up of the assembly station can be seen in figure 4.22. This station features a computer for running the test sequences on the cameras as well as reference blackbodies, one set to ambient temperature, the other to 50° C in order to evaluate the radiometric accuracy. For powering the blackbodies a power supply unit is present, also powering the boresight stations heater assembly. Similar to the previous station, for powering the cameras a combination of POE injectors and a network switch is used (not pictured)

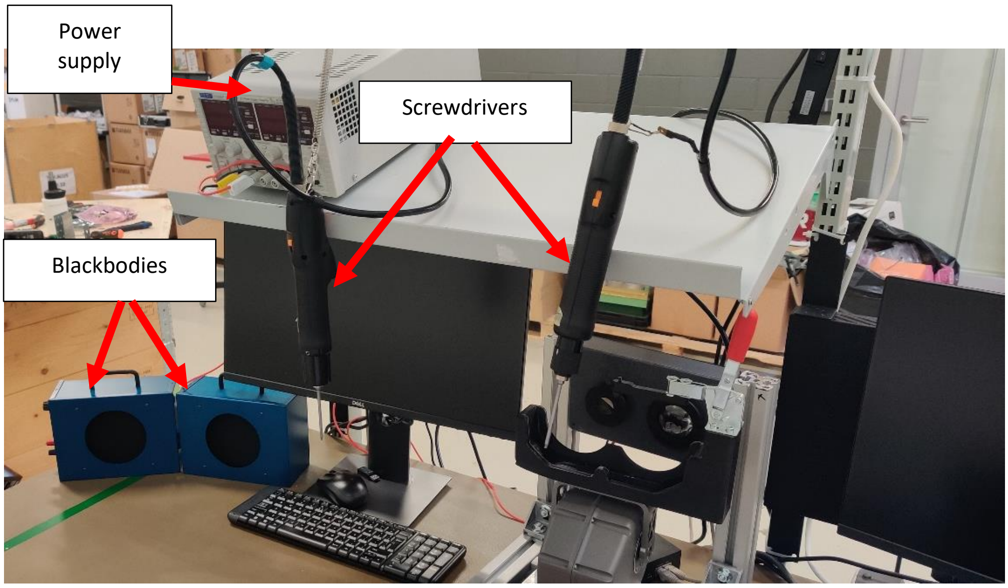


Figure 4.22. Assembly station 3

5. TECHNO-ECONOMIC ANALYSIS

5.1 Project timeline slips and list remains

Due to numerous setbacks, the set project timeline could not be kept. While the project originally aimed to deliver DVT units in the beginning of april, due to the component shortages brought on by the global pandemic and difficulties dealying with the ODM, the test units could not be provided by the set time and the actual delivery time got pushed nearly two months further, to the end of May. Due to the material shortages the cost of materials for the product also increased by around 10%

While in normal circumstances a smaller volume production test series is produced before the PVT or null-series, to validate production line concept, due to the fact that the PVT-series units already have a large customer lined up, the project must carry on with a compressed timeline in order to deliver the 400 units by the end of July, which means the PVT series needs to start in the start of July. This means that the project is carrying a big risk in terms of production setup, leaving very little time for changes if they are found to be necessary.

From the point of production set-up these activities are still to be carried out before the launch of the product:

- Setting up production-BOM's and routing's;
- Full validation of production equipment via a test series including a test report regarding the issues encountered and yield status;
- Assembly optimization based on test series feedback;
- Building a dedicated production line based on the feedback of workers with an aim to reduce floorspace and increase ergonomics;
- Documenting work instructions;
- Instructor and worker training;
- Disassembly of a randomly chosen unit from production line in order to verify everything is being done correctly;
- Creating a component control plan for incoming inspection based on the analysis of most critical components and the risk for errors;
- Defining spare parts for service and providing equipment for service locations;
- Handing the product over to the production team;
- Carrying out a lessons-learned workshop with the project team in order to learn from the mistakes made and improve in the future projects.

5.2 Budget analysis

At the start of the project the total cost for the production line bring-up was estimated at approximately 164 702 dollars, split between hardware costs of 110 019 dollars and labour costs of 54 683 dollars.

At the time of finishing writing this thesis the total amount spent on hardware was 25 688 dollars or 23.3% of the estimated budget with most of the critical pieces of equipment in place. The main place area of savings for hardware was the boresight alignment station, which was budgeted at nearly 50 000 USD, however thanks being able to design this equipment in-house the cost of hardware came out to little less than 1500 USD. Thanks to the savings on the boresight station the forecast for spending on hardware was reduced to 51 207 dollars. The main costs for the remaining hardware consist of building product-specific worktables and setting up equipment for the technician's rework station.

At the time of finishing the thesis people involved in the project had acumulated a total of 802 man-hours of work which amounts to 75,5% of the budgeted 1062 hours. In case of most of the modules estimated in the budget preparation the amount of work estimated was consistent with the time spent, however due to delays in the project and problems in dealing with the ODM the amount spent for project leader's activities required more time than expected. The hours spent by the project leader were increased from 280 hours to 400 hours, bringing the total man-hours amount for the project up to 1162 hours. This increase represents an 11,3% or 6178 dollar overshoot of the budget.

In total the actual spend for the project at the timing of writing was 66 983 dollars or 41,3% of the budget. While the projections for labour costs increased this is projected to be offset by the savings on equipment bringing the total forecast down to 111 689 dollars or 67.8% of the total estimate at the start of the project. A graph representing the budgeted, forecasted and actual spendings on the production line bring up can be seen below if figure 5.1.

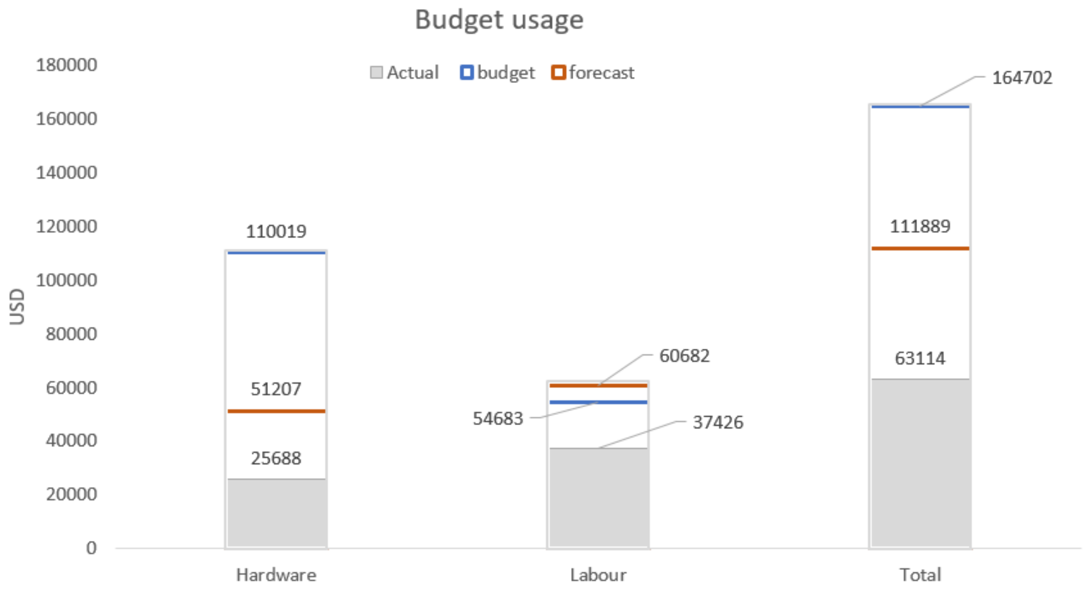


Figure 5.1. Production line budget usage

5.3 Product cost analysis

A target was set for the average COGS of the camera to be less than 2200. COGS is a good indication of the total cost for the company to produce one unit and is the baseline for find out the products profit margin. Product COGS is a sum of the BOM cost, material overhead cost, direct labor cost, Overhead (OH) cost and depreciation of capital expenses. Initial data for the COGS calculation are brought out in table 5.1.

Table 5.1. Initital data for COGS calculation

Component	Value
Direct labor time	1,01 hours
Labor cost per hour	12,67 USD
Overhead per hour	19,18 USD
Average BOM cost	2081,16 USD
Material overhead rate	7.2%
Equipment	111 889 USD
Molding tools	235 034 USD
Amortization period	7 years
Units per year	3000

For finding the direct labor cost we can multiply the direct labor time with the hourly cost shown in equation 5.1.

$$Direct\ labor\ cost = Direct\ labor\ time * labor\ cost\ per\ hour = 1{,}01 * 12{,}67 = 12{,}80\ \ USD \qquad (5.1)$$

For OH costs we multiply direct labor time with the overhead per hour as seen in equation 5.2.

$$OH = Direct\ labor\ time * overhead\ per\ hour = 1{,}01 * 19{,}18 = 19{,}37\ \ USD \qquad (5.2)$$

For material overhead (MOH) costs we multiply the BOM cost with the material overhead rate as seen in equation 5.3.

$$MOH = BOM\ cost * material\ overhead\ rate = 2081{,}16 * 0{,}072 = 149{,}82\ \ USD \qquad (5.3)$$

For finding the depreciation per unit we add together the cost of equipment and molding tools, and divide this by the product of amortization period and units per year as seen in equation 5.4.

$$Depreciation = \frac{Molding\ tools + equipment}{units\ per\ year * amortization\ period} = \frac{235\ 034 + 111\ 889}{3000 * 7} = 16{,}52\ USD \qquad (5.4)$$

Adding this all together we end up with the COGS as seen in equation 5.5.

$$COGS = BOM\ costs + Direct\ labor\ cost + OH + MOH + Depreciation = \\ = 2081{,}16 + 12{,}8 + 19{,}37 + 149{,}82 + 16{,}52 = 2362{,}14\ USD \qquad (5.5)$$

As we can see the COGS of the product is projected to be 162,14 dollars or around 7,3% higher than initially set out to be. While the projected cost for the production line could be reduced during the project this was negatively offset by the increase in the BOM cost, leading to this goal not being filled, however since this is related to state the economy is in right now this really couldn’t be mitigated.

SUMMARY

The goals of this thesis were to propose and carry out a plan for the product implementation, develop and build a production line for the product, and evaluation of the product implementation project.

In this thesis the following tasks were completed:

1. **Initial data analysis and project planning**

Based on analysis of the product itself as well as the broader business environment, requirements for the manufacturing of the chosen product were worded as a basis for the success of the implementation work. Firstly the general requirements of the product itself were drawn up, relating to the functions the product needs to have, as well as the cost of production. Some of these requirements were then translated to requirements for the production set up, such as the test and traceability scope. Other part of the requirements that were generated were requirements stemming from the needs of the factory and the supporting processes, such as the factory layout requirements and requirements for quality- and environmental management. In the second part of this task a general scope for the assembly operations were presented, based on which a budget estimate could be generated.

2. **Implementation of the product into production**

This part started with presenting a project implementation time plan based on the scope of work to be done during the project, this plan governed the rest of the activities. An early design and manufacturability analysis was carried, resulting in finding and proposing countermeasures for a dozen issues. Also in this part a production line was designed, starting off with generating a production flow concept, moving on to defining the workstations, finding the need for operators based on volume demands and productivity. The production flow was sequenced and split into workstations, analysing the efficiency of the process and proposing improvements. A process for the traceability of the production process was set up.

During this task the need for equipment was analysed, based on which a number of test stations, fixtures and assembly aids were designed. In addition to that equipment to be bought were selected. Based on the selections and designs made in the previous tasks a production layout design that utilizes LEAN manufacturing principles such as minimal movement and space usage was proposed, the location of the assembly line within the factory was chosen. As a result of this most of the equipment could be manufactured

and bought and an initial production line set up. The set up of the production line was one of the goals of this thesis so that can be considered as fulfilled.

3. **Techno-economic analysis of the product implementation project**

As a part of this task the project timeline fulfilment was analysed, finding that the project timeline could not be followed as intended as delays from the ODM, as well as the global material shortage delayed the completion of some major milestones on time. An adjusted timeline was described with a proper production test series being skipped due to timeline constraints. While it was planned for the project to conclude by the time of submitting this thesis, this has now been pushed to the future, however these delays were not in the control of the author and a considerable amount of the total work is already completed.

As a part of this task the production line budget set in the first task was analysed for actual spending, as well as projections for the end results made, and it was found that the actual spending for equipment was able to be reduced considerably, with projections of equipment costs for the project being only nearly half of the budgeted. The manpower costs were found to be projected as exceeding the set amount by approximately 11,3% due to additional work related to the delays. Considering both the hardware and manpower the total forecast for the spending was found be 67.8% of the budgeted, so overall it can be said that financially this work was a success.

In the last section of this task the total cost for manufacturing this product was calculated and compared against the set target. It was found that the cost for the product would be about 7,3% higher than targeted, mainly attributable to the material cost increase of 10%. This was partially offset by the reduced cost on depreciation of equipment. Overall, even though the price was higher, this increase was mainly due to macro-economic factors out of control for the author, while thanks to work carried out in this task the cost could be reduced, therefore this could still be considered as a success.

In conclusion, the author considers this thesis a success since the goals set for the thesis were accomplished, even though the thesis could not cover the whole implementation from start to finish. The work on the project will continue afterwards, with a planned public launch of the product in the coming months.

KOKKUVÕTE

Antud lõputöö eesmärkideks oli välja pakkuda ja läbi viia plaan uue toote juurutamiseks, välja töötada ja üles seada tootmisliin, ning hinnata antud toote juurutamise projekti õnnestumist.

Töö käigus täideti järgnevaid ülesandeid:

1. **Lähteandmete analüüs ja projekti planeerimine**

Võtteks aluseks toote analüüsimise ning ka laiema ärikeskkonna sõnastati eesmärgid valitud toote tootmiseks, ning need olid aluseks edasisele tööle. Esimesena sõnastati üldisemad nõudmised toote enda kohta, seostuvana funktsioonidele mida toode kandma peab ning selle tootmise hinnaga. Mõned nendest nõudmistest teisendati nõudmisteks tootmise jaoks, nende seas näiteks testimise ja jälgitavuse kava. Teine osa sõnastatud nõudmistest on seotud toodet tootva tehase ning selle tugiprotsesside vajadustega, nende seas näiteks nõudmised tootmise paiknemisele tehases, ning kvaliteedi- ja keskkonnajuhtimisega. Töö selles osas pakuti välja läbi viidavate koosteoperatsioonide raamistik, mille alusel loodi projekti eelarve.

2. **Toote juurutamine tootmisesse**

Antud osa tööst algas projekti läbi viimise ajakava esitamisega, millest sai alus kõigele edasisele tööle. Viidi läbi varajane disaini ja toodetavuse analüüs, mille abil suudeti tuvastada ning välja pakkuda lahendused kaheteistkümnele leitud probleemile. Selles osas disainiti ka tootmisliin, alustades kõige pealt toote voo konseptiooni loomisega, seejärel defineeriti töökohad, leiti vajalik tööliste arv arvestades tootmismahu nõudmisi. Toote voog järjestati ja jagati tööjaamade vahel, lisaks sellele analüüsiti voo efektiivsust ja pakuti välja parendusettepanekuid. Lisaks sellele loodi protsess tootmisoperatsioonide jälgitavuse jaoks.

Selle ülesande jooksul analüüsiti seadmete vajadus, mille alusel disainiti hulk testseadmeid, fikstuure ja koostamise abivahendeid. Lisaks sellele valiti välja seadmed mida ostetakse. Eelnevate valikute ja disainide põhjal loodi tootmiseliini paiknemise disain, mis rakendab LEAN tootmise printsiipe, nagu näiteks liikumiste ja ruumi kasutuse minimiseerimist. Antud ülesande tulemusel suudeti valmistada ja osta enamik seadmetest ning esialgne tootmisliin üles seada. Tootmisliini üles seadmine oli ka üks lõputöö eesmärke, seega võib selle lugeda kordaläinuks.

3. **Tehnoloogilis-majanduslik analüüs toote juurutamise projekti kohta**

Selle ülesande käigus analüüsiti projekti ajakava täitmist ning leiti, et projekti ajakava ei suudetud täielikult täita, sest ODM-i poolsete viivituste ning globaalsete materjalide defitsiidi tõttu nihkus mõne olulise verstaposti täitmine edasi. Pakuti välja kohandatud ajakava milles korralik tootmise testseeria jäeti ära, viidates ajalistele piirangutele. Kuigi oli plaanitud, et selle lõputöö esitamise ajaks on projekt lõpule viidud on see lõpp nihkunud tulevikku, polnud antud edasinihkumised autori poolt mõjutatavad ja sellegi poolest on väga suur osa juurutamise tööst juba läbi viidud.

Ühe osana sellest ülesandest analüüsiti esialgu seatud tootmisliini eelarve kasutamist reaalsuses, lisades sinna juurde ka prognoosid kulutustest ning leiti, et tegeliku kulutust tootmisliinile suudeti märkimisväärselt, ligi 50%, vähendada. Tööjõu osas leiti, et projekti prognoositud tundide kulu saab tõenäoliselt olema suurem kui arvestati, ületades plaanitut umbes 11,3%, seetõttu, et projekti edasi nihumise tõttu oli vajalik sooritada täiendavaid ülesandeid. Arvestades nii kulutusi liinile kui tööjõule, leiti, et prognoositav kulutus saab olema 67,8% plaanitust, seega üldiselt võib öelda, et majanduslikult oli antud ülesanne edukas.

Selle ülesande viimases osas arvutati toote tootmise kogukulu ja võrreldi seda seatud eesmärgiga. Leiti, et eeldatav hind saab olema 7,3% kõrgem plaanitust, peamiselt tänu sellele, et toote komponentide hind tõusis seosus turu olukorrale umbes 10%. Osaliselt suudeti seda hinnatõusu kompenseerida sellega, et kulutused seadmete amortisatsioonile olid hulka väiksemad. Kokkuvõttes võib öelda, et olgugi, et tootmise hind saab olema suurem seatud eesmärgist, oli kõige suuremaks mõjutajaks makro-ökonoomilised tegurid mida polnud autoril võimalik mõjutada ning tänu töös tehtule suudeti tootmisliini arvelt seda hinda natukene vähendada, seega võib ülesande täitmise lugeda edukaks.

Kokkuvõttes peab autor tööd edukaks, kuna enamus seatud eesmärke sai täidetud, olgugi, et töö ei saanud hõlmata projekti algusest lõpuni. Töö projektiga jätkub ning juba lähikuudel jõuab toode turule.

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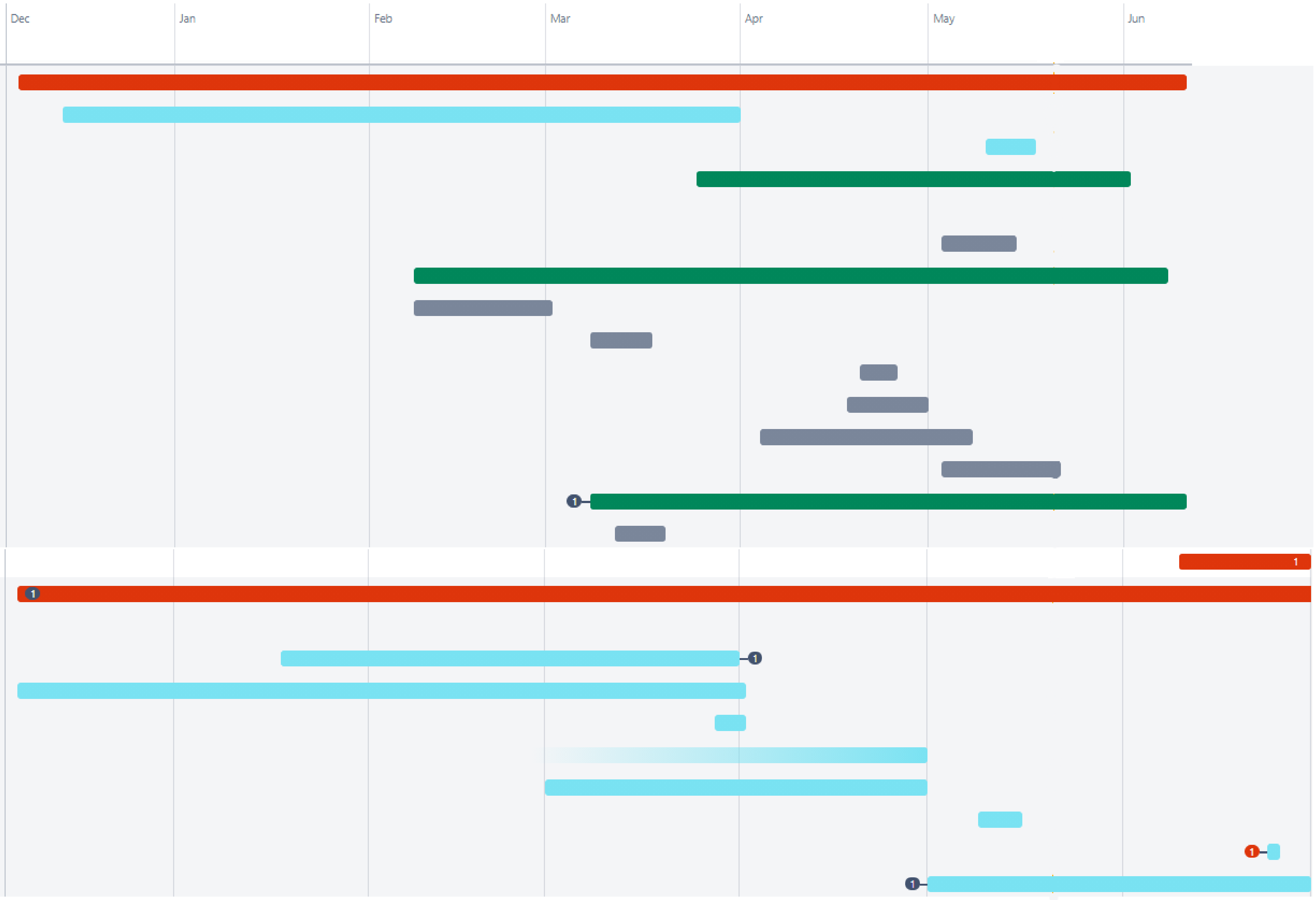
APPENDICES

APPENDIX 1. PROJECT TIME PLAN

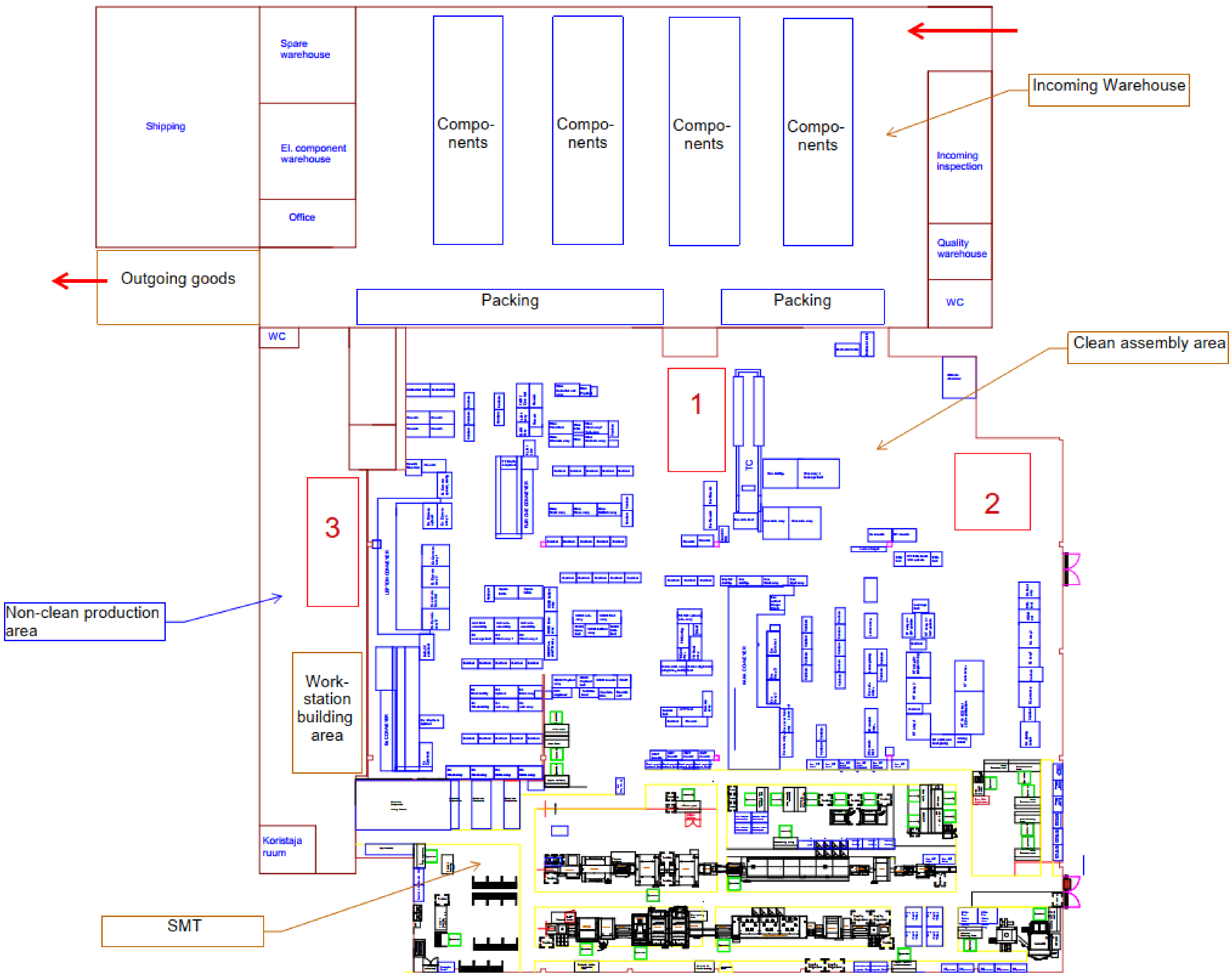
#	Issue	Target start	Ta...	Status
1	TLLTEC-56 HB Production line	07/Dec/20	10/Jun/21	NEW
	TLLTEC-58 HB Build boresight test setup	14/Dec/20	31/Mar/...	IN IMPLEMENTATION
	TLLTEC-88 Document new Equipment as Production Modules	10/May/21	17/May/...	NEW
	TLLTEC-69 Production flow / Production modules set up	25/Mar/21	01/Jun/21	NEW
	TLLTEC-81 Set up labels and printers			NEW
	TLLTEC-78 Drawings reviewed	03/May/21	14/May/...	NEW
	TLLTEC-68 New Product Introduction	08/Feb/21	07/Jun/21	IN IMPLEMENTATION
	TLLTEC-74 Preliminary Assembly drawings	08/Feb/21	01/Mar/...	NEW
	TLLTEC-72 Order prod. equipment	08/Mar/21	17/Mar/...	NEW
	TLLTEC-76 Resource requirements specification	20/Apr/21	25/Apr/21	NEW
	TLLTEC-73 Prod. flow balancing	18/Apr/21	30/Apr/21	NEW
	TLLTEC-71 Assembly optimization	04/Apr/21	07/May/...	NEW
	TLLTEC-75 Production layout	03/May/21	21/May/...	NEW
	TLLTEC-59 HB Assembly fixtures	08/Mar/21	10/Jun/21	IN IMPLEMENTATION
	TLLTEC-77 HB Core2Cam assembly fixtures	12/Mar/21	19/Mar/...	NEW
2	TLLTEC-85 PVT series (400 pcs)	10/Jun/21	30/Jun/21	NEW
3	TLLTEC-57 HB Indus project leader	07/Dec/20	01/Jul/21	NEW
	TLLTEC-90 HB - Create component PN's			NEW
	TLLTEC-66 Tests, traceability, SW configs	18/Jan/21	31/Mar/...	IN ANALYZE
	TLLTEC-62 Production planning	07/Dec/20	01/Apr/21	IN IMPLEMENTATION
	TLLTEC-67 Introduction to production team	28/Mar/21	01/Apr/21	NEW
	TLLTEC-63 Design For Assembly (DFA) Analysis		30/Apr/21	NEW
	TLLTEC-82 Define Routing and costing in SAP to sell prototyp...	01/Mar/21	30/Apr/21	NEW
	TLLTEC-87 Production planning final	09/May/21	15/May/...	NEW
	TLLTEC-89 Production Handover Meeting	24/Jun/21	25/Jun/21	NEW
	TLLTEC-83 Verify test scope	01/May/21	30/Jun/21	NEW



APPENDIX 2. PRODUCTION LINE BUDGET

Module	Production module	Capitalizable costs	Work (h)	Department	Rate/h	Tot work cost SEK	Tot work cost USD	HW cost SEK	HW cost USD	Total SEK	Tot USD
Assembly Line	Front Cover Assembly	Furniture and Fixtures	24	Production Engineering	394	9 456 kr	$ 1 051	23 082 kr	$ 2 565	32 538 kr	$ 3 615
Assembly Line	Front Cover Assembly	Furniture and Fixtures	40	Indus	394	15 760 kr	$ 1 751	7 500 kr	$ 833	23 260 kr	$ 2 584
Assembly Line	Front Cover Assembly	Machinery and Equipment	24	Indus	394	9 456 kr	$ 1 051	18 564 kr	$ 2 063	28 020 kr	$ 3 113
Assembly Line	Front Cover Assembly	Machinery and Equipment	2	Indus	394	788 kr	$ 88	18 000 kr	$ 2 000	18 788 kr	$ 2 088
Assembly Line	Lens Module Assembly	Furniture and Fixtures	24	Production Engineering	394	9 456 kr	$ 1 051	23 082 kr	$ 2 565	32 538 kr	$ 3 615
Assembly Line	Lens Module Assembly	Furniture and Fixtures	40	Indus	394	15 760 kr	$ 1 751	7 500 kr	$ 833	23 260 kr	$ 2 584
Assembly Line	Lens Module Assembly	Computer Equipment & Software	40	Indus	707	28 280 kr	$ 3 142	10 000 kr	$ 1 111	38 280 kr	$ 4 253
Assembly Line	Lens Module Assembly	Machinery and Equipment	2	Indus	394	788 kr	$ 88	18 000 kr	$ 2 000	18 788 kr	$ 2 088
Assembly Line	Camera Body FW Upgrade	Computer Equipment & Software	40	Indus	707	28 280 kr	$ 3 142	10 000 kr	$ 1 111	38 280 kr	$ 4 253
Assembly Line	Core2Cam Assembly	Furniture and Fixtures	40	Indus	394	15 760 kr	$ 1 751	7 500 kr	$ 833	23 260 kr	$ 2 584
Assembly Line	Core2Cam Assembly	Furniture and Fixtures	24	Production Engineering	394	9 456 kr	$ 1 051	23 082 kr	$ 2 565	32 538 kr	$ 3 615
Assembly Line	Core2Cam Assembly	Machinery and Equipment	4	Indus	394	1 576 kr	$ 175	18 000 kr	$ 2 000	19 576 kr	$ 2 175
Assembly Line	Vis Alignment	Furniture and Fixtures	40	Indus	394	15 760 kr	$ 1 751	32 000 kr	$ 3 556	47 760 kr	$ 5 307
Assembly Line	Vis Alignment	Machinery and Equipment	16	Indus	394	6 304 kr	$ 700	516 000 kr	$ 57 333	522 304 kr	$ 58 034
Assembly Line	Vis Alignment	Computer Equipment & Software	80	Indus	707	56 560 kr	$ 6 284	10 000 kr	$ 1 111	66 560 kr	$ 7 396
Assembly Line	Vis Alignment	Furniture and Fixtures	16	Production Engineering	394	6 304 kr	$ 700	23 082 kr	$ 2 565	29 386 kr	$ 3 265
Final	Final Config and EoL Test	Machinery and Equipment	16	Production Engineering	394	6 304 kr	$ 700	17 000 kr	$ 1 889	23 304 kr	$ 2 589
Final	Final Config and EoL Test	Furniture and Fixtures	24	Production Engineering	394	9 456 kr	$ 1 051	23 082 kr	$ 2 565	32 538 kr	$ 3 615
Final	Final Config and EoL Test	Furniture and Fixtures	20	Indus	394	7 880 kr	$ 876	32 000 kr	$ 3 556	39 880 kr	$ 4 431
Final	Final Config and EoL Test	Computer Equipment & Software	40	Indus	707	28 280 kr	$ 3 142	10 000 kr	$ 1 111	38 280 kr	$ 4 253
Final	Final Config and EoL Test	Machinery and Equipment	8	Production Engineering	394	1 752 kr	$ 195	26 000 kr	$ 2 889	27 752 kr	$ 3 084
Final	Final Assembly	Furniture and Fixtures	20	Indus	394	7 880 kr	$ 876	28 000 kr	$ 3 111	35 880 kr	$ 3 987
Final	Final Assembly	Machinery and Equipment	4	Indus	394	1 576 kr	$ 175	36 000 kr	$ 4 000	37 576 kr	$ 4 175
Final	Packing	Machinery and Equipment	16	Production Engineering	394	6 304 kr	$ 700	15 700 kr	$ 1 744	22 004 kr	$ 2 445
Final	Packing	Computer Equipment & Software	40	Indus	707	28 280 kr	$ 3 142	10 000 kr	$ 1 111	38 280 kr	$ 4 253
Other	Production line	Capitalizable installation direct labor	40	Production Engineering	394	15 760 kr	$ 1 751	- kr	$ -	15 760 kr	$ 1 751
Other	Production line	Computer Equipment & Softwa	40	Production planner	394	15 760 kr	$ 1 751	- kr	$ -	15 760 kr	$ 1 751
Other	Production line	Capitalizable installation direct labor	40	Production Engineering	394	15 760 kr	$ 1 751	- kr	$ -	15 760 kr	$ 1 751
Other	Project lead	Other Capitalizable Costs	280	Indus	394	110 320 kr	$ 12 258	- kr	$ -	110 320 kr	$ 12 258
Rework	Rework Station	Machinery and Equipment	2	Indus	394	788 kr	$ 88	18 000 kr	$ 2 000	18 788 kr	$ 2 088
Rework	Rework Station	Furniture and Fixtures	16	Indus	394	6 304 kr	$ 700	9 000 kr	$ 1 000	15 304 kr	$ 1 700
		Total	**1062**			**492 148 SEK**	**$ 54 683**	**990 174 SEK**	**$ 110 019**	**1 482 322 SEK**	**$ 164 702**

APPENDIX 3. FACTORY LAYOUT



GRAPHICAL MATERIAL

Table. List of drawings.

Drawing number	Description	Format/Scale
F10066644	Core focusing station assembly	A3 1:3
F10067542	Boresight jig assembly	A3 1:3
F10064610	Front assembly holder for boresight	A3 1:2
F10066607	Thermal core holder	A4 1:2
F10066494	Front assembly holder	A4 1:2
F10066516	Camera trolley	A3 1:2