Automating final assembly of MINI-LINKs at Ericsson Sandlid

A DYNAMO++ approach

Master of Science Thesis in the Master Degree Programme, Production Engineering

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Cover:
The microwave transmission node, MINI-LINK TN (Ericsson, 2011)

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Abstract

Ericsson AB is a world-leading supplier of telecommunication hardware and software, with company values focusing on high quality, safety and delivery on time. As part of continuously improving production, Ericsson Sandlid has requested this thesis on the possibilities of automating the final assembly of the MINI-LINK product. Automation will be deemed viable if it contributes to higher productivity, increased quality or increased volume flexibility over the current system without compromising sustainability. By setting the wrong level of automation in a process, one or more of these parameters will be affected negatively. To assess the current situation in production and setting a framework for concept models, the DYNAMO++ methodology has been used. Coupled with methods for setting requirements and screening of concepts; three are put forward for cost estimation. By evaluating the performance of these systems in conjunction with their payback time and sustainability profile, a recommendation is presented that should guide Ericsson to a suitably automated assembly process. Analyses of the three concepts show an increase in productivity and quality at three levels of automation, with varying investment cost, volume flexibility and payback time. Based on the results, the recommendation to Ericsson AB is to incrementally invest in a semi-automated process that focuses on automating the tasks least suited for humans, proposed as concept 2 in this report. Therefore, the recommended concept automates the screw driving tasks; which leads to increased quality and decreased cost. Visualisations of all concepts are included to be helpful in understanding the concepts' functionality.

Acknowledgment

This Master Thesis report is the final part of the Chalmers Masters Programme in Production Engineering. The master thesis has been carried out during twenty weeks at Ericsson Sandlid, Borås. The Department of Product and Production Development at the Division of Production Systems at Chalmers University of Technology has supervised the thesis.

We would like to acknowledge Ericsson for their hospitality and inviting us to their factory to give us this opportunity. A special thanks to our supervisor at Ericsson, Torbjörn Dahl, who has supported us with his knowledge and experience throughout the project.

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We also want to give a special thanks to our supervisor at the Department of Product and Production Development, Tommy Fässberg. Many great discussions have arisen in our meetings and have contributed greatly in making this thesis come together as a whole. We also thank our examiner Bertil Gustafsson and also Anders Skoogh for their contribution to the project.

We hope this thesis may be of use to those who read it, it has been a learning experience.
Best regards;
Katarina Beillon & Wilhelm Wramsby
Gothenburg, June 2012

Nomenclature

CB	Control Board
DYNAMO++	Methodology used for analysing the potential for automation in an existing system.
EMW	Electro Magnetic Wave
ESD	Electrostatic discharge
HTA	Hierarchical Task Analysis, used for identifying all operations that are performed and divide them.
LoA	Level(s) of Automation
MB	Microwave Board
MINI-LINK	Product name as end customer.
Outdoor production	Production flow that produces products used outside.
Rau2, RauX	Radio Access Unit; suffix 2 and X identifies the model version.
RauCal	Radio access unit calibration
SoPI	Square of Possible Improvements
UKL	Internal definition, referring to an assembled product prior to testing.

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1. INTRODUCTION

This chapter gives the reader the background to the project and history of Ericsson, which leads to the aim of the master thesis. In order to define the frame of the project the purpose and objective, the project questions and the delimitations will be stated.

1.1 BACKGROUND

Ericsson is a communications company originating from Sweden. With a market share of 40% in wireless communications equipment, they are a main actor in pushing development forward in a still growing market.

A main part of Ericsson's business strategy lies in providing their customers with the highest quality products on the market. All products manufactured at Ericsson Sandlid are tested before they leave the facility and are functioning perfectly. Erroneous products are found and reworked, as little as possible is scrapped (Telefonaktiebolaget LM Ericsson, 2010).

Ericsson Sandlid is a manufacturing facility boasting a high level of automation in production. Over many years, the facility has gone from full manual production to a point where almost every step of production is automated for high volume products. The reason for this is not only to increase production but also technological advancements and quality demands. Every investment in automation has beforehand been deemed as economically beneficial.

The highest volume product manufactured at Ericsson Sandlid is a radio link referred to as the "MINI-LINK". It is a high volume product with high demand on customisation of hardware setup. Currently, there are over a thousand variants. Roughly estimated, 20% of variants supply 80% of total demand. Thanks to technological advancements, most of the processes involved have been automated, but not all. Among the manual assembly processes is the final assembly of MINI-LINKs. It is the last assembly step before final testing and packaging. Because it is a manual process, fault rates are slightly more common than in the automated processes. In addition, during peak order rates, temporary staff is supplied through staffing companies. Temporary staff is not as efficient as regular staff and more costly if overused.

Ericsson Sandlid has a continuous improvement policy within the entire facility and continuous work to decrease lead time and lower cost can be found throughout the entire facility. The production line has been improved along the complete flow, looking both at the ergonomic situation and the efficiency of the flow. In order to stay ahead of their competitors, it is essential that new ideas are brought to attention and thoroughly investigated.

The MINI-LINK produced at Ericsson Sandlid is currently in very high demand and expectations are even higher in the coming years. This of course gives an opportunity to increase profit. As part of this, a need has arisen to improve the final assembly of MINI-LINKs. Ericsson Sandlid has put in a lot of effort in making this assembly efficient, but has also recognised the advantage of a major step up in efficiency and quality. Even though the manual assembly continues to improve, there is an interest in automating the process in hopes of a much bigger improvement than would otherwise be possible in the long run.

Ericsson Sandlid, a successful production facility, has high demands on the payback of potential investments, both in long term and in short term. Any suggestions for investments need to be well motivated from a financial point of view in addition to being an improvement to the process.

1.2 AIM

The aim of the project is to provide Ericsson Sandlid with suggestions of viable automated cells to replace the manual assembly stations in the final assembly process. The suggestions are put forward in concept models; stating cost, quality and flexibility performance for a specified list of equipment. This is accomplished by presenting results on the topics below:

- Analysing the current system, finding key requirements and prerequisites for concept models.
- Conceiving 3 concept models, capable of replacing the current system.
- Design of layouts for the concept models, keeping load balance and product flow in mind.
- Visualising the concept models using suitable 3D environment software.
- Verifying output of the concept models with spreadsheets or discrete event simulation depending on the input parameters, or possibly another method if circumstances require it.
- Calculating profitability for all concept models.
- Assessing all concept models and finding a recommendation for Ericsson Sandlid.
-

1.3 PURPOSE

The purpose of this master thesis assignment is to give Ericsson Sandlid an opportunity for increased quality, lower production cost and higher flexibility in their final assembly of MINI-LINKs. This also gives an opportunity to take advantage of the knowledge of a master of engineering in their production line setup. Moreover, the assignment is meant to further the creative drive of the students and give insight in what it means to create and propose an automation project in large scale production.

1.4 PROJECT QUESTION

- What level of automation is most feasible to implement in final assembly of MINI-LINKs at Ericsson Sandlid, with regards to quality, cost, flexibility and production rate?

1.5 DELIMITATIONS

Due to time constraints for the project and to ensure that the report will present results that satisfy the aim and purpose, some delimitations need to be set. Possible time consuming events that are not crucial to the project are limited to take less time, or in some cases eliminated entirely. Anything not contributing to the aim of the report will be discarded in its entirety.

- The project focuses on the product assembly in the year 2013.

- The layout of the proposed solution may not exceed the area of the current layout and the RauCal equipment area.

- The design of the components may not be changed, but suggestions can be given for preparatory work.

- Only a general work hazard analysis of the automated cell will be performed.

- Time studies will only be performed if it is required for the intended result of this project. No new time studies will be made if historic data is available.

- The 3D models will be used only for visualising the automated cell and not for offline programming.

1.6 THESIS OUTLINE

The thesis has been divided into seven chapters and the outline of the thesis is described below.

Chapter	Content
1. Introduction	This chapter gives an introduction to the master thesis and quick background to the company. The Aim and the Purpose of the project will be presented and the project question will be stated. The delimitations for the project will also be presented.
2. Theory	This chapter will explain concept, terminologies and definitions that are used further on in the project and important in order to follow the reasoning during the project.
3. Method	The methods that have been used during the project will in this chapter be explained. DYNAMO++ that has been used as an overall methodology will be explained but also the additional methods that have been used.
4. Result	The results achieved during this project will be presented in this chapter. The current situation will be explained and the concepts that have been generated will also be described. The result that is presented in this chapter will be used as a basis for the analysis, discussion and conclusion.
5. Analysis and Discussion	In this chapter an analysis and discussion regarding the result will be presented but also a discussion about the methods that have been used throughout the project.
6. Conclusion	In this chapter the final conclusions brought from this project will be presented.

2. THEORY

This chapter includes theory describing concepts, terminologies and definitions that are identified to be the most important to cover all aspects in this thesis. First an introduction to automation with an explanation of different levels of automation is given. Different robot types will be described and further on task allocation will be presented describing the performance of tasks when performed by humans or machines. The rest of the chapter describes different system characteristics, cost of production, product planning and finally sustainability.

2.1 AUTOMATION

Production systems in the 21st century have become increasingly reliant on automated processes. These processes produce faster, cheaper and better than their manual counterparts. The trade-off is high demand on knowledge of the processes and programming machines, as well as high initial costs. Much consideration is put into decisions leading to a higher degree of automation (Parasuraman et al., 2000).

The term automation has many definitions, one of which is the following: “automatically controlled operation of an apparatus, a process or a system by mechanical or electronic devices that take the place of human organ of observation, decision and effort" (Sheridan, 1992). In other words, to replace human beings in environments where there is high risk to health and safety, or in tasks where humans cannot keep up with the pace of a robot. According to Hollnagel (2003), there are three main purposes of automation:

- To ensure a more precise performance of a given function, such as the self-regulating flow valve or the flying-ball governor.
- To improve the stability of performance by relieving people of repetitive and monotonous tasks, which they do very badly.
- To overcome the capacity limitations of humans when they act as control systems, thereby enabling processes to be carried out faster, more efficiently – and possibly also more safely.

Even though many companies tend to invest in either a fully automated process or a fully manual process, this may not be the best course of action (Frohm et al., 2008). There is an interaction between humans and machinery in many processes, where the task allocation between the two is a changeable factor. The division of these tasks define a level of automation (Parasuraman et al., 2000).

2.1.1 Levels of Automation

When referring to an automated process, there is some uncertainty in how the process is constructed. Which part of the process is automated? For example, are operators in charge of supervision or is this also handled by machines? To further define a process the concept of levels of automation is constructed (Frohm et al., 2008).

A production system's level of automation may be measured in many different scales. The earliest was created in 1958 by Bright and ranges from 1-17 and was limited to strictly measuring mechanical automation. Since then, many scales have emerged; each setting its own focus on either mechanical or cognitive automation, or a combination of the two (Fasth et al., 2009).

Because decisions to automate need to be very well motivated, tools have been sought for making such motivations easier. To start, a scale of one to seven is used to define levels of automation. One corresponds to the lowest form of automation (fully manual) and seven to the highest, (completely automated, no human interaction required). Levels of automation, LoA, are applied in two categories: physical and cognitive. Physical LoA reflects how parts are assembled or joined. Cognitive LoA reflects how information about the process is given and relayed. See Table 2.1 for a description of all levels of automation.

Table 2.1: Levels of Automation according to Frohm, divided between mechanical and informational level (Frohm et al., 2008).

Levels	Mechanical	Informative
1	**Totally manual** - Totally manual work, no tools are used, only the users own muscle power. E.g. The user's own muscle power	**Totally manual** - The user creates his/her own understanding of the situation and develops his/her course of action based on his/her earlier experience and knowledge. E.g. The user's earlier experience and knowledge
2	**Static hand tool** - Manual work with support of a static tool. E.g. Screwdriver	**Decision giving** - The user gets information about what to do or a proposal for how the task can be achieved. E.g. Work order
3	**Flexible hand tool** - Manual work with the support of a flexible tool. E.g. Adjustable spanner	**Teaching** - The user gets instruction about how the task can be achieved. E.g. Checklists, manuals
4	**Automated hand tool** - Manual work with the support of an automated tool. E.g. Hydraulic bolt driver	**Questioning** - The technology questions the execution, if the execution deviates from what the technology considers suitable. E.g. Verification before action
5	**Static machine/workstation** - Automatic work by a machine that is designed for a specific task. E.g. Lathe	**Supervision** - The technology calls for the users' attention, and directs it to the present task. E.g. Alarms
6	**Flexible machine/workstation** - Automatic work by a machine that can be reconfigured for different tasks. E.g. CNC machine	**Intervene** - The technology takes over and corrects the action, if the executions deviate from what the technology considers suitable. E.g. Thermostat
7	**Totally automatic** - Totally automatic work. The machine solves all deviations or problems that occur by itself. E.g. Autonomous systems	**Totally automatic** - All information and control are handled by the technology. The user is never involved. E.g. Autonomous systems

2.1.2 Definition of robot types

When automating a task, it is crucial to define the work volume and angles of the work piece. Complex work volumes will require complex articulated robots; increasing cost and demand on information regarding the process (Frohm, 2008).

An automated robot is comprised of several moveable joints. These joints either move along an axis or revolve around an axis. This defines a Prismatic joint and a Revolute joint, respectively. Combining these joints in various numbers and orders will give varying operating volumes. The volumes have varying size, maximum and minimum range and will reach the work point from different angles. Finding the appropriate configuration for specific tasks is very important, as other solutions are much less cost efficient (Maynard, 2001).

According to Maynard (2001), there are five basic configurations of joints, illustrated in Figure 2.1, that make up the majority of commercially available robots. These are shown in Figure 2.2. Additional joints are added to these if more articulation is required. The five configurations are:

- Cartesian coordinates (rectangular) configuration [PPP]
- Cylindrical configuration [RPP]
- Polar coordinates (spherical) configuration [RRP]
- Jointed-arm (articulated) configuration [RRR]
- Selective compliance assembly robot arm [RRP]

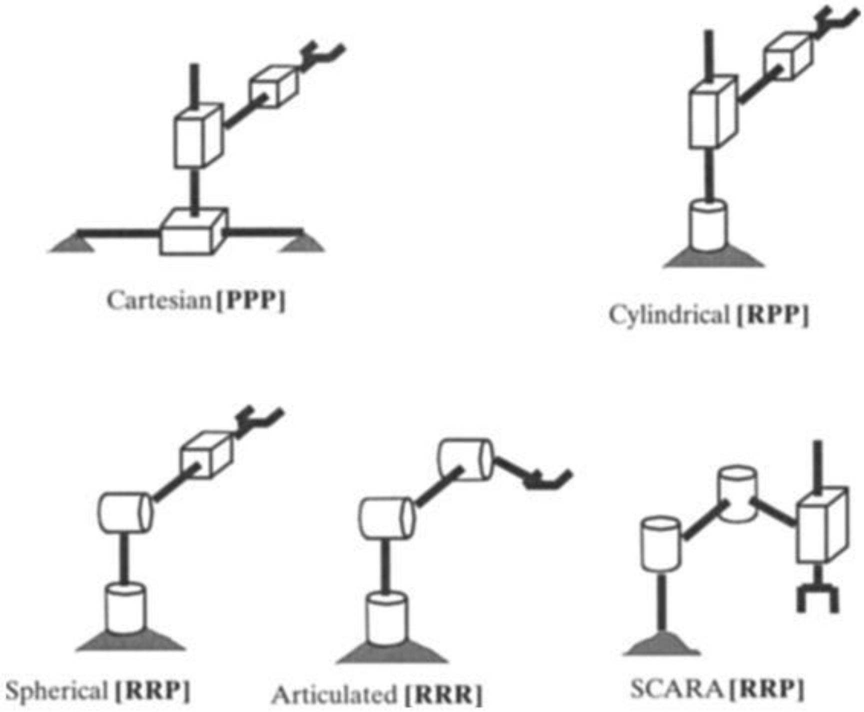


Figure 2.1: Basic robot configurations. Index R denotes a revolute joint (angular), index P denotes a prismatic joint (linear). (Maynard, 2001)

These combinations, in industry, generate the common examples shown in Figure 2.2.

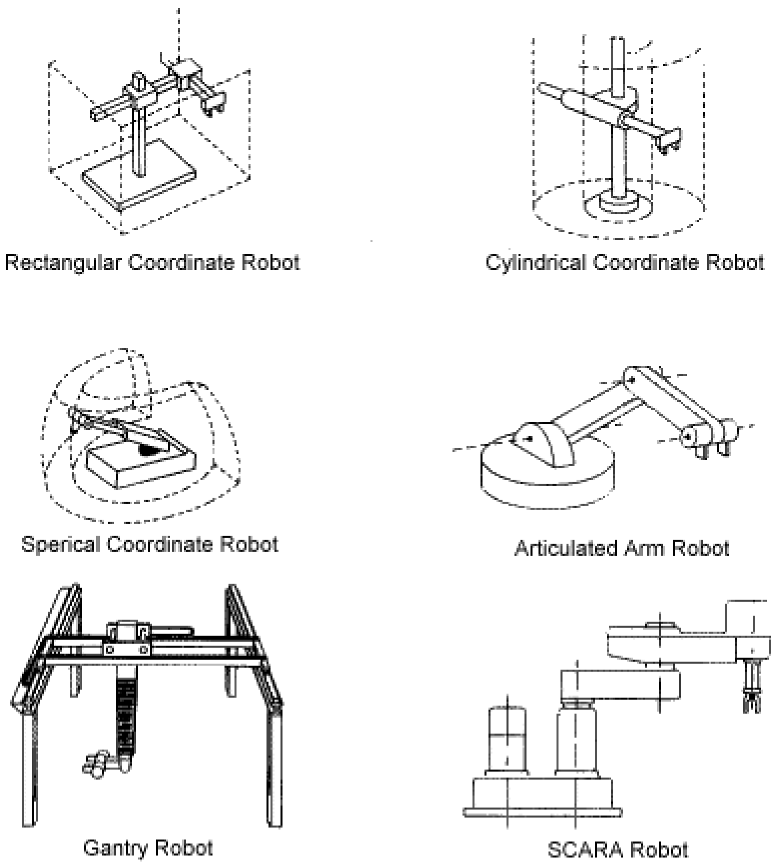


Figure 2.2: Common robot configurations in industry (OSHA.gov, 2012).

2.1.3 Task allocation

The task of automating a process isn't as simple as choosing whether to automate or not - it is about allocating tasks between humans and machines depending on what they are best suited to perform. Sheridan brought this up in 1995; "Allocate to the human the tasks best suited to humans and allocate to the automation the task best suited to it." By automating tasks where humans are inherently more suited, automation will generate more loss than gain (Endsley and Kiris, 1995).

According to Fitts (1951), the list in Table 2.2 may be compiled, known as the MABA-MABA list. The list shows strong points of humans and machines respectively. Keeping this in mind when either choosing between automated or manual work, or when designing a process, increases the chance of getting an optimised system.

Table 2.2: The MABA-MABA list (Fitts, 1951).

Men are better at:	**Machines are better at:**
Detecting small amounts of visual, auditor or chemical energy.	Responding quickly to control signals.
Perceiving patterns of light or sound.	Applying great force smoothly and precisely.
Improvising and using flexible procedures.	Storing information briefly, erasing it completely.
Storing information for long periods, and recalling appropriate parts.	Reasoning deductively.
Reasoning inductively.	Doing many complex operations at once.
Exercising judgement.	

Designing a process includes the step of allocating tasks to the resource most proficient at it. The tasks may be divided in three categories (Price, 1985):

- Category 1 - Tasks that must be allocated to the human operator.
- Category 2 - Tasks that can be performed by the operator or by automation.
- Category 3 - Tasks that must be automated.

From these categories, Price constructed a decision matrix to help find the optimum degree of automation, see Figure 2.3. The idea is that by judging the performance of tasks when performed by humans and machines, coordinates are given which may be placed in the matrix. The position of the coordinate will give a strong indication of the most suited level of automation (Price, 1985).

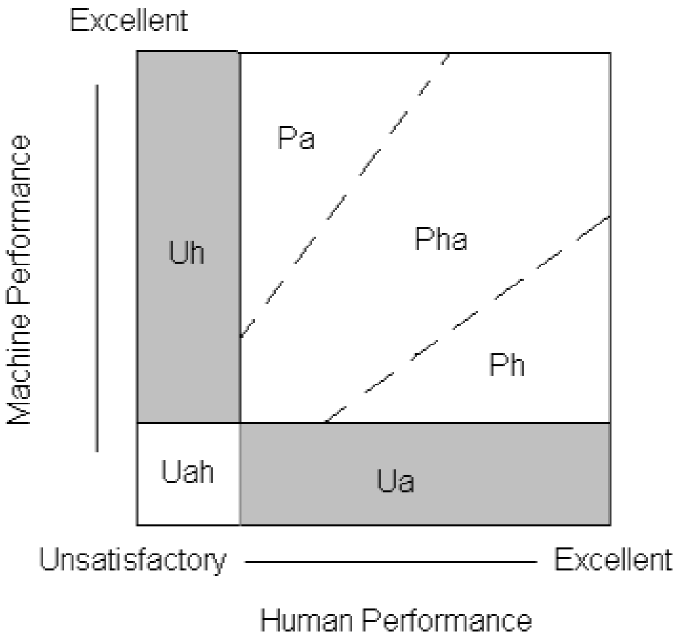


Figure 2.3: The Price Decision Matrix. Each area represents a different level of automation (Price, 1985).

The abbreviations used in the figure represent different levels of automation. Uah represents a level unsuitable for both man and machine. Uh represents unsuitable for man and the opposite Ua is unsuitable for machine. Pa represents an advantage for machine and Ph, the opposite, an advantage for man. Pha represents decisions based on other parameters (ibid).

According to Sheridan (2000), a relation may be found between the time it takes to teach a machine to do something, and the time it takes to manually perform it. This relation changes as the task complexity increases. Sheridan (2000) produced the following diagram showing this, presented in Figure 2.4.

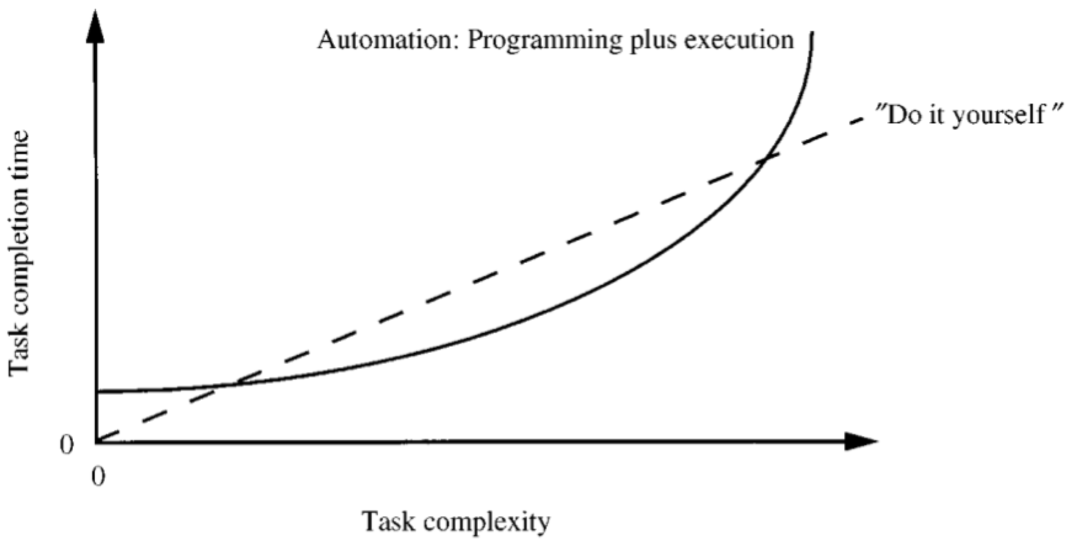


Figure 2.4: Advantages of automation for tasks of intermediate complexity. Automation becomes more time consuming for complex tasks due to programming difficultie. (Sheridan, 2000).

With increasing automation, new problems emerge. Humans, while only performing control activities, may not feel fulfilled or make errors they normally wouldn't. The mental workload transient from simple monitoring to advance technical troubleshooting may be overwhelming. Because of this fact, Sheridan (2000) suggests the use of human centred allocation. This includes 10 bullet point considerations to ensure functional human-machine integration:

1) Allocating to the human the tasks best suited to the human, allocating to the automation the tasks best suited to it.
2) Keeping the human operator in the decision and control loop.
3) Maintaining the human operator as the final authority over the automation.
4) Making the human operator's job easier, more enjoyable, or more satisfying through friendly automation.
5) Empowering or enhancing the human operator to the greatest extent possible through automation.
6) Generating trust in the automation by the human operator.
7) Giving the operator computer-based advice about everything he or she might want to know.
8) Engineering the automation to reduce human error and keep response variability to a minimum.
9) Casting the operator in the role of supervisor of subordinate automatic control system(s).
10) Achieving the best combination of human and automatic control, where best is defined by explicit system objectives.

2.2 SYSTEM CHARACTERISTICS

There are a lot of variables that affect a production system and there is no best way for producing a specific product. The circumstances have a large impact on the choice of production system. This chapter will explain important concepts and variables that need to be taken into consideration when designing a production system.

2.2.1 Measurement objectives

Performance objectives described by Slack & Lewis (2008) can be used in order to measure the performance of a system and are as follows:

- Quality
- Speed
- Dependability
- Flexibility
- Cost

The measurement objectives will shortly be described in this section.

Quality

Looking at internal quality, the potential benefits that can be achieved are; more internal reliability, error-free processes, less distribution and complexity, but also lower processing cost (Slack and Lewis, 2008). Number and defects produced and cost of quality are the issues that can be used in order to measure quality, due to the definition that quality is how well specifications are conformed. Cost of quality can be described as the cost of the effort to prevent and detect discrepancies but also the cost for disposing of, and correcting, the discrepancies (Neely et al., 1995).

Speed

Speed is used for indication of the time between two events. Looking at an assembly system, the time may be between the launching of a product and until it is leaving the final operation as a finished product. (Slack and Lewis, 2008) Below the important concepts related to the speed of an assembly system will be explained.

Cycle time

The maximum time that each workstation in a paced line has to process the work piece is, according to Scholl, defined as the cycle time. The longest operation time will set the lower limit for the cycle time. Looking at an unpaced line, the cycle time will be defined as the average of the maximum station time (Scholl, 1999).

The cycle time can, according to Wild (1995), be explained as Equation 2.1:

$$\begin{aligned} Cycle\ time &= Service\ time + Idle\ time\ or\ loss \\ &= Productive\ work\ time + Non\ productive\ time + Idle\ time\ or\ loss \end{aligned} \tag{2.1}$$

The service time can be explained as the time it takes to complete the work at a specific workstation. Normally the service time is shorter than the cycle time because the cycle time is the time available at each station for completing the work. Transportation of the work piece between stations and other movements not contributing to add value to the product is called non-productive work (Wild, 1995).

Takt time

The takt time can, according to Access Science, be defined as the rate of customer demand. When calculating the takt time the available production time is divided by the customer demand, see Equation 2.2 (Access Science, 2012).

$$Takt\ time\ = \frac{Available\ production\ time}{Custumer\ demand} \tag{2.2}$$

In other words, takt time (time spent per unit) is defined by available time in a limited period (seconds, minutes or hours) divided by demand during the same time period (number of units).

Dependability

Looking at dependability as an internal measurement objective the potential benefits can be described as higher confidence in the operation, lower processing cost and more internal stability (Slack and Lewis, 2008).

Flexibility

In order to get a good internal flexibility the system should reach better response to unpredicted events, lower processing costs but also better response to variety of activities (Slack and Lewis, 2008). Flexibility of a system can be described in many different ways and there are many different definitions of the concept. A definition stated by Sethi and Sethi (1990) reads: "Flexibility in manufacturing means being able to reconfigure manufacturing resources so as to produce efficiently different products of acceptable quality."

Cost

Cost can be seen as the most important measurement objective. The cost of production is clearly related to the price of the end product and will influence the margins. In order to positively affect the cost it is important to have a productive process and high margins (Slack and Lewis, 2008).

2.2.2 Process flow structure

One of the decisions that need to be taken into consideration when it comes to a production process is the layout. The equipment and machines used for transforming materials into a final product can be arranged in many different ways. Some characteristics of the process that is important to keep in mind when consider a layout is number of variants and production volume. According to Bellgran and Safsten (2010) there are four basic layouts of a production process:

- Fixed position
- Functional layout (process oriented)
- Batch flow (cells)
- Assembly line / line-based flow (product oriented)

Assembly line

An assembly line is a special flow-line production where a number of workstations are used in order to step by step manufacture a product. In a flow-line production the technological sequence of the operations will determine the layout and the facilities will be arranged according to this. In an assembly line the work needed in order to reach the final product is divided between different stations. The stations are often linked together with conveyor belts or similar mechanical equipment used for material handling. Assembly line balancing problems are important issues to take into consideration when designing an assembly line. It is important to balance the line which means levelling out the workload as even as possible between the stations. Using a paced assembly line will limit all workstations to performing the task in a maximum amount of time. Each workstation will then produce the same number of units in a given period at all times; fixed production rate (Scholl, 1999).

Looking at an unpaced line, the cycle time varies between stations. This will result in waiting times for products when trying to enter the next station and a buffer with work pieces will arise. At the same time, some workstations will get starved, which means the station waits for work pieces from the previous workstation to be ready (ibid).

Flow-line techniques can result in an effective production, but that requires a product variety that is small. The number of variants of the product is crucial when it comes to assembly line design. When the number of variants of a product increases the design will be more complex and it will also result in reduced operating efficiency (Wild, 1995).

An assembly line can be categorised in the following three categories depending of the product variety (Scholl, 1999):

- *Single-model line* – Large quantities of one homogenous product is produced. (See Figure 2.5 a.)
- *Mixed-model line* – Several models or versions of a basic product is produced. (See Figure 2.5 b.)
- *Multi-model line* – Different models but also different versions of the same is produced. (See Figure 2.5 c.)

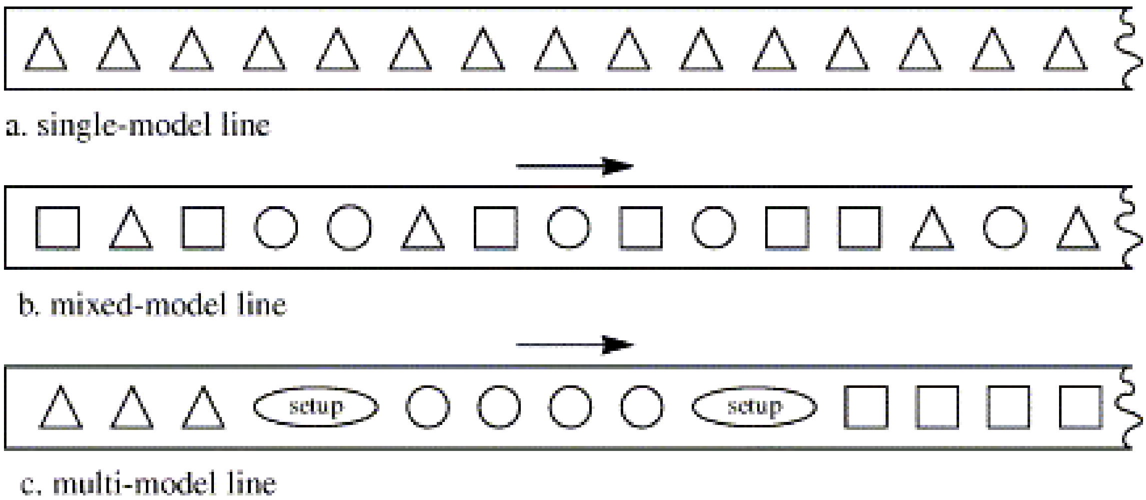


Figure 2.5: Assembly line models (Scholl,1999).

A mixed-model line has a steady flow of models in production but with some varieties in between. Theoretically this model can produce according to customer requirements without having large stocks of finished goods. But the difference between different products results in an uneven workload at the stations that further on end up with idle station time (Wild, 1995).

Using a line-base layout will result in a process that is visual, the products will be kept in the right sequence from start to a finished product and the pulse in the system will have a continuous pulse. These can be seen as the most important advantages of a line-based layout but obviously there are disadvantages as well. (Bellgran & Safsten, 2010) In Table 2.3 the advantages and disadvantages of a line-based layout according to Bellgran & Safsten, 2010 are listed.

Table 2.3: A list of the advantages and disadvantages of a line-based layout (Bellgran & Safsten, 2010).

Advantages of a line-based layout	Disadvantages of a line-based layout
Better and simpler control of process and organisation	Reduced possibilities for assemblers to control their work
Visual	Reduced variant flexibility
Space efficiency	Reduced volume flexibility
Problems become visible, provides a driving force for improvement	Increased requirement when introducing new products
More rapid learning	Reduced work content
Improved quality	More sensitive to disturbance
Improved possibilities for good ergonomics	Balance losses

Line Balance

Line balancing is a crucial problem that is important to investigate when introducing an assembly line. Normally an implementation of an assembly line is a large capital investment and need to be seen as a long-term investment. Line balancing should be used to make the line as efficient as possible by levelling out the work between the workstations (Becker and Scholl, 2003).

Dealing with line balancing at a mixed-model line is more complex than single-models lines, due to the differences between different products such as size, equipment needed for assembly and material required. It is almost impossible to find a perfect solution where regardless of which model is produced, the station times and the equipment needed is the same. A mixed-model assembly line needs to be flexible when it comes to the local cycle time at each station. It is also important that the equipment needed and the qualifications of the operators are flexible (ibid).

Looking at a specified cycle time or output rate, the standard times for each work element and other constraints; the objectives of line balancing according to Wild (1995) are:

- Minimize idle time or balancing loss
- Minimize the number of workstations
- Distribute balancing loss evenly between stations
- Avoid violating any constraints

Balancing problems for mixed-model lines can only be solved by looking at each model or product variant separately, resulting in several different single-model balancing problems. A crucial problem when balancing mixed-model lines is also the sequencing problem, which concerns the time between starting production of models and in which order the models should be produced (Wild, 1995).

2.2.3 Time Losses

It is almost impossible to achieve a perfect line balance with no losses at all. Precedence constraints influence the possibilities for dividing the work between the workstations and a line almost always end up with some balancing losses or balancing delays. Balancing losses can be defined as the difference between the cycle time and the average workstation time as a percentage of the cycle time, see Equation 2.3 (Wild, 1995):

$$Balance\ losses = \frac{C - \bar{c}}{C} * \ 100\ [\%] \tag{2.3}$$

Where C is the cycle time and $\bar{c}$ is the average workstation time. The average workstation time is the quota between total work content, $\sum t$, and the number of stations, n, see Equation 2.4 (ibid).

$$\bar{c} = \frac{\sum t}{n} \tag{2.4}$$

Balancing delay on the other hand express the difference between the total time required for finishing the job and the total time available (ibid).

Lines that involve humans will always result in a variability of service time. Looking at a machine performing a task the time required to perform the task would be constant, which is not possible when humans are involved. These losses occurring in a line with humans involved is referred to as system losses. The only way to reduce system losses is to minimize the pacing effect. Letting the worker have the work piece available for a greater time will help to reduce the system losses, due to reducing the pacing effect (ibid).

Looking at a line, the pace needs to be set in order to make the line efficient. It will not be effective to have workers waiting for the work piece to arrive from the previous workstation. One way to reduce the pacing effect is to, in some way, decouple the station. By using buffers between each workstation the stations can get less dependent to each other, but buffers also result in additional required space. The tied-up capital due to a higher work-in-progress will also be increased (ibid).

2.3 COST OF PRODUCTION

Calculating the cost of producing a specific product can be done in many ways and is commonly referred to as accounting cost. The aim is to define whether or not a product is profitable for the company. The most commonly used costing method (in Sweden) is absorption costing. Other common methods include activity based costing and standard cost accounting. These methods will yield the same result when calculating net profit for your company, but will give differing indicators for investments. The main difference is which costs to include as a recurring cost for a product line. Costs are categorised according to recurrence (initial, set cost, scaling cost) and type (overhead, management, material costs) and distributed differently for each method (Andersson, 2001).

When introducing new products or investing in equipment, the cost of the change is considered in a new absorption costing model. Looking at the differences, a payback time for the change or new product is observed, after which the investment is outweighed by increased profit or decreased cost. Many companies today only consider investments with a very short payback time, due to short product life cycles (ibid).

With absorption costing, costs are separated in direct and indirect costs. Direct costs are easily defined and assigned to the product, for example material costs, assembly labour costs and so on. Indirect costs are not easily defined for a specific product. Warehouse costs, energy costs, marketing and so on fall into this category. The indirect costs are then partially distributed to each product (ibid).

When looking at the payback of an investment, an absorption cost model is made for the before and after scenario. The payback time is the time in which the savings made from the new model outweighs the initial investment cost (ibid).

2.3.1 Cost calculations

Ericsson uses different methods for calculating manufacturing cost. One of them is hourly cost, “timtaxa”, which expresses the cost per hour, for one operator, including all costs connected to the process. The costs that are included in a business or a part of a business is for example costs for personnel, locale, support, equipment, tools and articles of consumption. Hourly cost is normally used when the business is well known and when the calculating Business Cases where the process is stable. Using cost divided by operation time can be misleading. A low hourly cost does not always mean a low production cost and a process will not be free of charge even if all operation time is removed (Liderud, 2012).

Another method for calculating the production cost is the TK-matrix (Tillverknings-kostnadsmatris – Manufacturing cost matrix). There are two different kinds of TK-matrixes, the TK-yield matrix and the new TK-matrix. The TK-yield matrix is based on the hourly cost for the process and the operation time is multiplied by the hourly cost. The new TK-matrix on the other hand calculates the process cost based on the actual cost for each cost centre. This matrix divided the cost between the amounts of products produced. Looking at a specified amount of time, the cost for the operators should be divided by the number of products produced. The cost for the equipment should in the same way be divided between the number of parts produced during a specific time period. All costs contributing to the total cost of the process need to be taken into account. The most important costs are listed below (ibid):

- *Personnel cost* – involves all costs related to the personnel, for example wages, IS/IT fee and PA service.
- *Equipment cost* – include all costs that are related to equipment; such as rental fee, write-offs and support of the equipment.
- *Technical support* – including cost for production technicians, planning etc.
- *Overhead cost* – all cost that cannot be related to any other cost centre is summarised here, for example the cost for top management and the property.

2.4 PRODUCTION PLANNING

When planning production it is important to take into consideration the expected volume that need to be produced but also the timing of the production. There are many ways of organising the production planning but in order to reach an effective system, that is competitive, it is important to utilise the capacity of the system in a good way. When scheduling the production it is important to plan the required resources and the required material in a way that secure that the customer requires is met (Anil, Kumar and Suresh, 2008).

Production lines that are producing more than one product or different product variants will result in a sequencing problem when planning. Due to the variation between the products produced, the processing times at the individual stations can differ but the material used during production can also vary. Having a known set of products that should be produced, sequencing is the determination of the best processing order. Sequencing can be used in order to minimize queuing, minimize facility idle time but also minimize the total throughput time (Wild, 1998).

Batch production is one type of organising the way the products are produced. Items are manufactured in batches instead of singly, grouping the products that are similar together. There are, according to Wild (1998), three problems that need to be investigated during planning of batch processing:

- *Batch sequencing* – Taking care of the order that the batches should be processed. In order to minimize the set-up cost it is important to take the similarities between batches into consideration and find the best sequencing order when it come to set-up times. Variants that require similar set-ups should be produced in sequence.
- *Batch size* - Determination of the quantities of products that should be produced in one batch.
- *Batch scheduling* - Determine the timing of the production of the batches trying to optimise the utilisation of the available equipment.

2.5 SUSTAINABILITY

It is clear that at the rate of consumption of resources in modern society, the Earth we live on will not be able to accommodate us forever. In order to ensure that the system does not get out of control, sustainability must be considered and implemented in any and all areas possible (Dodds and Venables, 2005).

Sustainability may be defined as the balanced interaction between Eco-centric concerns, Socio-centric concerns and Techno-centric concerns. By taking all concerns into consideration at each step of development, a balance may be kept. In the article Engineering For Sustainable Development, a guide has been prepared with the purpose of helping engineers keep sustainability in mind when constructing and designing various projects (ibid).

According to Dodds and Venables (2005) there are twelve principles of engineering that should be considered when attempting to create a sustainable process or product:

1. Look beyond your own locality and the immediate future
2. Innovate and be creative
3. Seek a balanced solution
4. Seek engagement from all stakeholders
5. Make sure you know the needs and wants
6. Plan and manage effectively
7. Give sustainability the benefit of any doubt
8. If polluters must pollute... then they must pay as well
9. Adopt a holistic, ‘cradle-to-grave’ approach
10. Do things right, having decided on the right thing to do
11. Beware cost reductions that masquerade as value engineering
12. Practice what you preach.

Designing a process or product involves many decisions throughout the product life span, many of which are made before the product actually exists. In the report Engineering For Sustainable Development, a five stage model for these decisions is put forward. The stages are more or less categorised from chronological events in the product life cycle. These stages are (ibid):

- Framing the requirements – often completed in a Feasibility Study
- Scoping the decision – often made in a Project Definition Study
- Planning and Design – decisions made in the detailed design stage
- Implementation, Delivery and Operations
- End of usable life

Applying the twelve principles of engineering may be difficult in the way of knowing when to do what. Some principles are straight out not feasible to consider in certain stages. The table in Figure 2.6 has been presented in Engineering For Sustainable Development in order to guide engineers throughout the course of a project. The importance of each principle has been rated for each applicable stage, showing the relation between the two definitions. From this the author has gathered which principles are crucial for ensuring a sustainable method throughout a full project, which principles are optional and which are not viable (ibid).

Stage: Guiding Principle:	Framing the requirements	Scoping the decision	Planning and detailed design (incl. end-of-life considerations)	Implementation, Delivery and Operations	End of usable life
1 Look beyond your own locality and the immediate future	★★★★★	★★★★★	★★★	★	★★★★★
2 Innovate and be creative	★★★★★	★★★★★	★★★	★★★	★★★★★
3 Seek a balanced solution	★★★	★★★★★	★★★		★★★★★
4 Seek to engage all stakeholders	★★★	★★★★★	★★★	★★★	★★★★★
5 Make sure you know the needs and wants	★★★★★	★★★★★	★★★	★★★★★	★★★★★
6 Plan and manage effectively		★★★	★★★★★	★★★★★	★★★
7 Give sustainability the benefit of any doubt	★★★★★	★★★★★	★★★		★★★★★
8 If polluters must pollute… then they must pay as well	★★★	★★★★★	★★★	★★★	★★★★★
9 Adopt a holistic, 'cradle-to-grave' approach	★★★★★	★★★★★	★★★		★★★★★
10 Do things right, having decided on the right thing to do		★	★★★★★	★★★★★	★★★★★
11 Beware cost cutting that masquerades as value engineering			★★★	★★★★★	
12 Practice what you preach	★★★★★	★★★★★	★★★	★★★	★★★

Figure 2.6: Characteristics of the twelve guiding principles (Dodds and Venables, 2005).

3. METHOD

To meet the goals and fulfil the purpose of this project, a well structured approach must be formed and maintained throughout the duration of the project. The project will be carried out using the DYNAMO++ work methodology in order to end up with a system model that has the right level of automation. This is important to make sure the system is not too expensive and does not underperform.

Both quantified and qualified data will be gathered if no historic data is available. Gathering methods should be based on literature supporting its viability.

3.1 DYNAMO++

Building an automated production facility is not an exact science, nor is it done by inspiration alone. There are tools available for optimising parts of the process, but very few to cover the entirety of such a project. The DYNAMO++ methodology is a structured approach to analyse an existing production system and finding the ideal levels of automation in a possible improvement. It was first mentioned in its current form by Granell in 2007 and is based on the 7 levels of mechanical and cognitive automation defined by Frohm. Observations are made and measurements are done in order to assess the current system and its theoretical limits, both towards manual labour and towards fully autonomous systems. The end result is a solution space in which to find system concepts. Analysis of the solution space will point you in the direction of an optimised system. However, additional thought needs to be put into measuring and using performance system attributes in order to find a truly optimised system (Frohm, 2008). Figure 3.7 illustrate the DYNAMO++ methodology and how the steps that is included in this project is related to the different phases.

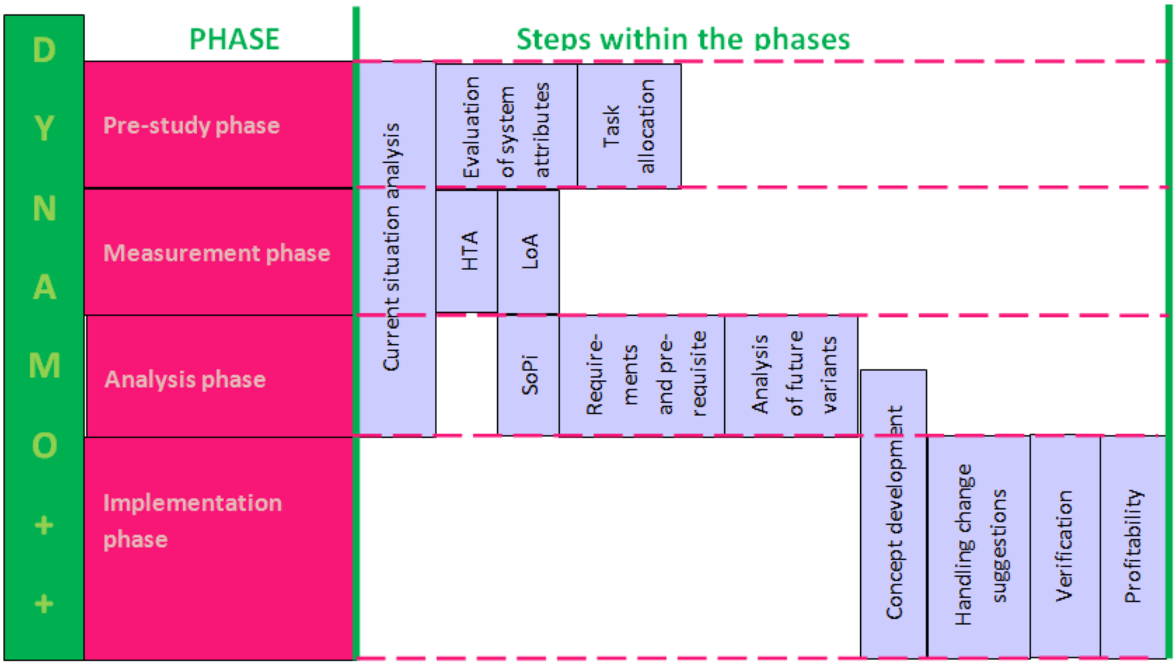


Figure 3.7: Illustration of the DYNAMO++ methodology and the steps included in the project.

3.1.1 Pre-study phase

This is the first phase of the DYNAMO++ process. This phase will be used in order to analyse the current situation and identify the triggers for change, using data collection methods and precedence map. This pre-study will be the basis for defining the requirements of the new system (Fasth et al., 2008).

In order to motivate specific changes from the LoA of the current system to a different LoA, the triggers of change need to be specified (Fasth, 2011).

Current situation analysis

The current situation analysis will involve different data collection methods including historic data, interviews and observations. In order to analyse the current situation there is a division of five different subgroups; product flow, product analysis, efficiency/waste, cost and order variance. The first step in the analysis of the current situation is to do observations in the production during two days of trial assembly. Time studies of the entire flow are available from earlier improvement work. These time studies will be used when analysing the production flow. If needed, the time studies will be complemented with further studies.

The current situation will be analysed using practical studies performed at the assembly station. An experienced operator will show all tasks performed at the station. All tasks will be explained in detail with additional information about where the material should be picked up. Because of the sensitivity for static electricity among some parts there are safety arrangements in place in order to prevent damaged of part. These are displayed to experienced and new operators alike.

The authors will gather practical experience. Step by step all tasks will be performed, with guiding from the experienced operator and the manuals for the assembly station. In time, the operations can be performed without supervision and about ten MINI-LINKs will be assembled.

The practical studies will be used in order to analyse the assembly sequence but also to identify all included components in the MINI-LINK. Just one specific frequency band will be assembled and additional observations are needed to catch the differences between different frequency groups.

A deeper analysis of the product is essential to the project and to set up requirements and prerequisites for the automated cell. Unstructured interviews with the operators and the design department will be made. Exploded views of the product, data sheets and product schematics will be used together to map up the product specifications. The limitations for the assembly sequence that is set by the design of the product will be visualised using a precedence map. This will be described further on in this chapter. The precedence constrains will be based on the product analysis together with assembly instructions and observations.

Efficiency and waste within the assembly station will be analysed using interviews and observations during the two days of trial assembly. If available, historic data of efficiency will be used.

The quality issue will be investigated using observations but it is also important to catch problems occurring less frequently which makes interviews of operators a good choice. In this project the focus will be on quality problems occurring during the assembly of the MINI-LINK and problems due to bad quality on included parts will not be analysed further.

Calculations of the cost of assembly in the current situation need to be made in order to make it possible to compare with the new solutions. The figures that need to be used should be collected at the financial department.

Information about the order variances will be gathered from the department where production is planned. An analysis will be made to see if there are daily or weekly trends in variance.
Knowledge about the planning system used at the facility is crucial when designing a new system or re design the current system. Information will be gathered from the planning division at Ericsson.

Data collection methods

There are several different methods for gathering data that will be used during this project. Methods including observations, interviews, questionnaires, focus groups and written documents can be used separately or as complements to each other. The methods will be explained in this section.

There are two main types of data; qualitative and quantitative. Quantitative data are easily measured in units, while qualitative data needs to be processed and categorised to be of use. There are advantages and disadvantages of both; quantitative data is considered to be more objective, while qualitative data is more subjective. On the other hand, quantitative data may easily dismiss correlations between variables not explicitly considered. Qualitative data always has a possibility to uncover unforeseen variables, which may then be put forward as newly discovered correlations (Silverman, 2006).

While engineers, due to the ease of processing numbers, generally prefer quantitative data there are some relevant critiques to quantitative methods that need to be considered on a case-to-case basis before deciding to use it. The following five criticisms are put forward by Silverman (2006):

1. Quantitative research can amount to a 'quick fix', involving little or no contact with people or the 'field'.
2. Statistical correlations may be based upon 'variables' that, in the context of naturally occurring interaction, are arbitrarily defined.
3. After-the-fact speculation about the meaning of correlations can involve the very common-sense processes of reasoning that science tries to avoid.
4. The pursuit of 'measurable' phenomena can mean that unperceived values deep into research by simply taking on board highly problematic and unreliable concepts such as 'discrimination' or 'empathy'.
5. While it is important to test hypotheses, a purely statistical logic can make the development of hypotheses a trivial matter and fail to help in generating hypotheses from data.

Observations

Observation is a method used to get an understanding for the process that is observed. It is an objective method that can be carried out without affecting the ongoing process. Observing operators at a working station makes it possible to catch the actual behaviours without interruption for measurement or questions. This can be seen as an advantage of the method. It is also an advantage that it is possible to catch behaviours that are outside the instructions and behaviours that the operators themselves are not aware of (Bohgard et al., 2009).

An observation can be systematic or unsystematic. Doing a systematic observation means that there is a specified scheduled that is followed during the observation. Compare to an unsystematic observation where the observer does not look for something special but rather documents everything of interest. The unsystematic observation is commonly used early in a project where the knowledge of the process is limited (ibid).

Using observations will not result in information about underlying factors why operators act as they do and this can be seen as a disadvantage, but can be complemented using other data collection methods. Another disadvantage can be the fact that people act differently when someone is observing them (ibid).

Interviews

Interview is a subjective method used for gathering users' opinions. The method can be used in many different situations and can result in both qualitative and quantitative data. An interview can be structured, semi-structured or unstructured and depending on the choice of structure the data will be quantitative or qualitative respectively. For achieving qualitative data an unstructured interview should be chosen and a structured method should be chosen if quantitative data is preferred. When an interview is planned it is important to carefully put together the questions and have a logical connection in between. The interview should start with an explanation of the purpose of the interview and what the result should be used for (Bohgard et al., 2009).

The advantage with interviewing is that it is a flexible method that can be used to gather information about what people think and feel. It is also a great advantage that if an answer is vague the interviewer can ask for further explanations, which results in fewer misunderstandings. At the same time, it is a disadvantage that the interviewer can affect the answer by the way the questions is presented and formulated. It is also possible that the respondent tells the answer that they think the interviewer wants to hear. This can make the result misleading and the method should preferably be used with a complementation from another data collection method (ibid).

Questionnaires

Questionnaires are similar to a structured interview but without the personal contact. Questions are summaries in a form where the respondent is writing down the answer. It is very important that the questions are well formulated in order to get the best result. When creating a questionnaire, a pilot study should preferably be done. By using a smaller amount of people answering the questionnaire it is possible to evaluate if the questions are understandable and also if the answers are as expected. Otherwise the questions have to be formulated in another way or further explanations need to be done in order to secure that the information the questionnaire delivers is correct (Bohgard et al., 2009).

This method is economical when data should be gathered from a large amount of people. It is also an advantage that all people participating will get the same information. Using anonymous questionnaires can result in answers that are hard to get otherwise. But at the same time there are some disadvantages with questionnaires as well. It is hard to get people to answer the questionnaires and there are almost always some dropouts. It is important to always analyse the number of dropouts in order to achieve an accurate result where even the extreme values are represented. Another disadvantage is the risk of misunderstanding the questions, which can result in incorrect answers (ibid).

Focus groups and Workshops

Focus group can be described as a group interview, with a group of 6 to 10 persons. There should also always be a moderator that should lead the discussion. Using people with different experience makes it possible to get a good result even if just a few persons are contributing. People can also inspire each other to be creative. Preferably a loose structure should be used in order to encourage people to be spontaneous and creative (Bohgard et al., 2009).

A great advantage with this method is that it can be more economical compared to interviews. But at the same time a disadvantage with focus groups is that dominant people will contribute more to the result than people that are less dominant. In order to make the distribution more even it is important that the discussion leader help all participants to express their opinions (ibid).

A workshop is similar to focus groups and normally involves both talking and doing but also making. The persons that are participating at the workshop allows being creative using different channels to express their opinions and ides (Westerlund, 2007).

Written documents

Data collection can also be gathered using manuals and instructions for the process. The manuals and instructions can provide information about the sequence of tasks that is performed. System manufacturers, management, training personnel and operators can help provide this information (Bohgard et al., 2009).

Background information needed for the study can be gathered from literature studies. Literature studies can be performed using books, articles, checklists, standards and guidelines within relevant areas. Literature studies can be used to get knowledge within the project area (ibid).

Precedence map

The precedence constraints for an assembly station are the fact that operations that should be performed at a station need to be performed in a certain order. It is the design of the product that puts limitations to the assembly order. In order to visualise the relationship between the different operations a precedence graph is constructed, also called precedence diagram or map. An operation is represented by a node and all nodes are connected to each other showing the required order for the operations. A precedence diagram will be constructed during the current situation analysis in order to understand the precedence constraints for the assembly situation (Scholl, 1999).

Evaluation of system attributes

System attributes connected to the outdoor production will be identified and analysed. The outdoor production is the production where products that will be used outside are produced. The trigger for change identified for Ericsson will be used to elaborate the system attributes. A questionnaire will be set up and used to collect information about how the system attribute relate to each other. The method that will be used is pair-wise comparison between the system attributes. This method result in a matrix showing the importance of each criteria but also the utility of each criteria compared with all the other. This method can be helpful during a decision-making process (Deng, 1999).

The method will be used during the design of the concept in order to assigning weights to system attributes. Two and two they will be prioritised against each other having the outdoor production in mind. The answers will be summarised in a matrix presenting the weighted importance and a ranking of the criteria. The questionnaire will be answered by a group of people having different background and functions at Ericsson.

Task allocation

Deciding on a level of automation can be very difficult, as there are so many options and there are downsides to over and under automation alike. This is mostly because decisions are based on qualitative criteria. By combining LoA and the Price decision matrix, the result is a quantified criteria placed in a qualitative criteria scheme. The advantage of this is the objectivity gained in most quantifiable methods (Liu et al., 2011).

The main task is for experts to evaluate system attributes pair-wise and comparing the scores, finding a weighted importance value of each indicator. Afterwards, each system attribute is scored individually, assessing the performance of a fully automated task versus a fully manual task. This in turn will return a weighted importance value for the levels of automation, for each system attribute (ibid).

Next, consider each system attribute as a point in the Price Decision Matrix. The weighted importance value for automation will become the Y axis coordinate for the point, and the weighted importance value for manual work will become the X axis coordinate. This will give the optimised position in the Price Decision Matrix for this specific task (ibid).

To find the optimised position of the point when considering the entire automated process, one must also weigh in the weighted importance value of the system attribute. Because the sum of the two coordinates is always one, the point is only able to move along a line (ibid).

This may be performed on each task individually, or on the system as a whole by finding the average of all the presented coordinates. By placing this averaged point in the Price Decision Matrix, you are presented with an optimised system state based on quantifiable methods (ibid).

3.1.2 Measurement phase

The second phase in the DYNAMO++ methodology is the measurement phase. In this phase the current level of automation in the system will be measured and calculated. An HTA analysis will be used in order to break down the assembly situation into different operations and tasks. The level of automation will be defined for the identified tasks. Time studies are used for all the tasks. The last step in the measurement phase is to document the results (Fasth et al., 2008).

Hierarchical Task Analysis, HTA

Using a hierarchical task analysis, HTA, will help getting an understanding of the assembly situation and all the steps included. The analysis will result in a detailed and structured description of the tasks (Embrey, 2000). The information needed will be collect during practical studies at the workstation and in addition to that - manuals, old documented time studies and observations will be used.

The first step in the analysis is to identify the overall operations that are carried out. These operations will later on be divided into subgroups and if necessary, the subgroups will be divided into additional subgroups (ibid). The information needed for this analysis will be gathered using observations of operators working at the assembly station, observations during the two days trail and written documents and manuals. The result of the analysis will be visualised in a tree diagram or, alternatively, in a table. In Figure 3.8 an example of an HTA is shown, analysing making a cup of tea.

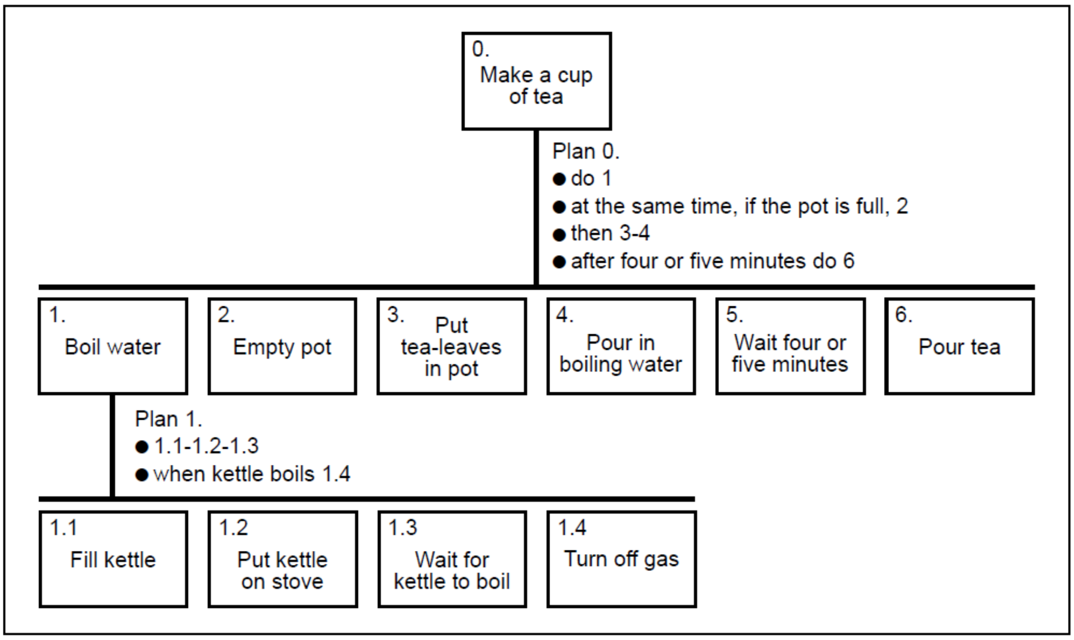


Figure 3.8: Example of hierarchical task analysis (Dix, 1994).

Levels of Automation, LoA

The definition of Levels of Automation, LoA, for Frohms scale reads: "The allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging from totally manual to totally automatic"(Fasth et al., 2009). The possible solutions of LoA when looking at an assembly tasks is described in Figure 3.9.

The LoA of the system at Ericsson Sandlid will be evaluated according to the 7 degree scales of mechanical and cognitive automation created by Frohm. All the tasks that have been identified in the HTA analysis will be taken into consideration when evaluating the level of automation.

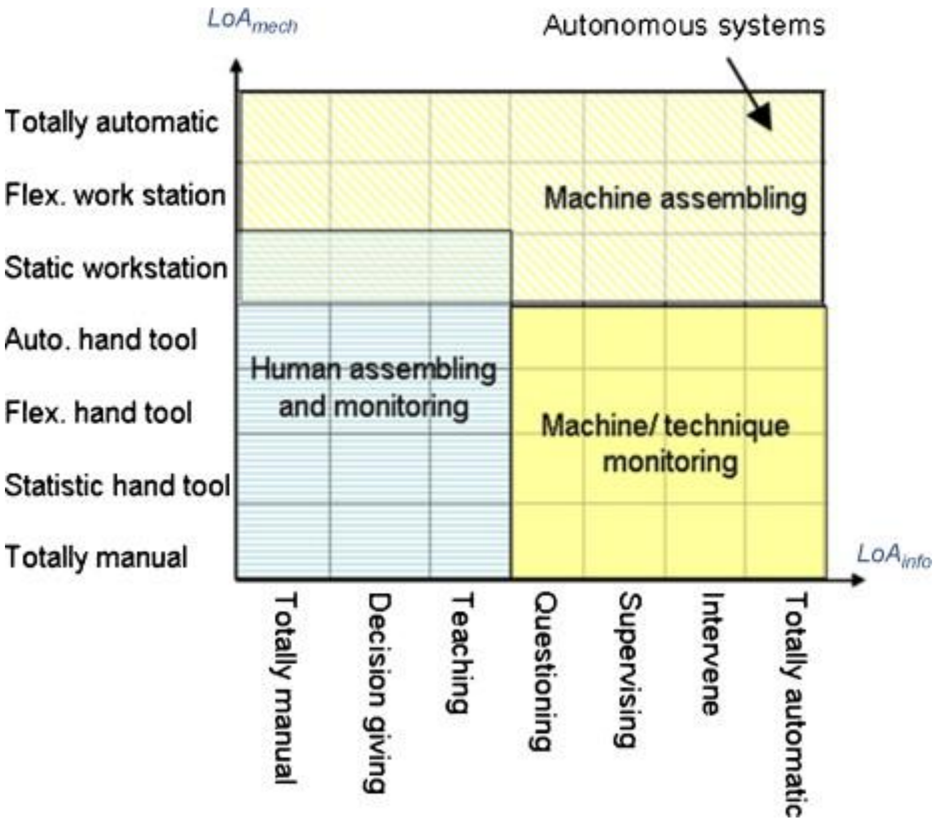


Figure 3.9: A visualisation of the 7 degree scale of mechanical and cognitive automation (Dencker, 2009).

Time studies

In order to get a deeper knowledge about the task that is included in the assembly station a time study will be used. The time study will be used as a complement to the HTA. According to the delimitations no new time studies will be done if a time suited have been performed earlier and still have relevance.

3.1.3 Analysis phase

In the third phase, possible improvement areas will be defined using the Square of Possible Improvements tool, SoPI. Within these improvement areas, conditions can be set for the coming concept models by giving an indication where to set the Level of Automation (Fasth et al., 2008).

In addition, requirements and prerequisites for the concept models will be very well defined during this phase based on data of the current and future production.

Square of Possible Improvements, SoPI

The Square of Possible Improvements is a tool used for giving an indication of where to set the level of automation for specific operations and tasks. Using information gathered from workshops with the staff, the maximum and minimum automation levels for the operations and tasks will be defined. Technical restrictions, quality issues and costs of the solutions are the facts that will contribute to this specific area. The SoPI is the area where these automation levels coincide. An example of Square of Possible Improvements analysis is presented in Figure 3.10.

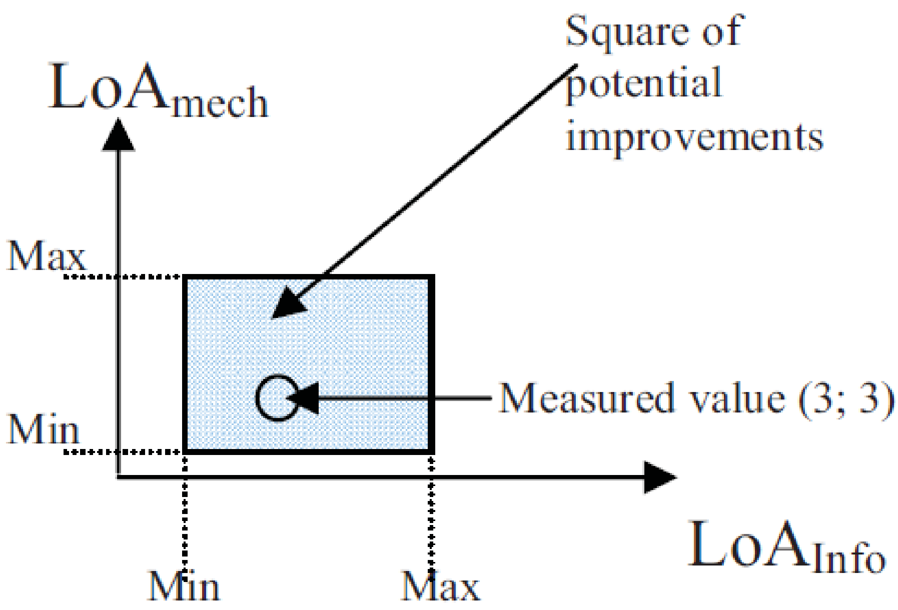


Figure 3.10: An example of a Square of Possible Improvement analysis (Fasth et al., 2007).

Requirements and prerequisites

Before models can be conceived, a thorough list of requirements and prerequisites must be compiled. A more thorough list will give a more viable model. If prerequisites or requirements differ substantially in the year 2013, these may be taken into account up during the time allocated for this step. The requirements and prerequisites set here will be set in stone for the remainder of the project. They have been defined based on documentations, interviews and forecasts.

Analysis of future variants

Since the models conceived need to be viable in 2013, some data needs to be gathered on the future variants of the product. Hopefully there will be fewer variants and this should be considered to ensure cost efficiency in the model. Data will be gathered through interviews from various sources working with product development. As with the previous step, once the allocated time is over, this data will be set in stone and not investigated further.

3.1.4 Implementation phase

The Implementation phase is where the new solution is designed and implemented. Implementation of the new concept will not be possible during this project, but the concept models will be put against each other as well as the current situation, to compare the profitability of the investment. There will also be a verification step, where a few contending models will be verified to make sure all requirements are met (Fasth et al., 2008).

Concept development

The concept development will include different methods and steps in order to end up with three final concepts. The information gathered from the previous phases will be used when the design concept will be generated. The SoPI will be used as a guideline indicating what level of automation the generated concept should aim for. During the development of the concept the first step is to define the categories that will be used during the development process. Further on concepts will be generated and the ones that least fulfil the criteria will be eliminated. These can later be designed in detail. Finally they can be compared to each other and a winning concept can be pointed out. Methods that will be used are often included in product development but here they will be applied to the production development process. Johannesson et al. (2004) presents a figure by Ulrich and Eppinger that visualise the concept development process, see Figure 3.11.

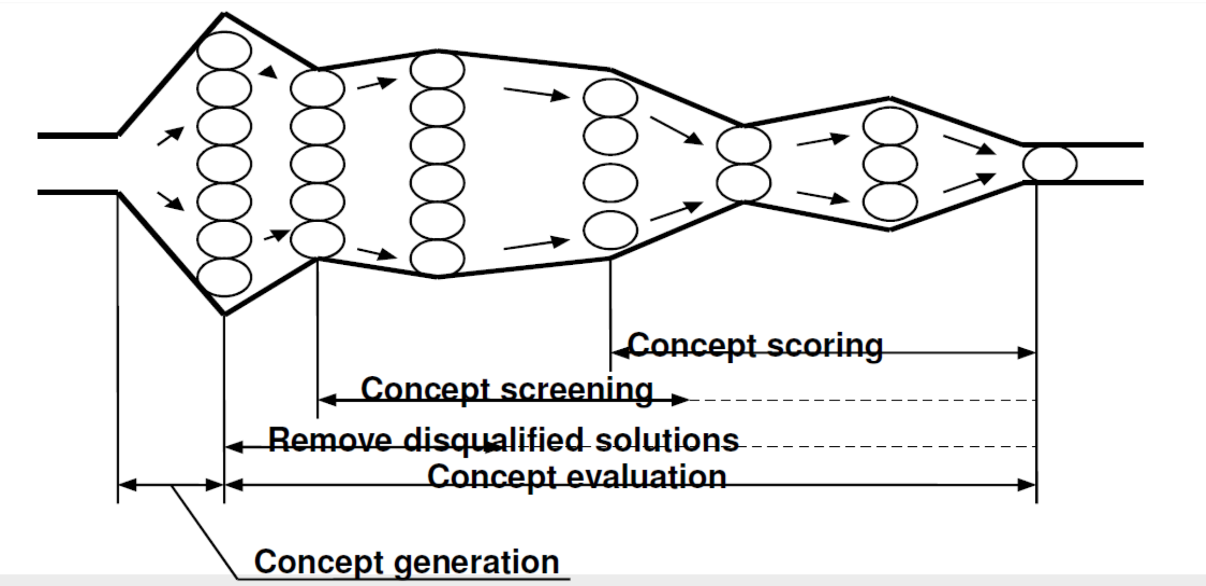


Figure 3.11: The concept development process according to Ulrich and Eppinger (Johannesson et al., 2004).

Concept categories

The limitations in levels of automation generated from the SoPI will be used in the first step of the concept generation. The SoPI suggest a frame indicating where the concept solutions are placed based on the level of automation. Keeping this in mind, three concepts will be developed with different levels of automation within the SoPI. Three different categories are chosen to be investigated further and they should be placed in different regions of the SoPI. They will be treated separately and concepts will be generated looking at one category at the time.

As mentioned in the theory chapter a flow line assembly can result in an effective production but it is to prefer a product variety that is small. Looking at the assembly of the MINI-LINK the variety between the products is small and the flow line assembly will be chosen as one of the categories that should be looked into. The assembly of the MINI-LINK has been identified to correspond to a mixed-model assembly line. The level of automation chosen at the assembly line will be stated according to the SoPI and depending on where the other categories will be placed.

Concept generation

The way the concept will be generated for the different categories will be presented in this chapter. Category two and three will be treated in the same way.

Category 1

During development of this concept the line balancing problem for mixed-models will be used, described in section 2. The operations performed during the assembly will be grouped together in order to level out the workload between the stations, but also to try to aim for the desired cycle time. The cycle time will be calculated based on the volume that is needed to be produced.

The grouping of operations will be stated during a workshop together with technicians selling automated systems. When the operations have been divided between stations there will be another workshop together with the same persons and each station will be investigated and a technical solution for each of the station will be stated. Type of robot will be chosen looking at the reachability of the robot, based on the theory chapter describing different robot types. The required reachability will be compared with the robot specification and the final solution will be the most cost efficient robot that can meet the requirements. The transport between the solutions will also be discussed during the workshop but even the material support will be investigated. The basic solution for this concept is generated from the workshops and will be putting forward directly to the detail design development.

Category 2 and 3

The other two categories that will be elected for further investigation will be based on the outcome of the SoPI. When the category is stated a brainstorming session will be used to generate concept within the categories. During a brainstorming session the participants generates ideas within a given area. The problem that should be solved during the session should be presented for the participants in advance and the problem is encouraged to think through before the session. It is forbidden to criticise ideas and the participants should strive for as many ideas as possible. The ideas should be documented using sketches and short descriptions. A brainstorming session that is longer than 45-60 minutes is not to prefer (Johannesson et al., 2004).

Concept elimination

The categories that end up with more than one concept will need a method for elimination of concepts that least fits the criteria. In this step a Pugh decision matrix will be used, this is the concept screening phase in Figure 3.11. This method is based on relative comparison between concepts looking at different criteria. It is important to focus on the problem that the system should solve. A matrix is used where the criteria and the concept is stated. One of the criteria should be used as a reference and in this case it will be the current situation. It is important that the knowledge about the reference is good which makes the current situation a perfect choice. All concepts is compared with the reference and by define if the concept satisfy the criteria better (+), the same (0) or less (-) a total score on the concept can be generated. The total score will be calculated looking at each sum of the ratings (-, 0, +) but also the net value of the total rating on each concept. Looking at the net value for each concept a ranking of the concept can be presented. It is important to also look at the distribution of the rating; even if the net value is the same the distribution can look totally different. A concept having only 0 have the same net value as a concept having equal - and +, which also need to be taken into consideration (Johannesson et al., 2004). The winning concept will be put forward to the next step where a detailed design will be produced.

During this step the requirements and prerequisites that have been set up during the previous phases will be taken into considerations. The concept needs to fulfil this or at least have potential to fulfil the requirements and prerequisites in order to put it forward into the next step, the detailed concept design. Requirements and prerequisites that have potential can for example be the volume, where the capacity of the solution can be adjust by duplication.

Detailed concept design

The winning concepts within the three different categories will in this step be designed in detail. 2D sketches will be generated and technical description on each concept will be described. 3D models will be created for the concept models that are deemed viable enough to go to the verification stage. The 3D models will later be used as a visual aid for the employees at Ericsson Sandlid to help understand the concepts and show progress in the project very clearly. The detailed concepts will then be sent to companies delivering automated systems in order to get a price indicator.

Evaluation of concepts

The system attributes defined in the pre-study phase will be used during the evaluation of the concepts. The Kesselring matrix will be used to compare the final solutions against each other and rank them, in Figure 3.11 this can be seen as the concept scoring phase. This method includes criteria that are weighted but they should also have a defined grading scale. The criteria is defined and weighted in the pre-study phase under evaluation of system attributes. The concept will be stated in a matrix together with an ideal concept that is given the highest grade. Each concept will be graded by how well they achieve the different criteria and the score will be inserted in a matrix. The grade will then be multiplied with the weight on each criteria. A total score for each concept will further on be generated. The ideal concept will get the possible highest score and the other concepts score can then be compared with this and a ranking can be generated. When the ranking is stated it is important to take into consideration if the total score between two concepts is only differing by a small amount or if the distribution of score between criteria can be important (Johannesson et al., 2004). The result from the Kesselring matrix will be used further on together with other analysis in order to nominate the best solution.

Each concept will be pointed out in the Price decision matrix explained under Task allocation in section 3.1.1 Pre-Study Phase. The concept will be pointed out based on the automation level of the concept. Economic concerns are analysed by comparing initial and reoccurring costs of different concepts to the current system.

The concepts put forward in this thesis should be sustainable in the sense discussed earlier in the theory chapter. Environmental concerns are discussed and limited to making efforts to reduce scrap and not introduce harmful materials or processes. Social concerns are considered and analysed by including operators and managers in the design process - by setting the system attributes and form system requirements based on their feedback.

Finally a best solution can be selected using the result from the Kesselring matrix, the price decision matrix, together with a comparison of the business cases and a sustainability analysis.

Handling change suggestions

When conceiving the models, some prerequisites may be beneficial to change. Changes to incoming material flow or composition may be suggested through the report if viable. Discussions with production managers will determine which changes are viable and which are not. Non viable changes will be discarded and not considered further in the report, but the rejected idea and the reasons may be brought up.

Verification

Apart from showing the profitability of the concept models it is essential to verify their function. Depending on the complexity of incoming parameters, a suitable verification method will be selected to match the generated concept. Available tools are Excel spreadsheets or discrete event system models.

Profitability

A profitability analysis for each suggestion will be made with the help of one of the recurring suppliers of robots for Ericsson. Investment costs will be based, in part, of their cost suggestions. Financial information concerning labour costs will be collected from the financial department at Ericsson in order to do the analysis. Most calculations will be made using Ericsson standard tools, mainly TK matrices. Other calculations will be well supported with theory to prove their viability.

In order to calculate the production cost according to the new TK-matrix, described in the theory chapter, the information about the costs listed above is needed but also the production volume. In this project the new TK-matrix will be used and information about the costs will be collected from a steering document at Ericsson.

3.2 METHOD SUMMARY

The DYNAMO++ methodology will be used as a base for the project, including a pre-study phase, a measurement phase, an analysis phase and an implementing phase. The current situation will be analysed in detail looking at different categories. Information will be gathered using observations, interviews, questionnaires, focus groups and written documents. System attributes will be stated based on the triggers for change identified for Ericsson. These will further on be used when evaluating the concepts. A task allocation analysis will be done in order to identify the quantified requirements as weighted goals, setting the wanted level of automation. An HTA will be used in order to identify all task performed at the assembly. The level of automation for each task will be stated, the current level but also the minimum and maximum. These will be used to make a range for the level of automation on each task. These will then be analysed in a SoPI adding all tasks range together and where they overlap will be stated as the optimal level for the system. At this stage the knowledge about the system is good and the requirements and prerequisites for the system can be stated.

The concept development will be based on the analyses done on the current situation. The SoPI will be used as guideline for which level of automation the system should try to aim for by limiting the possible solutions. Three categories will be developed at different level of automation within the optimal area. During the concept development there are different steps that should be gone through in order to end up with a best solution. The final evaluation between concepts will be done using a Kesselring matrix, the Price decision matrix, business cases for the concept and a sustainability analysis. Finally a recommendation can be given to Ericsson.

4. RESULT

Using the methods described, over the duration of the project, large supplies of results were established. After many iterations, the results in this chapter are the final results and are the basis of the analysis and conclusion.

4.1 PRE-STUDY PHASE

During the pre-study phase the trigger for change for Ericsson has been identified. For Ericsson, a trigger for change is anything contributing to increased competitiveness with their competitors. In this case, the triggers for change are:

- Cost; possible savings in staffing and production benefited from changes.
- Quality; possible quality improvements benefited from changes.
- Flexibility; possible flexibility improvements benefited from changes.

These triggers for change are related to each other and cause a trade off situation. For example reducing the cost parameter will probably affect either the quality or the flexibility negatively. When making decisions it is important to investigate both the upside and the downside of a particular choice and find a balance between them that suits Ericsson.

4.1.1 Current situation analysis

The current situation analysis will be used as a basis for the concept that will be suggested. In order to get an accurate solution this part of the project is very important and need to be investigated in details. The parts of the current situation that is needed for this project will be described in this section divided into different categories.

Product flow

Part of the MINI-LINK production chain is the Outdoor production process. The product enters the final assembly step, then moves on to a series of tests. Erroneous products are sent to a Swap station for repair and after a following screening, the product is sent back to the start of the flow (Final Assembly). When the Outdoor production process is completed, the product is sent to a packaging process. The process flow for the MINI-LINK is illustrated in Figure 4.12.

For the final assembly process, material is supplied from a material train to storage space connected to the work area. Each operator fully assembles each product based on an incoming order. The order is displayed on a monitor at the workstation. When a product is assembled, the operator moves it to the RauCal station, where the radio is tested.

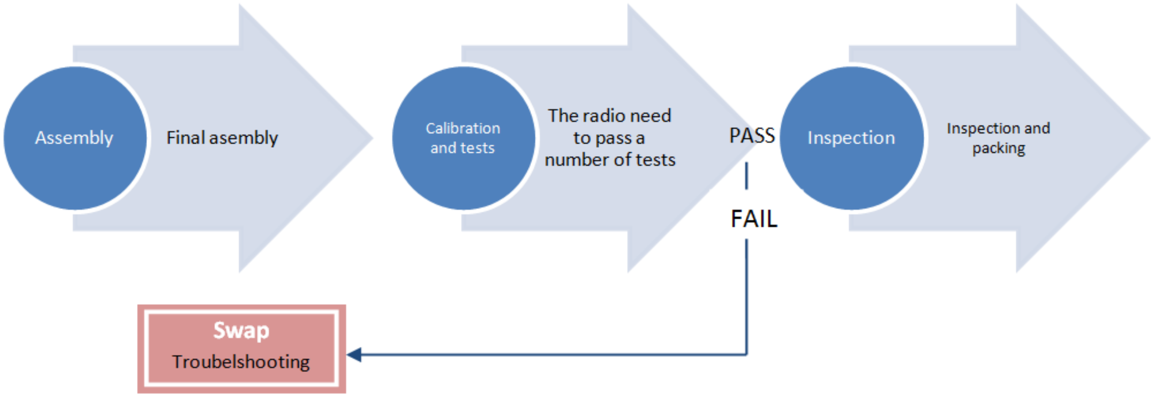


Figure 4.12: The process flow for the MINI-LINK.

Product analysis

The product assembled in this case is the MINI-LINK radio transmitter and receiver.
Each MINI-LINK consists of:

- An outer casing in two parts, see number 1 and 6 in Figure 4.13
- One hardware signal filter, see number 5 in Figure 4.13
- One microwave circuit board with EMW screen on top, see number 2 and 3 in Figure 4.13
- One control circuit board, see number 4 in Figure 4.13
- Three interconnecting cables between the control circuit board and microwave circuit board
- Two cables connecting the control circuit board to external connection ports

The outer casing comes in several slightly varying variants. The variants fit different filter sizes, but one variant may be compatible with many different filters.

The filter comes in many varying sizes and designs. Which filter is mounted depends on the customer order and corresponds to the desired signal frequency. All filters have one common width.

The microwave and control circuit boards have a common width and length, but may sometimes vary in height. The circuits vary greatly, and some circuit boards may require an additional operation before assembling it into the casing.

The cables are of varying size, length and connector types. All cables are connected from the top and sometimes protective caps are removed from the circuit boards before connecting them.

A blow up diagram showing the internal components and their placement of a MINI-LINK product can be found in Figure 4.13.

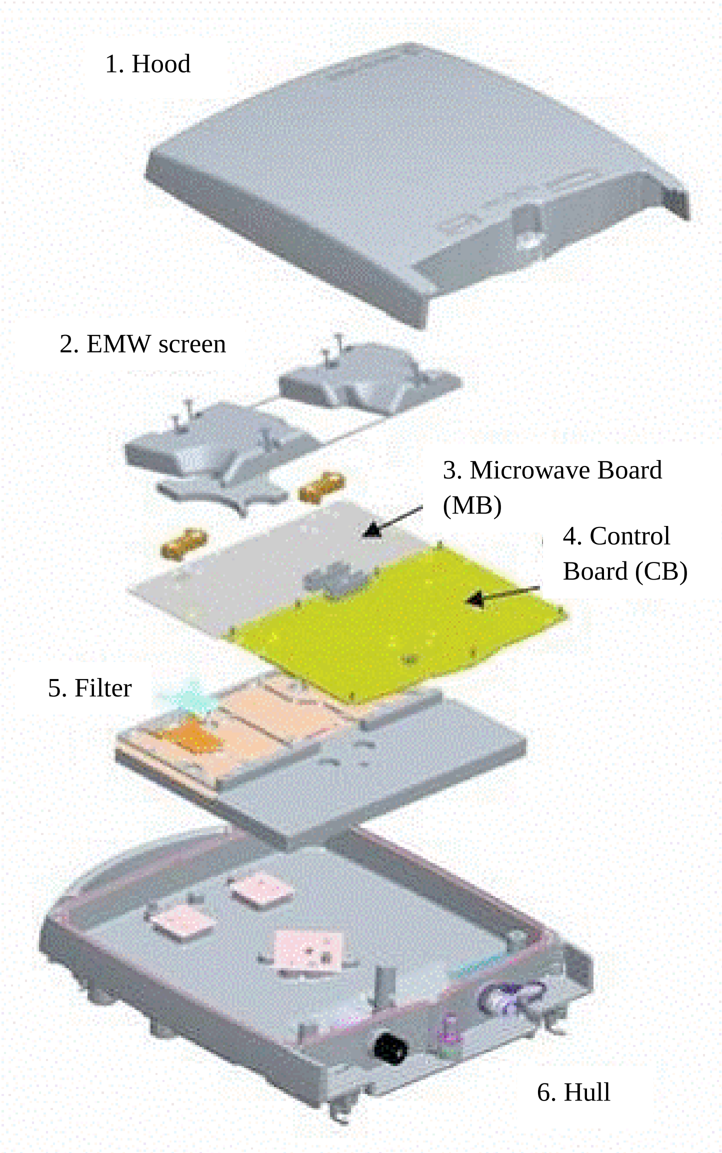


Figure 4.13: Blow up diagram of the MINI-LINK.

Rau2

The product that is produced today is called Rau2, which stands for Radio Access Unit, and 2 represent the model. The included parts in the product are described in detail below.

Filter

There are a large number of filter types available. They vary in design, dimensions and weight. The dimensions vary from about 25x25x3 cm down to 15x25x3 cm. The largest variants weigh several kilograms, the smallest weigh about one kilogram. The filter casing is made of metal and there are some rough edges left over from the cutting edges on some of the models. This varies depending on the manufacturer.

Casing

The MINI-LINK casing is composed of two parts. One bottom half and one top half, effectively making a lid for the assembled components, which are assembled onto the bottom half. The outer dimensions, when assembled, are about 30x30x10 cm. The casing consists of coated metal with a smooth surface. There is a handle on one end for carrying. There are also two cables in the bottom half of the casing that are connected to the CB card.

MB card

There are a number of MB cards available to the customer, but they vary little when it comes to dimensions. Length and width are consistently about 20x10 cm; height is about 3 mm but may vary upwards by a few millimetres. The surface of the card has sensitive components and should be handled with care but the sides are insensitive to handling. Underneath there are no components, but there should be some care taken when handling this surface.

CB card

There are only a few CB card types and they all have the same dimensions, about 20x15x0,3 cm. The surface components are sensitive to handling but the sides are not. The bottom has no components but should be handled with some care.

Coaxial cable

The coaxial cable is about 10 cm long, with a 3 mm diameter. On each end there is a round connector which will connect the two circuit boards. The connectors also have a cubic metal casing.

Flat cable

The flat cable is about 7 cm long, 5 cm wide and 2 mm thick. In both ends are rectangular connectors to connect the two circuit boards.

Gapfiller

The gapfiller is placed in between the MB card and filter. The purpose is to avoid direct contact and to act as a heat conductor. It is a flat piece of plastic with dimensions about 6x3 cm.

EMW screen

The EMW (Electro Magnetic Wave) screen is placed on top of the MB card and consists of two domes with flat tops. There is a shape for each different MB card design. The EMW screen is about 2 cm in height and matches the size of the MB card.

Labels

There are two labels that are positioned on predetermined spots of the MINI-LINK. This is done after assembly. The labels are about 3x5 cm.

Supersorb

Supersorb is a part that is included in some of the products. The supersorb can look different when it comes to size and shape. The part should be place on top of the MB card, at a certain area. The supersorb is used as a protection for the covered area.

RauX

The RauX is the next generation MINI-LINKs, very similar to the Rau2 in terms of assembly and dimensions. There have also been some design alterations to speed up assembly. Some of these changes may be carried over to the Rau2.

CB Card

The CB card of the RauX is a card with components on both sides, and the thickness is slightly different from the CB cards used in the MINI-LINKs. This means that the bottom side needs to be handled with care in addition to the top side. Also, due to the new design and thickness of the CB card, a new gapfiller component must be added to fixate the distance between CB card and filter.

Gapfiller (metal)

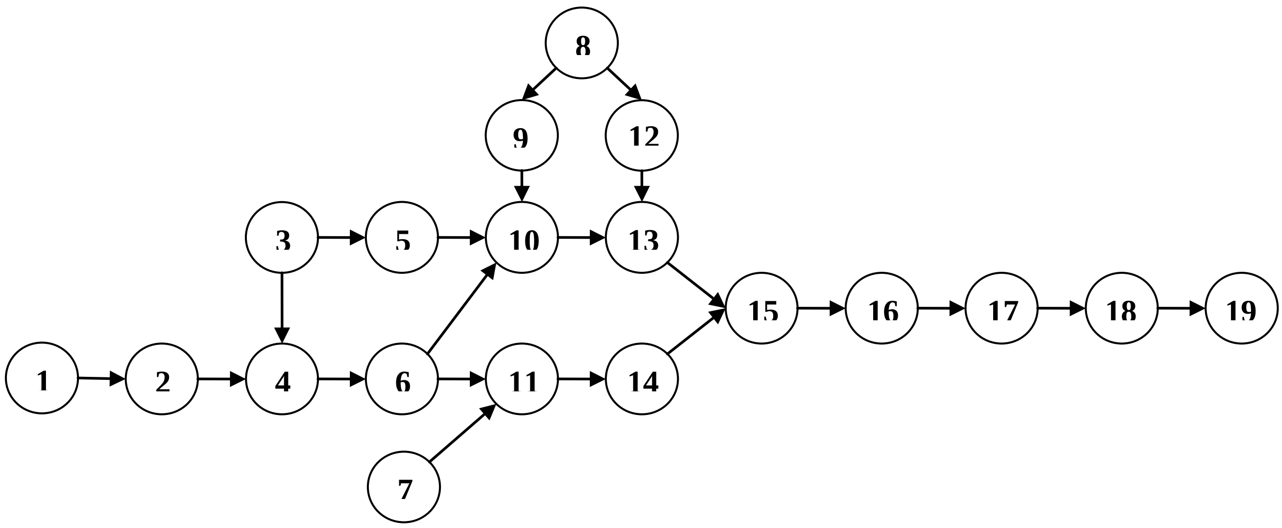
The new metal gapfiller is about 5 mm thick and has the same length as the width of a filter. The point of the gapfiller is to ensure the correct distance between the filter components and CB card. There are also holes drilled into the gapfiller so that the CB card may still be screwed onto the filter.

Cables

There are two main differences from the old MINI-LINK regarding cables. The coaxial cable contactors have a slightly different shape, and the flat cable is replaced by a band cable. With the band cable, the connectors are built into the circuit boards, and the cable is just a flexible conducting film that is inserted into the connectors. Due to new functionality, there are no longer any cables connecting the circuit boards to the casing.

Casing

The new casing is screwed together from the top instead of the bottom. This removes an assembly task compared to the MINI-LINK. The new casing also has different outgoing ports. There are a few different casings depending on the size of the filter. Inside of the top half of the casing, there are cooling pads that come into contact with a few components of the CB card.



1) Get hull
2) Place hull
3) Get filter
4) Place filter
5) Place gapfiller
6) Screw filter in place
7) Get CB
8) Get MB
9) Place subersorb
10) Place MB
11) Place CB
12) Place EMW screen
13) Screw MB and EMW screen in place
14) Screw CB in place
15) Assemble cables
16) Screw hood
17) Place label 1
18) Place label 2
19) Deliver to RauCal

Figure 4.14 Precedence map of the MINI-LINK assembly based on observations.

A precedence graph of the product assembly is constructed in Figure 4.14. From this, it is apparent that a few parts are completely independent, and some steps can be parallelised. However, most of the steps must be performed in series.

Efficiency

The efficiency of the current final assembly process can be described in more ways than one. There is a time study available at Ericsson defining a theoretical assembly time, as well as a realised takt time that includes break time used for scheduling.

Two types of efficiency can be established. The cycle time gathered in the time study is the theoretical minimum. The current takt time is considered the real assembly time.
With this system, there are days where the goal is not fulfilled. The orders are pushed and will eventually be fulfilled, but the delay costs money in additional assembly time. This efficiency is established using the production goals and actual products produced.

A clear definition of the availability for human operators is difficult to establish. The best possible definition is attained from Ericssons own calculations. The takt time in the current process is the theoretical cycle time divided by the expected availability of personnel. This availability is defined as 70%, and includes unscheduled meetings, bathroom breaks, unexpected production problems and so on. This is the availability used in calculations from here on in this report. Detailed information can be found in Appendix K.

Quality

As one of the trigger for change for Ericsson the quality issues are important to identify. Quality problems as a result of the assembly of the MINI-LINK are difficult to pinpoint, due to some problems being undetectable by the testing equipment. For example, the screwing operations can result in such quality problems. The operator use an automatic hand tool with torque control. There is no check that all screws are in place. This makes it possible for the operator to miss a screw and the differences of number of screws between the MINI-LINKs makes it even harder for the operator. This quality problem can be discovered when the MINI-LINK is moved between stations and rattles, or when it do not pass the test stations further on in the production flow. The MINI-LINKs then need to be reworked and afterwards go through the calibration and the test stations again.

Another quality problem that can occur is due to the use of ESD-protection not being used in a correct way. This can result in damaging of parts that are sensitive for static electricity.

Cost

The cost for producing at the assembly station that is used today is calculated. The cost has been calculated using the new TK-matrix based on the produced volume today. Cost for estimated volumes in the future has also been calculated in order to compare the new concept with the cost for producing the same volume manually.

Order variance

Due to the complexity of the product and the possibilities given to the customers by the technology, there is high demand on customisation. This leads to Ericsson having a large number of variants available of their MINI-LINK product. The customer may customise the MB card, the CB card and filter of each ordered product. With these customisations, there are currently over a thousand variants in production. Some of these are much more common than others, but Ericsson is currently aiming to satisfy every customer and produce all variants. Due to the large number of variants, all possible components cannot be kept in stock and buffers at all times. Production planning decides what products are assembled and this will control orders from component suppliers.

Assembly, today, is managed as a one piece flow. This means that there is, ideally, no over production. This also means that there can be a very high variance in what products are assembled each day. The main component deciding daily manufacturing goals is customer order lead time. Every order is assembled chronologically according to order date.

Even though there are many variants, the assembly and the tools required are standardised. All variants are assembled using the same tools. Some MB cards, however, require a small additional task. Due to the standardisation, the main lead time delays are caused by lack of specific components.

Planning system

SAP is the order planning system that is used at Ericsson. The production will be planned depending on customer requirements and at what date the order should be delivered. SAP communicates with the production planning system called Knallban. SAP sends information to Knallban including the products that should be produced within the following four days.

Using this information Knallban automatically generate work queues. The operator chooses one type of product within the work queue that he or she wish to assemble. Knallban will then inform the operator what material that should be used for the current product. When all material is scanned correctly the MINI-LINK will get an identity and a barcode for the individual MINI-LINK is produced. Knallban will automatically proceed in the work queue when a product is finished at the assembly station.

Knallban is communicating with a system call BarTrack, used for scanning barcodes at included parts in order to ensure that correct material will be used during assembly of the product. By scanning the barcode with a serial number BarTrack connects the parts with the individual MINI-LINK. Knallban also communicates with a system called TestNet that is used for keeping track of whether the MINI-LINKs has passed or failed at the different test stations that is in the process flow.

Knallban presents both a daily and a weekly goal that all operators have access to and easily can follow and see how well they are achieving the goal.

Evaluation of system attributes

By breaking down the triggers for change into further defined categories, the identified system attributes for the assembly situation are listed below:

- **Investment cost** - Cost of the investment
- **Maintenance cost** - Regular reoccurring cost to ensure function
- **Accuracy -** Operating within requirements and tolerances
- **Uptime -** Machine is ready to operate
- **Product Flexibility** - Possibility to reuse the machine for new products
- **Volume Flexibility** - Lower production means lower use of resources
- **Safety** - Personnel safety
- **Ease of use -** Easy to operate
- **Varied work tasks -** Avoiding repetitive work for the operator
- **Speed** - Possibility to vary production rate

A questionnaire comparing the system attributes were answered by three persons. The system attributes was compare with each other two and two and decisions should be made which one of the system attributes that find out to be most important or if they are equally important. The questionnaire can be seen in Appendix A.

The result from the questionnaire is based on answers from persons from the production department and persons from the process development department. One of the questionnaires has been answered by a former operator and technician and a former production manager. They discussed the questionnaire and answered in unison.

Comparing the system attributes against each other result in that one of the attributes is most prioritised or they are equal prioritised. Credits are given for the different answers, 1 credit stands for most prioritised and 0,5 is equal prioritising. The credits from the questionnaire are summarised in a matrix, see Table 4.4. Two questionnaires have been summarised which result in a highest credit of two.

The score for the individual system attributes will be compared against each other in order to get a percentage weight showing the utility of each criteria compared with all the other. After having the percentage weight it is possible to rank the system attributes.

Table 4.4: Result from questionnaire on pair wise comparison between system attributes presented in a matrix.

	Investment cost	**Maintenance cost**	**Accuracy**	**Uptime**	**Product Flexibility**	**Volume Flexibility**	**Safety**	**Ease of use**	**Varied work tasks**	**Speed**	**Sum**	**Sum/Tot**	**Priority**
Investment cost		0,5	0	0,5	0,5	0	0	0,5	1	0,5	3,5	3,93%	6
Maintenance cost	1,5		0,5	0	2	1	0	1	2	1	9	10,11%	3
Accuracy	2	1,5		1,5	2	2	0,5	2	2	2	15,5	17,42%	1
Uptime	1,5	2	0,5		2	1,5	1	2	2	2	14,5	16,29%	2
Product Flexibility	1,5	0	0	0		1	1	0,5	1,5	0,5	6	6,74%	5
Volume Flexibility	2	1	0	0,5	1		0,5	1	1	1	8	8,99%	4
Safety	2	2	1,5	1	1	1,5		2	2	1,5	14,5	16,29%	2
Ease of use	1,5	1	0	0	1,5	1	0		1,5	0	6,5	7,30%	5
Varied work tasks	1	0	0	0	0,5	1	0	0,5		0	3	3,37%	7
Speed	1	0,5	0	0	1,5	1	0,5	2	2		8,5	9,55%	3
									Total:		89	100%	

According to the analysis; the accuracy is nominated as the most important system attribute, but not even one percentage point behind is uptime and safety. These three can be identified as the most significant system attributes. The lowest percentages are found in the investment cost and varied work task. The results of these weighted system attributes are a great indicator of what Ericsson is prioritising in production processes.

Task Allocation

By using the method described in section 3.1.3, this result gives a quantitative indicator of what the ideal system characteristics are when it comes to level of automation, shown in a graphic way. The result may be used in more ways than one, but the most intuitive way would be to use it as a reference point when evaluating the finished automation concepts. By inserting points in the same diagram, representing each concept, it is very easy to see which concepts are in line with what Ericsson requires. One could go so far as to say that the concept closest to the reference point is more suited than the others, but that requires good faith in the performed evaluation of system attributes. The point representing what Ericsson wants to be seen in Figure 4.15. Pa represents a part human part machine system, with an advantage towards machines. The full calculation can be found in Appendix H.

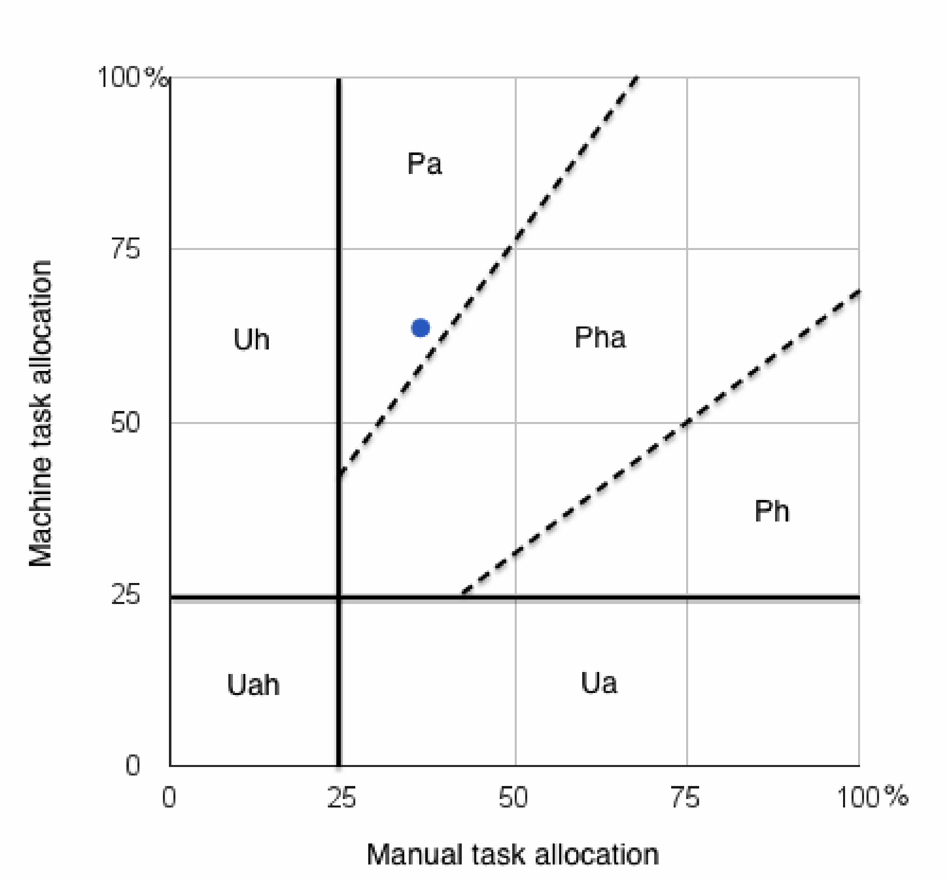


Figure 4.15: Task allocation matrix pinpointing Ericsson's requirements, in terms of human or machine dominance.

4.2 MEASUREMENT PHASE

Further investigation on the assembly station includes all operations performed. Each operation have been identified and divided into subtasks using an HTA. The current levels of automation at each task have been scored and the possible levels have also been stated. The result from these investigations will be described in the following chapter.

4.2.1 HTA

An HTA was carried out and all operations performed at the station were documented. Operations performed at the assembly station were divided into subgroups and some subgroups were also divided into additionally subgroups. This analysis gives a detailed description of the tasks performed at the station and the HTA analysis is presented with one HTA for each identified operation. The first level of operations in the HTA is described in Figure 4.16. The complete HTA can be found in Appendix B.

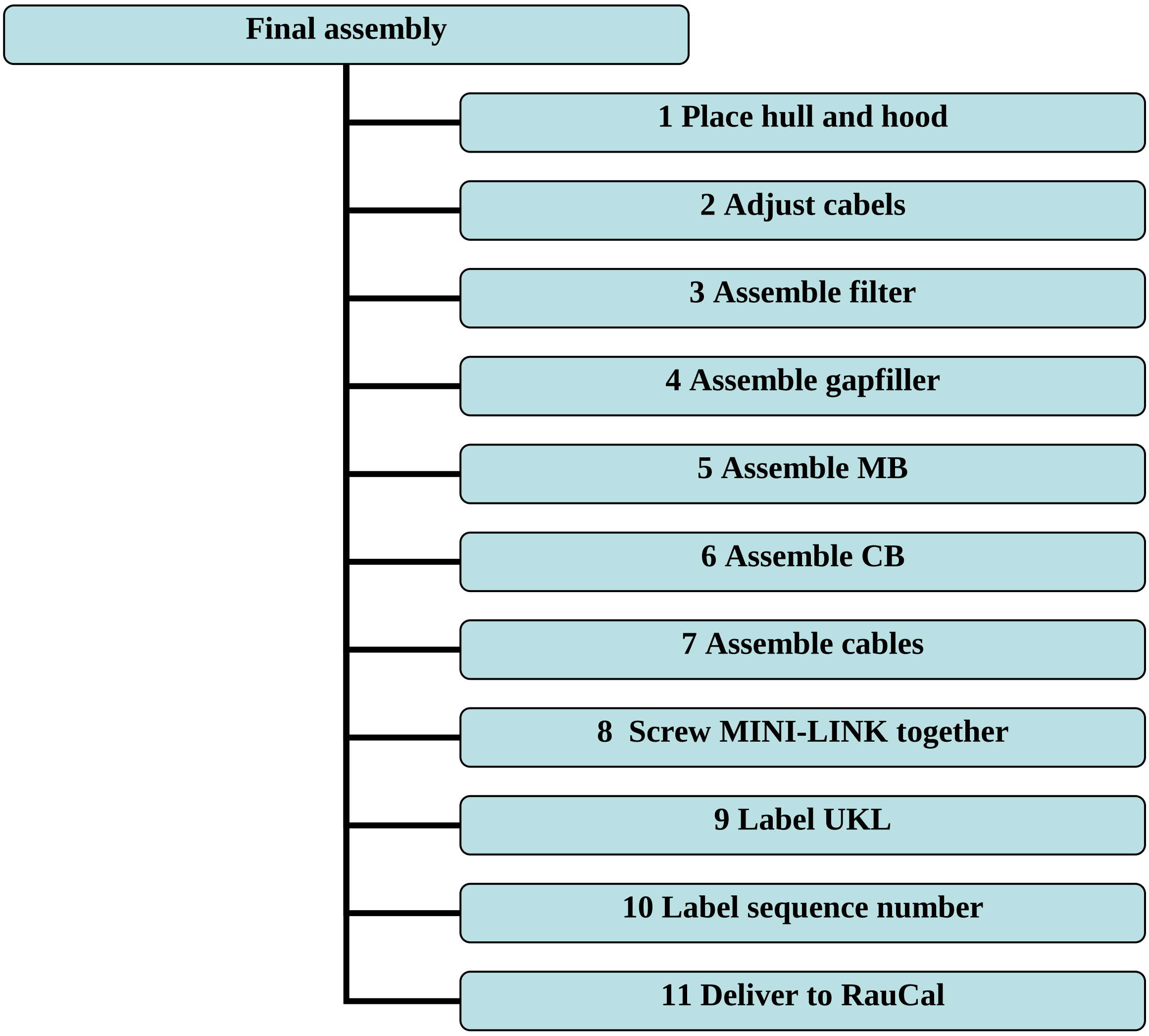


Figure 4.16: HTA of the assembly situation.

The complete assembly sequence was divided into 11 subgroups, shown in Figure 4.16. The first operation is to place the hull and the hood and further on the operations is adding parts to the hull successively until all part is mounted and the MINI-LINK is screwed together. Before the MINI-LINK can be delivered to the next station the MINI-LINK need to be labelled with two different labels.

4.2.2 LoA

A workshop was held and 3 people took part of a 1,5 hour session of discussion concerning each assembly task. The people included in the workshop have different backgrounds, including persons from the production department and persons from the process development department. The tasks discussed were identical to the ones established in the HTA. Settling on scores of the tasks was done in unison and additional comments were noted down for further consideration.

Many tasks of the process received very similar LoA scores. Most of the manual assembly is standardised and variation mainly consists of choosing the right component, contributing to an even work process. The span of the tasks was found to range from one to four in a mechanical perspective and from two to four in an informative perspective. Figure 4.17 represents a matrix visualising a summary of all LoA scores for each operations. Each individual LoA scorecard for each operation can be seen in Appendix C.

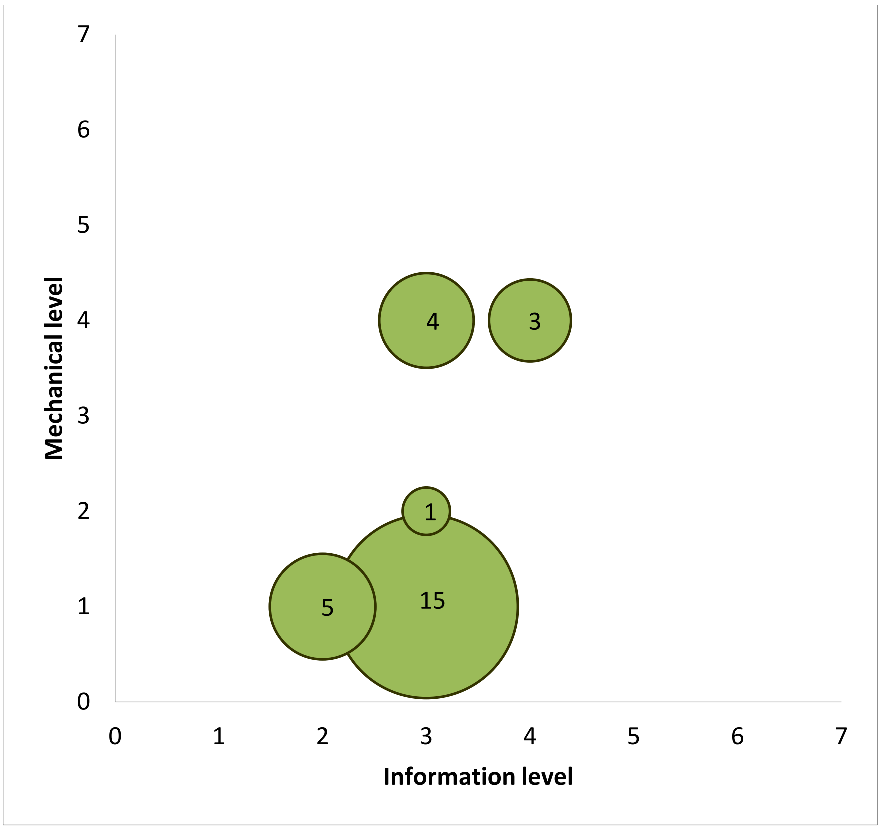


Figure 4.17: Illustrate how the current level of automation at the assembly station is distributed. The size of the circles represents the number of tasks within the specific area.

4.2.3 Time Studies

A time study at the assembly station was done in 2009 and this is deemed to be up to date. The time study is very thorough and there is no need for doing additional time studies. It has been performed using ten samples, where at least one per shift has been clocked. A mean value of the ten samples has been calculated. According to the time study the screwing operations take a large part of the total time, see Appendix D.

4.3 ANALYSIS PHASE

In this phase; the LoA scores from the previous phase have been plotted together in a matrix, visualising what the final solution should try to aim for. The construction of the requirements and prerequisites list is also an important part of the project in order to get a sufficient concept. Together with the analysis of the future variants this will end up as necessary inputs during the concept designing phase.

4.3.1 SoPI

The LoA information gathered from the workshop where analyses further. The span of such tasks was found to have a potential range from 1 to 6 in a mechanical perspective and from 1 to 5 in an informative perspective. A few cable operations may only be manageable as manual work tasks, leaving them at a mechanical 1. Some components are tracked in a specific software and need to be scanned, forcing them to be at least an informative 4. The LoA range identified for each task have been visualised in individual matrices, see Appendix E. Figure 4.18 shows an example of the range for the task 5.1 - Get MB.

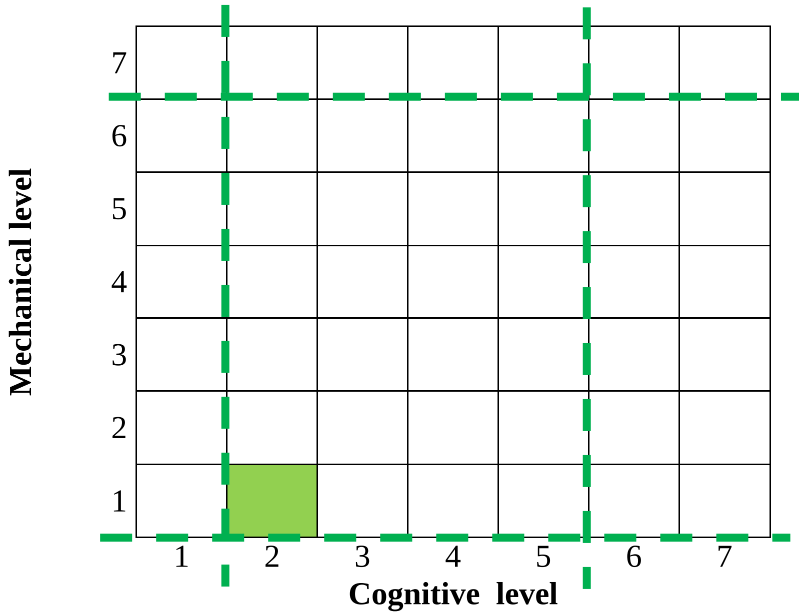


Figure 4.18: The LoA range for the task 5.1 – Get MB. Where the dotted line is the upper and lower limits and the green mark is the current level of automation. The limits are set up by technical restrictions, quality issues and cost for automation.

When putting all the matrices with the ranges in a combined SoPI, there is only a small area where all tasks, apart from cable operations, overlap. This overlap spans four to six mechanically and four to five informatively, this is illustrated in Figure 4.19. The assembly cables operation has been treated separately due to the difficulties to automate the task. Putting all operations within this overlap should provide an optimised system. Worth noting is that level 4 of mechanics still requires a full time operator.

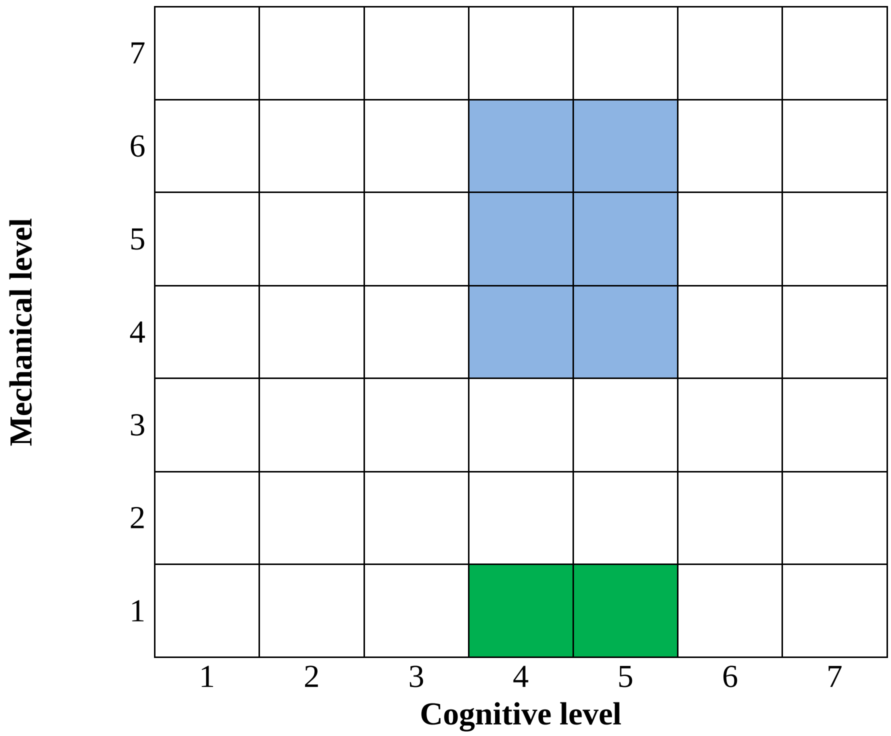


Figure 4.19: The area marked with a blue colour represents the Square of Possible Improvements. The green area represents operation 7, Assembly cables, which have been treated separately.

This analysis gives a goal of which level the future concept should aim for. This analysis will be helpful and used as a guideline during the development of new concepts. The matrix suggests an area of solutions that can be investigated further. The analysis has exposed solutions that are not needed to be investigated, due to that they are outside the overlap and the optimal zone for levels of automation.

4.3.2 Requirements and prerequisites

In order to construct a working concept model, clear requirements for the model need to be defined. The requirements must cover as many system variables as possible. They can further be complemented by setting prerequisites for the system, such as deciding some parameters regarding material handling.

Production volume

The concept model must be able to produce a forecasted amount of products per year and a forecasted amount of products per week. The peak production will be higher during shorter periods. If the system output does not correspond to forecasts, it is not feasible.

Cell area
The cell area may not exceed the area of the current manual assembly. The shape may be reconfigured but not the total area. Changing halls in the manufacturing facility is outside the scope of this project, space is already allocated.

Operators
The concept model must function with fewer operators than the current system in order to give a lower assembly cost. The goal is not to increase production rates without also lowering cost, and for obvious reasons this cannot be done without cutting expenses.

Variants
There are many product indices in production; in order to be a viable system the concept model must be able to keep track of all the components involved. Some components have barcode labelling but not all. The system must also keep track of the future product at every stage of assembly.

Quality
The quality of the finished products must equal or exceed the quality of the current system. Quality is judged by reworks caused by missing or damaged components. The final product must also be externally unscathed.

Precision
The machines must have tolerances so that no components are damaged during assembly. The assembly steps must also be fixated in such a way that the tolerances are the limiting factor.

Force
The machines should apply standardised pressure in operations where it is required, such as screwing or forceful joining of components. Applying too much force may damage components, too little may give performance issues in the product.

Finished goods
Finished goods needs to be presented in an easy-to-handle manner. Operators in the next process will make the calls on product priority and should be able to pick among a few indices. It is not allowed to influence the entire production flow in this project.

Material Handling
Automated component handling must be individually considered to avoid damaging them when not handled by human hands. Feeding material to the system must also be possible without occupying too much personnel or time.

Error Handling
The system must be able to detect assembly errors or faulty machinery and handle this by halting assembly of the product and if necessary stop the process. Clear information on errors should be available to technicians and standardised indications on where the problem occurred.

Safety
All parts of the assembly process and material handling must meet standardised requirements to ensure that no operators are in any danger even in unexpected situations. Additionally, situations where repetitive work or heavy lifting may cause long term injuries, thought will be put into how to avoid forcing these tasks on human operators.

4.3.3 Future variants

An implementation of a concept will be done not earlier that 2013. This makes the analysis of the future variants significant in order to prevent complications in the future.

The gapfiller may in the future be changed. Another material will be used with a metal alloy. The alloy is in a metal sheet which is cut into the gapfiller shape.

There is an ongoing project where the possibilities for reducing the number of different variants of filters are investigated. This will result in reducing the number of variants used in production. At the current state of the project it is not possible to say to what extent the number of variants will be reduced.

Today there are different variants of band cable used for connecting the MB and CB cards with each other. In the further this will be change to one common solution.

The MINI-LINK will in the future be screwed together from the top of the MINI-LINK and this will be a prerequisite for the solutions presented in this project.

When introducing the RauX there will be additional variants of CB cards used in the production.

To get an indication of the future product variance, the first step includes finding an order pattern. Summarised, there is a very large difference in volume between small orders and large orders every week. There are slightly more large orders than small orders, but in absolute numbers the small orders are a very small portion of production.

To get further insight, data is gathered from a modernisation project for the Rau family. One of its purposes is to reduce the amount of filters required in production. The result of the data shows that filter indices are somewhat reduced, but more importantly; many of the most common product indices now share the same filter, where they previously did not.

4.4 IMPLEMENTATION PHASE

In this phase of the DYNAMO++ methodology, large amounts of concepts are generated, evaluated and discarded in iterative processes. The goal is to have only a few remaining ideas that fulfil the specifications better than others, so that the final analyses may be done in detail on only the most suited concepts.

4.4.1 Concept development

Concepts have been generated within three different categories defined at different mechanical level of automation. Further on there has been an elimination of concepts that least stands up to the system attributes. One or two concepts in each category have been designed in detail and finally an evaluation of the concept has been done.

Concept categories

In order to get an optimal solution based on the LoA analysis summarised into a SoPI the mechanical level should be somewhere between level four and six, which represent anything between using of automated hand tool to flexible machine or workstation. The information level on the other hand should be placed somewhere between four and five, which stands for questioning and supervision. This is a requirement in order to secure quality. The three different categories that should be investigated further have been placed in the three different mechanical regions in the optimal area, see Figure 4.20. Solutions will be generated at these three different mechanical levels and the information level will be stated later on. Looking at the SoPI the level of automation on the cables assembly operation is limited to level one on the mechanical scale. This operation will, due to this, be handled as a manual task in all concepts. In a fully automated system this can result in left over automation.

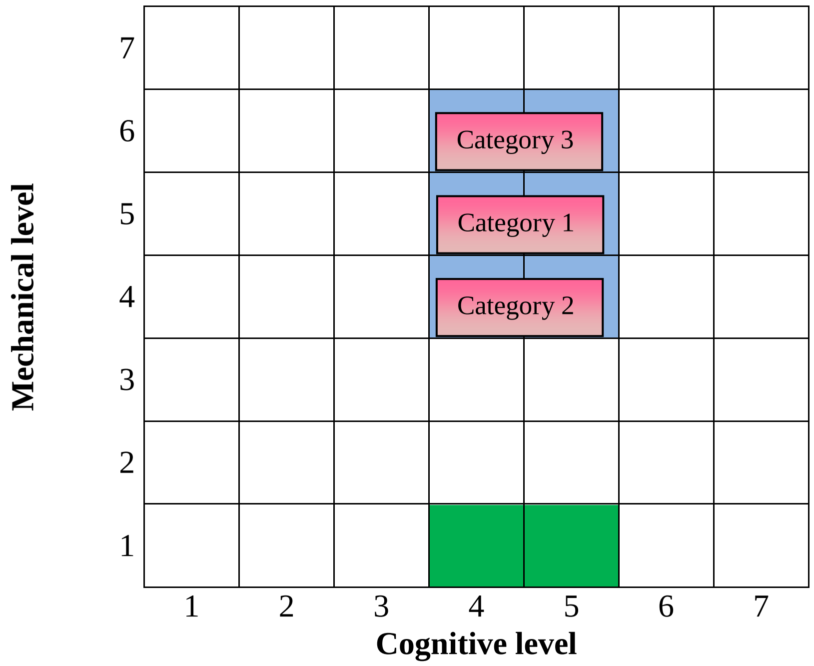


Figure 4.20: The categories for the concept will be placed according to the circles in the diagram.

Category 1

The first category is the assembly line concept. This concept will be placed at level five at the mechanical level, the middle region of the three categories.

Category 2

The next category that will be investigated is the lowest level of automation in the optimal is suggested from the SoPI, four, on the mechanical level. This means that an operator is required all the time. The concept generated in this category will be a semi-automatic solution. Looking at the quality aspects one identified quality problem is occurring due to the screwing operations at the assembly station. It is also according to the time study the most time consuming operations. This makes automating the screwing operation a suitable solution.

Category 3

The last category will be placed in the highest region of the optimal level, at level six on the mechanical level. This mechanical level represents flexible machine or workstation. A solution that would require a high flexibility is replacing the operator with one robot doing all the tasks and this concept have been chosen to continue to work with.

Concept generation

Concepts have been generated within the different categories.

Category 1

The basic concept for the assembly line has been developed during workshops with technicians selling automated systems. During the workshop a solution for the line balancing problem were solved. The operations were divided as follow:

- Station 1: Place the hull, place the filter and screw filter in place, label UKL
- Station 2: Place gapfiller, Assemble MB; including place supersorb and EMW screen
- Station 3: Screw MB in place
- Station 4: Place CB; including distance list for RauX.
- Station 5: Screw CB in place
- Station 6: Assemble cables
- Station 7: Place the hood, Label two labels
- Station 8: Screw MINI-LINK together

The robots needed for each station at the assembly line were also stated during the workshop. The transportation between the stations was also solved and solutions for the material support to the line were also stated. All solutions can be seen in Appendix F. This concept will be put forward in the concept development process and a detailed design on the concept will be generated.

Category 2

Using a brainstorming session, four concepts within this category were generated. The concepts are presented below with a short description:

- *Concept 1:* A table is used for switching the work piece between the operator and the robot. The operator adds parts to the work piece and gives a signal that the table can turn around. The screwing operations are dedicated to the robot and the operator adds all the parts to the work piece. The robot and the operator work in parallel on different work pieces.
- *Concept 2:* The work piece is inserted into the work area by utilising two parallel pneumatic shuttle carriers. The robot works on the one of the work pieces and the operator on the other.
- *Concept 3:* The operations are placed along an assembly line. Operators are working at stations along the line and between the manual stations robot cells are placed, performing the screwing operations.
- *Concept 4:* The robot is working opposite to the operator. Two fixtures for the work pieces are used and the robot works on one of the work pieces and the operator on the other, when the operator is ready a signal is generated to the robot and they switch.

Category 3

For category 3 all possible solutions of robot types described in the theory, also listed below, will be investigated:

- Cartesian coordinates (rectangular) configuration
- Cylindrical configuration
- Polar coordinates (spherical) configuration
- Jointed-arm (articulated) configuration
- Selective compliance assembly robot arm

Concept elimination

Categories 2 and 3 have in this step been investigated in order to eliminate the concept that is least suitable.

Category 2

The second category consists of four concepts that need to be investigated using a Pugh decision matrix. The concept that least measures up to the system attributes will be eliminated. The Pugh matrix where constructed using the system attributes to compare the different concepts, see Table 4.5. The authors of the project have performed the comparison between the concepts.

Looking at the Pugh matrix the winning concept is number 4, the robot is working opposite to the operator. Concept 1 and concept 3 have a negative net value and they will be eliminated. Concept 2, the parallel pneumatic shuttle carriers have the second best net value and is 2 points from the winning concept and is therefore also decided to be interesting to send to the next step in the development process. The two concepts that were chosen to put forward and do detail design for is concept 2 and concept 4.

Table 4.5: Pugh decision matrix for category 2.

System attributes		**Concept**			
	Current system	1	2	3	4
Investment cost	**0**	-	-	-	-
Maintenance cost	**0**	-	-	-	-
Accuracy	**0**	+	+	+	+
Uptime	**0**	0	0	0	0
Product Flexibility	**0**	-	-	-	+
Volume Flexibility	**0**	-	+	-	+
Safety	**0**	+	+	+	+
Ease of use	**0**	+	+	+	+
Varied work tasks	**0**	-	+	-	+
Speed	**0**	+	+	+	+
Sum +		4	6	4	7
Sum -		5	3	5	2
Net value		-1	3	-1	5
Ranking		3	2	3	1
Continue to develop?		No	Yes	No	Yes

Category 3

For the third category the choice of robot is quite limited. The robot needs to reach a lot of material and material therefore needs to be placed around the robot. In order to make this possible the robot needs to reach nearly 360 degrees in the horizontal plane. There is a huge need for flexibility within this concept looking at reachability, but the robot also needs to be able to pick the parts differently and sometimes relocating them.

According to the theory in section 2.1.2 there is one possible choice of robot that has the required reachability, a Jointed-arm (articulated) configuration. The concept will be designed in detail using this six axis robot. This concept will also have the cable assembly as a manual task and will require the work piece to get out of the robot cell in order to let an operator perform the task.

Detailed concept design

The three different categories have been investigated in detail and have end up in four different concepts. The first one is the line concept, the second and the third one is the automated screwing concept where two different variants have been investigated and the fourth one is the single six axis robot solution.

Category 1 - Automatic assembly line; Concept 1

The Line concept is based on eight working stations, including one manual station. The assembly operations are allocated between the workstation on the line and step by step the parts are added until it reaches the final station and finished MINI-LINK. After the last station the complete MINI-LINK will be sent on gravity roller conveyor with and wait for deliver to RauCal. Using a line will result in a constant flow of finished products.

The configuration of this concept is shown in Figure 4.21 and a detailed description of included components can be seen in Appendix F.

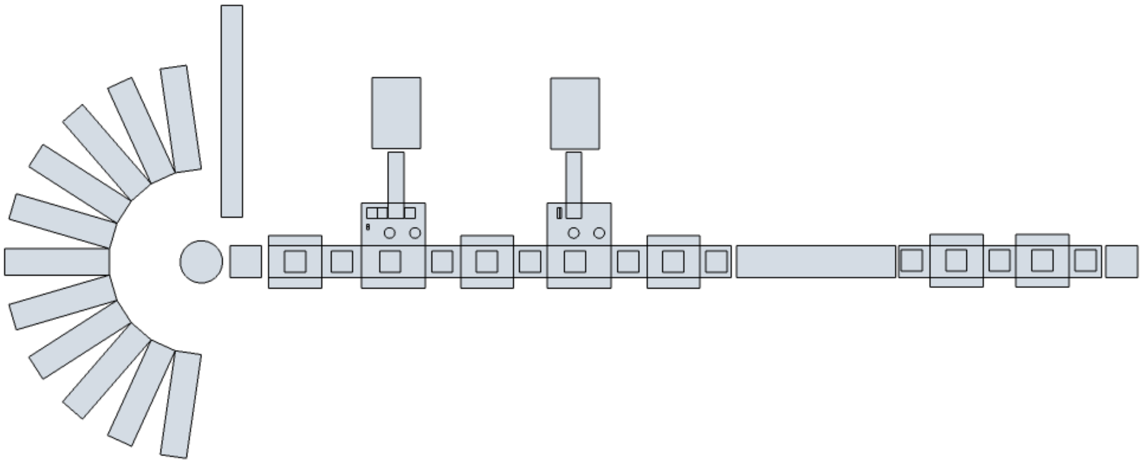


Figure 4.21: Concept 1 - Assembly line in 2D.

Requirements

This line concept is based on sequencing of the assembly order. To make the supply of material into the line more convenient this solution assume that the products, on a daily basis, will be grouped together in batches looking at the type of MB card needed, then CB card needed and the filter needed. The batches of product should be sequenced in an order to minimize the number of set-ups. Sequencing batches using for example the same MB will result in no set-up for the MB between the batches. The batches will be grouped together looking at the type of filter. The production will be batched and sequenced looking at one day of production.

Work sequence

The product goes through eight different stations at the assembly line, these are divided as follow:

- Station 1: Place the hull, place the filter and screw filter in place, label UKL
- Station 2: Place gapfiller, assemble MB; including placie supersorb and EMW screen
- Station 3: Screw MB in place
- Station 4: Place CB; including distance list for RauX.
- Station 5: Screw CB in place
- Station 6: Assemble cables - Manual Station
- Station 7: Place the hood, Label two labels
- Station 8: Screw MINI-LINK together

Technology

The transport system used in this line is a conveyor with fixtures, to ensure suitable accuracy and repeatability. There are buffer places between each workstation consisting of one fixture with a product. This is used in order to minimize the effect of system losses as a result of transport time. A lift is placed in the beginning and the end of the line used to make it possible to transport of the empty fixture back when reaching the end of the line.

All stations performing screwing (part of station 1, station 3, station 5 and station 8) consist of a three axis robot. The screwdriver has different bits depending on the dimension on the screw that should be used. Each screwdriver has a screw feeder connected.

Station 1 consists of one six axis robot, a vision system, labelling equipment, a scanner and a three angle robot. The hulls will be presented using 10 gravity roller conveyors with safety stops to secure no access to the robot cell. This results in a cell where the robot has access to up to ten different hulls, to cover all the product varieties. The six axis robot has a multi tool and is used to pick up the hull directly from the box delivered from the supplier. A vision camera will be used in order to inspect if the cables in the hull is in the correct position. If not the hull will be rejected and sent out from the cell on a conveyor. The filter will be delivered, in a predefined assembly order, to the cell on a conveyor. The filter will be picked with the six axis robot and scanned. The robot holds both the hull and the filter in the multi tool and a vision system is then used to detect the correct position of the parts. Then the robot places the hull in a fixture and the filter in the hull. The product in progress will be labelled in order to keep track of the product during the complete process from the start of the line until the product is finished. A three axis robot will then screw the filter in place.

Station 2 consists of a six axis robot with a multi tool, a scanner and a vision system. The gapfiller is placed in cartridge that consist of two locating pins. The robot picks a gapfiller. The MB card is delivered to the cell on a conveyor in a predefined assembly order and scanned to ensure that the part is correct. The MB is picked. For the product where the supersorb is needed, the robot also picks a supersorb. The supersorb is delivered using a feeder. The robot picks the EMW screener cartridges used for presenting the EMW screeners. The robot holds all parts in the multi tool and a vision system is then used to detect the correct position of the parts. Then the robot places it in the correct position.

Station 4 consists of a SCARA robot, a vision system and a scanner. The distance list needed for the RauX is presented in a cartridge and the CB card is delivered in the predefined assembly order to the cell on a conveyor. The robot picks the list and the CB, uses the vision system to detect the position and then place it.

Station 6 is a manual station where one operator is needed to assemble the cables. The fixture leaves station 4 to a roller conveyor of a length of 3 meter. This makes it possible for the operator to have a buffer when working.

Station 7 uses one two axes robot to place the hood and here labelling equipments also is used to label the MINI-LINK with two different labels.

The MB and CB cards have a standard solution for ejecting the cards from the cartridge. The machine will be loaded with two cartridges and by using a lift the cards will be ejected into a conveyor one at a time. When one cartridge is empty it will be sent out again. In order to avoid changing the cartridge too often, all product sequences with less than a specified number of cards will manually be selected and put in a cartridge with mixed cards. This number of cards is based on the highest even number that does not give a set up loss higher than five percent.

The cards will be placed in a predefined assembly order that is synchronised with the assembly sequence of the line. When a product sequences with the same type of card is larger than the specified number a cartridge with only this type of card will be inserted in the machine.

Operators

One operator is needed to the manual station doing the assembly of cables. There are two more person needed for support of material and one additional operator for the filter support.

Material Handling

This line concept requires operators supporting the line with material. The cartridges need to be loaded and the roller conveyors for hulls need to be refilled. The workload of serving the line with material is two operators working fulltime, including marginal. These operators also have time for the sequencing of MB and CB card that is needed. The line also requires one operator at the manual station. One operator will be needed to support the line with filters.

Output

The output from the assembly line will have a continuous flow, where the time between the finish products is equal to the cycle time.

Category 2 - Automatic Screw Station; Concept 2

The automated screwing station is a concept that highlights the advantages of maintaining human flexibility and learning while ensuring fast and accurate screw positioning and tightening. The goal is to achieve a higher quality of screw fastening in a cost efficient way and at the same time eliminate a very repetitive task from the operators.

Concept 2A – Automated screwing station, Static

The screwing operations in this concept will be performed using a 3 axis linear movement equipment that will accommodate two operators and four shuttle carriers. A visualisation of the concept is shown in Figure 4.22 and Figure 4.23.

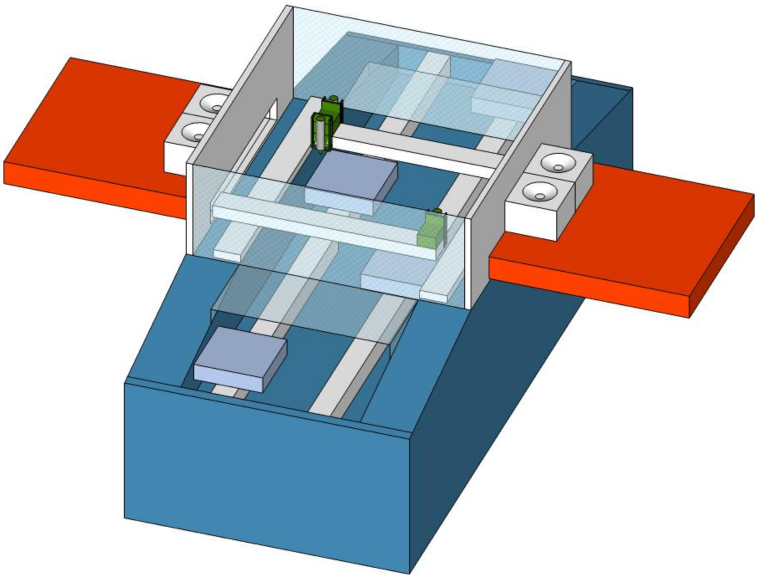


Figure 4.22: Concept 2A - Automated screwing station in 3D.

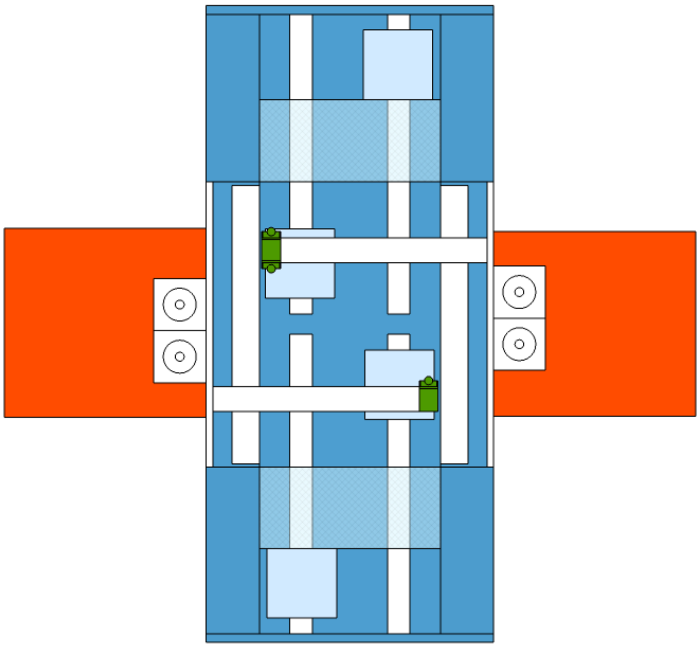


Figure 4.23: Concept 2A - Automated screwing station in 2D.

Technology

Computer controlled screwdrivers are mounted on 3 axis linear movement equipment. To each screwdriver there is at least one automatic dispenser of screws connected, but more than one connection is possible per screwdriver if necessary.

The work piece is inserted into the work area by utilising two parallel pneumatic shuttle carriers. Fixtures for the product are mounted on each fixture.

Safety is a primary concern, and for this reason the work area is physically restricted to operators. To avoid injuries on the pneumatic shuttle, the operators must first push the shuttle manually to a safe position before it is transported pneumatically into the work area.

This configuration generates the concept shown in Figure 4.24.

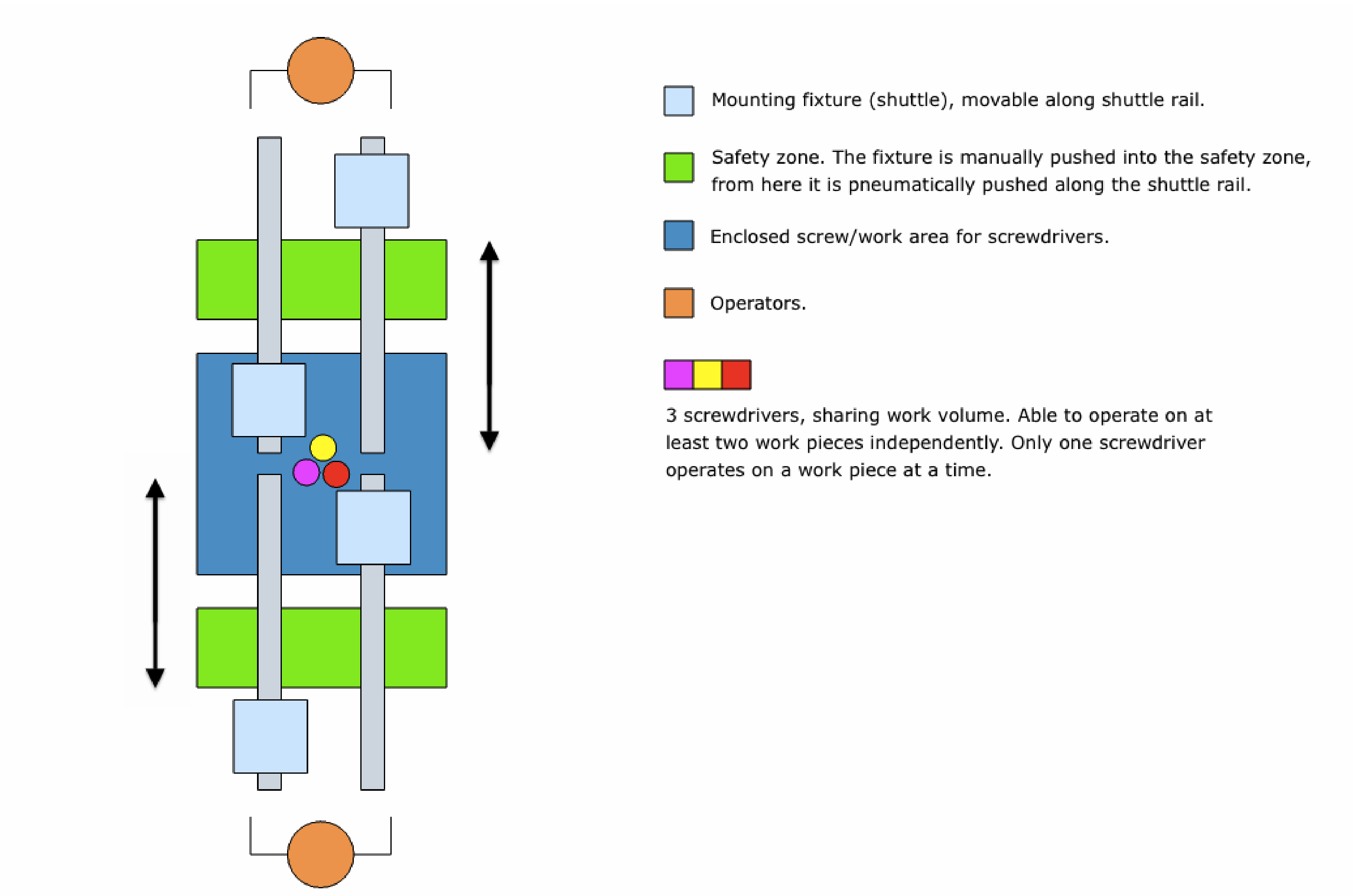


Figure 4.24: Concept 2A, a conceptual layout of an automatic screw station.

Work method

To enable the highest possible utilisation of the operator and the screwdrivers, the parallel shuttle carriers allow for the operator to work on one piece while the screwdrivers works on the other. In rare cases the operator may have to wait for the screw station to finish, but in theory the screw station is always faster than the operator.

Multiple operators

Because of the speed of modern automated screwdrivers, there is quite a lot of waiting time involved. Thanks to clever balancing, it is possible to construct the screw station to accommodate two operators and four shuttle carriers. These will be on opposite ends of the screw station and require separate material supplies.

Material handling

Each of the two operators requires a steady supply of materials in close reach for the system to function at full efficiency. This is carried out in much the same way as the current manual stations, but a worker dedicated to this task and other minor tasks refills the supply. However, one such worker may supply several screw stations.

Components should be available for the scheduled products in shelves behind the operator or at the sides. Screws are refilled at the screw station about once an hour.

Work sequence

The work tasks are always carried out in the same sequence to ensure consistent quality.
The sequence can be described as the following:

<u>Sequence 1:</u>
Manual operation A
Screw operation A
Manual operation B
Screw operation B
Manual operation C
Screw operation C
Manual operation D
Screw operation D

There is also an option to perform the following sequence:

<u>Sequence 2:</u>
Manual operation A
Screw operation A
Manual operation B + C
Screw operation B + C
Manual operation D
Screw operation D

The chosen sequence affects the configuration of screwdrivers in the station. Figure 4.25 illustrates the station performing work sequence 2, which is also the chosen sequence for verification. The operations included in the sequences are described in Appendix G.

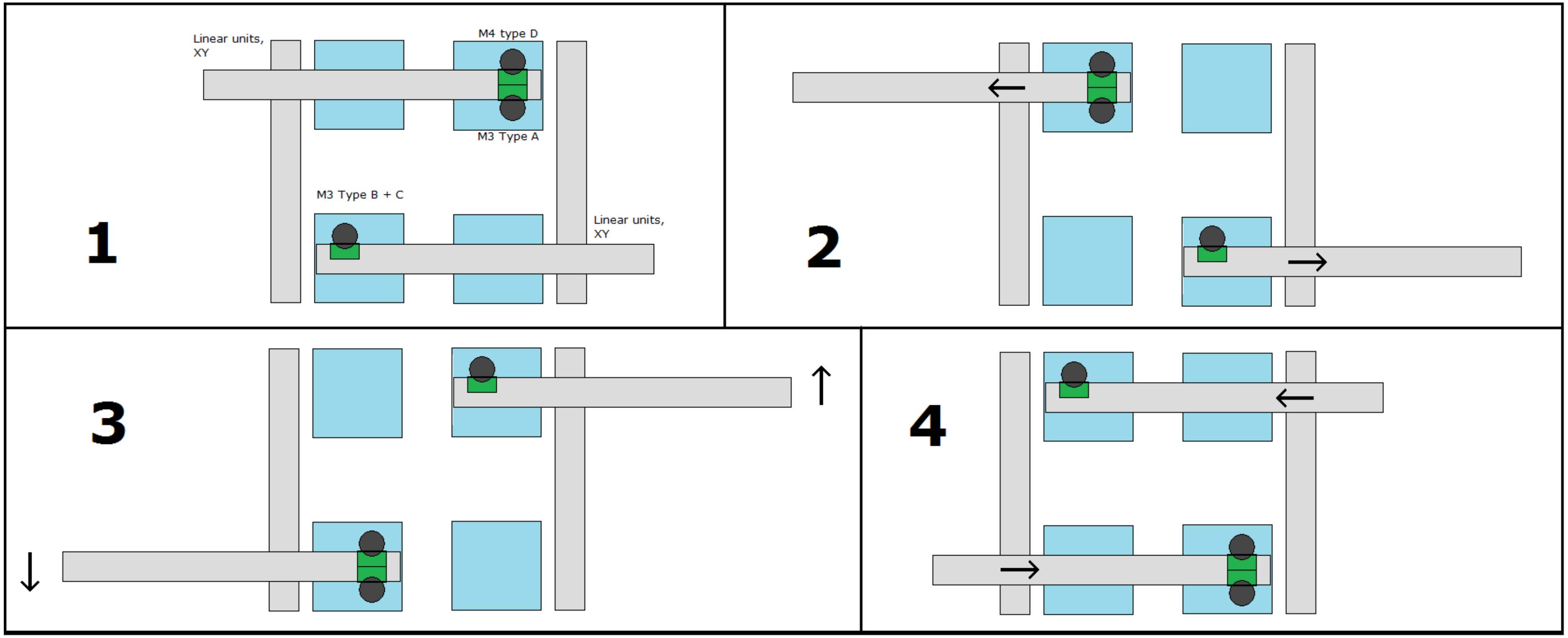


Figure 4.25: *Illustrating the station performing the recommended work sequence.*

Output

Because an operator should always be working on two products simultaneously, the output will also come out in pairs.

Concept 2B – Automated screwing station, Dynamic

The screwing operations in this concept will be performed using a six axes robot and the operator gives the robot access to the work piece by inserting a box to the robot cell.

Technology

Two screwdrivers will be used to cover all screw varieties. A six axis robot will be used for the screwing operation and the two screwdrivers will be placed in a station where the robot can change between them.

The work piece will be placed in a box and when the operator is finished with the operation the box will be inserted in the robot cell giving the robot access to work. Two boxes will be used, one where the operator can work and one that the robot can work. The configuration of the concept is shown in 3D in Figure 4.26 and in 2D in Figure 2.27.

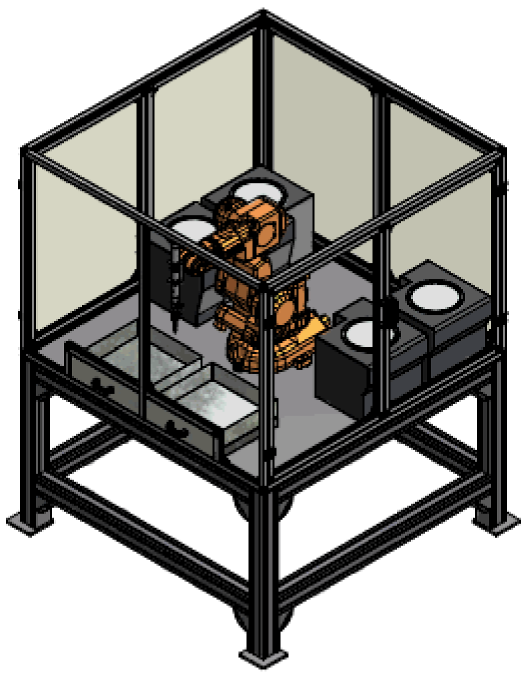
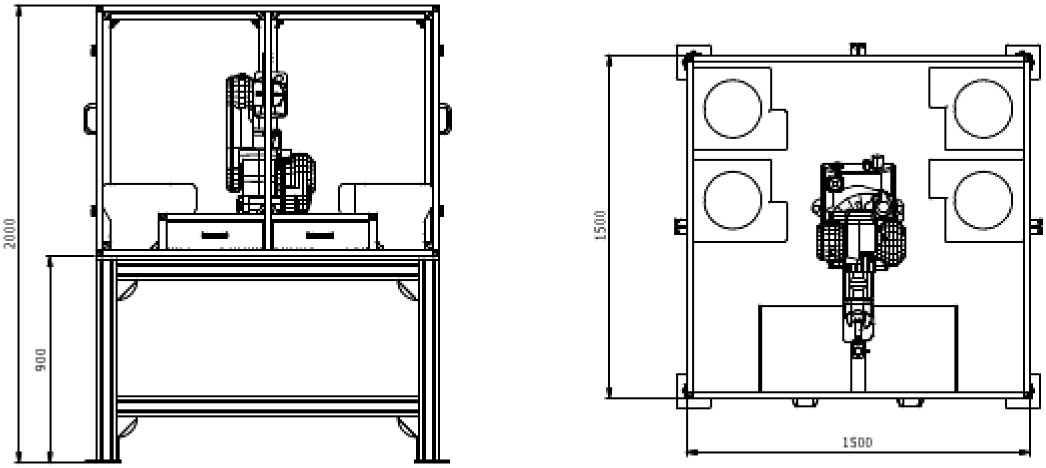


Figure 4.26: Concept 2B in three dimensions.



a.) Side view b.) Top view

Figure 2.27: Concept 2B in two dimensions.

Work method
The operator works in parallel with the robot. The operator will take more time to finish the operations, which results in that as soon as the operator is ready the boxes can be switched and the operator can continue on the other work piece.

Operators
One operator is working at the station performing all tasks except from the screwing operations.

Material handling
The operator requires a steady supply of materials in close reach for the system to function at full efficiency. This is carried out in much the same way as the current manual stations, but is refilled by a worker dedicated to this task and other minor tasks.

Components should be available for the scheduled products in shelves behind the operator or at the sides. Screws are refilled at the screw station about once an hour.

Work sequence
The work tasks are always carried out in the same sequence to ensure consistent quality. The operation order is the same as for the manual assembly station today.

Output
Because an operator should always be working on two products simultaneously, the output will also come out in pairs.

Category 3 - Robotic assembly cell; Concept 3
The concept is centred around allowing 6-axis robots assemble as much of the product as possible, ending up with a fully automated system, excluding cable assembly. 6-axis robots are easily reconfigured to accommodate product changes or new product families in future production, ensuring a long lifespan of the investment.

Technology
A robot is equipped with tools necessary to pick, place and screw all components up to the cable assembly stage. The robot will pick materials and apply them in a dedicated, per robot, fixture. Two robots are able to utilise the same supply of a crucial component. Some tool swapping may be necessary in order to be able to perform all the screw operations. This is considered in the cycle time. Fortunately, the balancing of screw operations will allow robots to share the screwdrivers between each other.

An additional automated station for mounting of the hood needs to be added after the manual cable assembly station. Both the manual station and the hood mounting station are capable of serving multiple robot stations. In addition, there is a 6-axis robot station in place to sequence filters for the robots assembling the product. The configuration of the concept is shown in Figure 4.28.

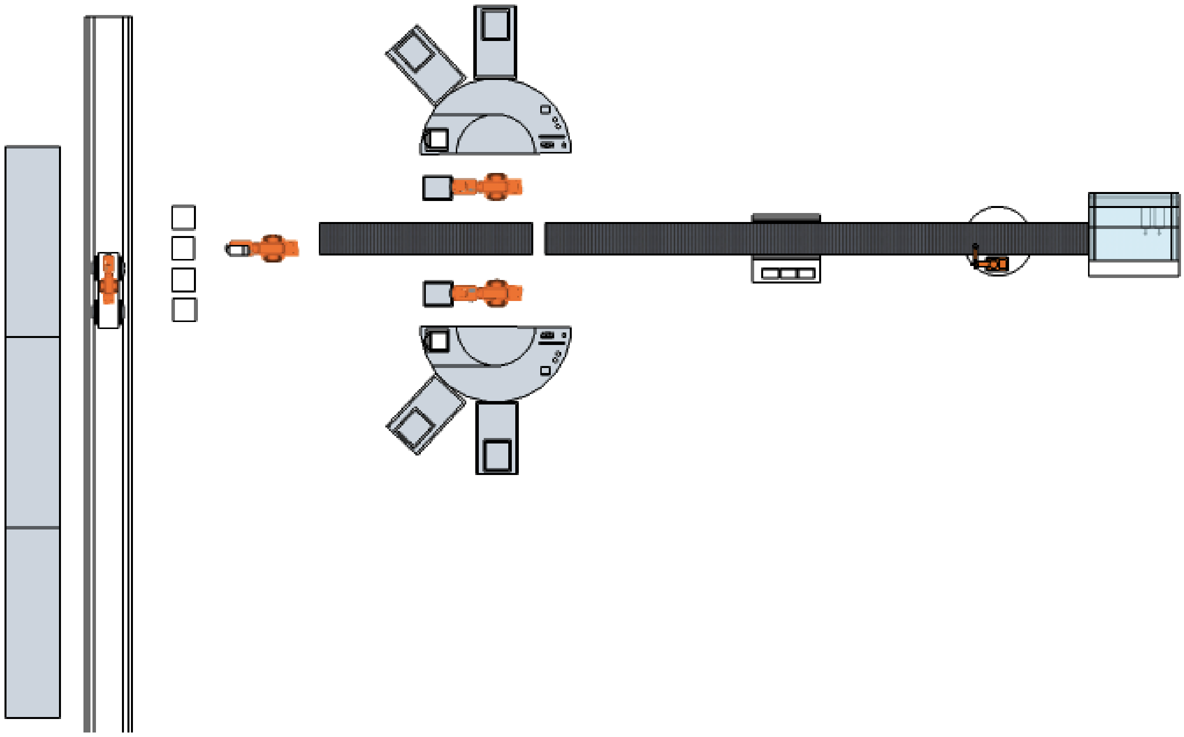


Figure 4.28: Concept 3, conceptual visualisation. Production flow direction is left to right.

Work method
The cells are built around utilising the robots close to 100%, keeping a continuous supply of material available. Since the robots will have a limited production rate, they will work in pairs to optimise usage of the filter sequencing robot.

Material handling
Operators are responsible for providing robots with material; each robot requires a separate supply of parts, except for filters. Material should be allocated between robots depending on the products currently being produced at the station. A robot at a sequencing station, delivering by conveyor, supplies filters.

Work sequence

There are 4 stations in the product flow. The first station selects the correct filter for the ordered product, picks and positions this on a conveyor leading to station 2.

Station 2 picks material from a connected supply, places it in a fixture and screws this in place with electric screwdrivers in 3 placement operations and 3 screw operations.
Afterwards, the robot places the product on a roller conveyor leading to station 3.

Station 3 is a manual station where cables are connected and protective plastic pieces are removed. It is then sent to station 4.

In station 4, the hood is placed and screwed in place by a 3 axis unit, and labelled by labelling equipment before ejecting a finished unit.

Output

The output of the process will be a continuous flow, with a rate of double the assembly rate of each robot.

Evaluation of concepts

Various evaluation methods have been used in order to nominate a best solution. The analyses will be used in order to complement each other by taking as many parameters as possible into consideration.

Kesselring

A Kesselring matrix was constructed and the concepts were graded how well they achieved the different criteria, see Table 4.6. A total score were summarised and a ranking of the concept could be made. The total score did not differ very much between the concepts, not even one percentage between the winning concept and the second best. The winning concept was the concepts in category 2, where the screwing operation is automated. Due to the similarities between the grading it is hard to make any conclusions looking at the separate system attributes.

Table 4.6: A Kesselring matrix comparing the final solutions.

System attributes	Weight	Ideal w	Ideal t	Concept 1 w	Concept 1 t	Concept 2A w	Concept 2A t	Concept 2B w	Concept 2B t	Concept 3 w	Concept 3 t
Investment cost	0,0393	5	0,197	2	0,079	4	0,157	4	0,157	2	0,079
Maintenance cost	0,1011	5	0,506	3	0,303	4	0,404	4	0,404	4	0,404
Accuracy	0,1742	5	0,871	5	0,871	5	0,871	5	0,871	5	0,871
Uptime	0,1629	5	0,815	5	0,815	4	0,652	4	0,652	5	0,815
Product Flexibility	0,0674	5	0,337	2	0,135	4	0,27	5	0,337	5	0,337
Volume Flexibility	0,0899	5	0,45	2	0,18	5	0,45	5	0,45	3	0,27
Safety	0,1629	5	0,815	4	0,652	4	0,652	4	0,652	4	0,652
Ease of use	0,073	5	0,365	5	0,365	4	0,292	4	0,292	5	0,365
Varied work tasks	0,0337	5	0,169	2	0,067	4	0,135	4	0,135	2	0,067
Speed	0,0955	5	0,478	5	0,478	4	0,382	4	0,382	4	0,382
T = ∑tj			5		3,944		4,264		4,331		4,241
T/Tmax			1		0,789		0,853		0,866		0,848
Ranking					4		2		1		3

Task Allocation Analysis

To evaluate all the concepts with regard to the reference point constructed in the Price Decision Matrix, the coordinates need to be conceived. They will be placed on the same axes, the degree of manual versus automated tasks, ranging from 0 to 100 percent. Because the values of the two axes are contradictory, the points will all be spaced out along the same line.

The degrees of automation of these solutions need to be quantified, which in this case will be done by comparing the degree of manual labour required in comparison to the current state process - giving a percentage value of the manual labour coordinate. The result of these calculations is displayed in Table 4.7 and a graphic representation of these coordinates is shown in Figure 4.29.

Table 4.7: Calculated coordinates for the level of automation in the Price Decision Matrix coordinate system. Detailed calculations can be found in Appendix H.

Coordinate	X	Y	% of Current Autonomy
Desired	36.38	63.62	-
Current State	87.04	12.96	100
Concept 1	24.26	75.74	27.87
Concept 2	37.30	62.70	42.86
Concept 3	16.17	83.83	18.58

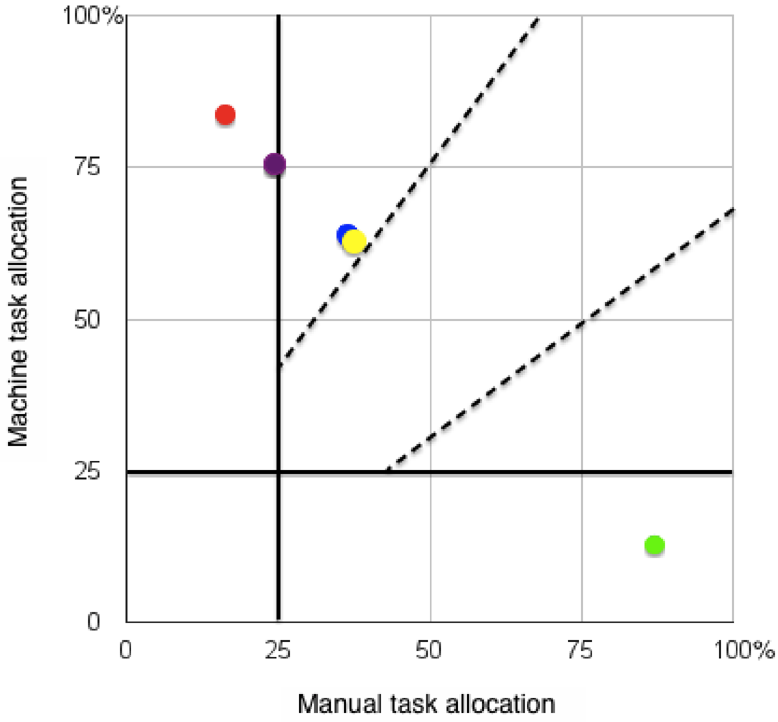


Figure 4.29: Scatter plot of the desired level of automation, the current level of automation, and the level of automation of the three concept models. The blue colour represent the desired level, the green the current state, the red Concept 1, the yellow Concept 2 and the purple Concept 3.

4.4.3 Profitability

After many meetings with several suppliers of automated solutions, cost estimations were put together for concept 1, concept 2A and concept 2B. These costs include hardware cost, basic software cost, installation and operator training. It is important to note that all costs are estimates, they may be used in this report for the purposes described in the goal, but to provide a strong business case when choosing to implement more secure number should be gathered. That being said, the costs do cover well-described processes that have already been discussed with the suppliers who Ericsson may deal with in the future. As such, it does have some good credibility. The implementation costs for the concepts are displayed in Appendix I.

To be able to calculate payback time; financial documents at Ericsson were used to calculate the costs of the currently implemented process, making assumptions on staffing and incoming orders. The calculation steps and final results are displayed in Appendix I.

To easily compare the concept implementations; the costs, savings and payback times for the current process and possible concepts are compiled in Appendix I. A summarised table showing the payback times is featured as Table 4.8.

Table 4.8: Payback time of concepts at various hypothetical production rates.

Production Rate	**Payback time [Years]**			
	Concept 1	**Concept 2A**	**Concept 2B**	**Concept 3**
Low volume	4,97	0,83	1,69	-
Medium volume	2,31	1,06	1,61	-
High volume	1,51	0,78	1,59	-

The Payback time at medium volume for all the concepts will, according to Table 4.8, be more than one year. For concept 1 it is over two years at a medium volume and nearly five years for a low volume.

4.4.4 Verification

To ensure viability of the concept models, verification on output is required. Independent suppliers, in addition to calculating costs, have verified both concept 1 and concept 2B. The result supports the viability of these concepts.

For the remaining concept, 2A, a discrete event system simulation has been performed on a model of the concept to verify that the system provides a stable output. This was done with AutoMod. Due to the complexity of the concept, the supplier was unlikely to perform this simulation pro bono. A description of the simulation can be found in Appendix J. The result clearly supports the viability of concept 2A.

5. ANALYSIS AND DISCUSSION

With all the data available, there is a significant amount of conclusions to be drawn. In this chapter, an analysis and discussion of the results is performed to build a base on which the conclusions will be reinforced. A discussion regarding the methods will also be presented.

5.1 TRIGGERS FOR CHANGE

The overlying themes when analysing the results of the project at Ericsson are the triggers for change. They are a vital part of the project that ensures usefulness and relevance to Ericsson. As mentioned earlier, these are: quality, cost and flexibility.

5.1.1 Quality

The quality when it comes to the screws will be better using automated cell instead of manual work. In the manual station there is no control securing that the correct amount of screws is screwed. Missing one screw can result in errors that end up with a product that need to be reworked. Reworking is something that should be avoided and it would be a good idea to secure this screwing process to avoid quality problems of this type.

Automated screw driving will result in a secure check that all screws are in place and screwed with the correct torque. If anything goes wrong the robot will generate an error-message, the product will directly be refused and correction can be done before adding more parts and finishing the product. This problem could also be solved in a manual station if the screwdriver had a memory that registers each screw that is screwed in place and give feedback that the operation is completed.

5.1.2 Cost

The cost of any system, new or existing, is divided into multiple categories and need to be considered separately. The most obvious of these is the investment cost; the cost that you pay up front. Possible savings, consisting mainly of hardware and installation costs (including programming and training), will be compared to the investment cost to find a payback time. While high investment costs are unwanted, it is important to remember that the yearly savings are likely to be much higher in these cases. All the investment costs in this report are based on assessments performed by three independent companies of the concept models put forward. This process has required a lot of time and many iterations of the concepts but has returned reliable estimations.

Maintenance costs are annual costs stemming from service costs and repairs due to malfunction. These costs have been estimated by a specialised department at Ericsson.

5.1.3 Flexibility

For Ericsson, it is highly desirable to have a flexible production facility in terms of volume. Demand varies over time and preferably; so will production. There are a few ways in which to accomplish this.

One is by varying staffing numbers; fewer operators will cost less money. This requires a system that can be run at different production rates depending on the staffing. It is also somewhat limited in how far ahead you can plan your staffing.

Another is by implementing incremental investments in the production line. Depending on the current production rates, several machines may be purchased or just a few. In extreme cases it may even be possible to rent equipment.

5.2 PRODUCTION RATE

In many cases in industry, a main reason for automation is to get an increase in production rates. Because machines are generally faster and do not grow tired of repetitive work tasks, the output per machine is normally higher than that of a person. However, in the case of Ericsson, the automated system should not increase total output when compared to a manual process. Instead it should try to increase production on a per operator basis. That is what gives a return on the investment in this case. Due to fluctuations in order volumes it is extremely important to design a system with the right level of flexibility and speed to accurately present the possible financial gain of automation. Designing a process with very high speeds will be very costly.

5.3 LOA AND SOPI

There are many ways to use the results of the levels of automation workshop. What is clear is that the manual process today is comprised of standardised tasks, which gives major similarities in the level of automation between tasks. There are a few special cases, such as the cabling, where mechanical automation has been deemed impossible for this project and kept at a manual level.

As a first step, the levels of automation for all tasks were placed in the same square of possible improvements, showing that there is a great overlap with a few special cases. By seeing that so many tasks overlap in their possible levels of automation, it is clear that automated solutions are equally viable if the product is:

- Fully assembled by a multipurpose machine.
- Assembled in sequence by multiple single purpose machines.
- Assembled partly by humans, partly by machines.

As such, there are additional combinations of concepts that may need to be considered. However, due to the complexity and high requirements on informational LoA, there is no clear distinction between category 4 and 5 on a system level. Therefore, not much consideration is put into defining this in the results or conclusion of the project. It is simply defined as a performance requirement that category 4 is minimum and category 5 is possible. Information level four represents Questioning, which gives verification before further actions can be performed and level five represents supervision which means that the system calls for the operator's attention if something went wrong.

5.4 SYSTEM ATTRIBUTES

By compiling questionnaires filled in by members of several positions in the affected departments, the result reflects the company profile as well as possible. The results are still very subjective, but so is the selection process of an automation concept. Many suggestions may provide similar characteristics, and these prioritisations will be a great tool for evaluating them.

Looking at the result from the questionnaire, the priority of the investment cost is low. In the beginning of the project the payback was required to be less than one year and therefore the investment cost was used as one of the system attributes. Due to the complexity of the system, a payback time on less than one year was found to be hard to reach and the payback time became a deciding factor when choosing between concepts. The persons who answered the questionnaire did not prioritise the investment cost, but involving persons from the economic department may have given another result. The investment cost itself is not a big issue for a large company such as Ericsson, but payback is. The system attributes could have been formulated differently in order to acknowledge the importance of the payback time.

5.5 FUTURE VARIANTS

From the data gathered on filter and order variance, it is possible to assume that in the future; the impact of the great number of filters will be reduced. The indices of filters will be reduced for high volume product indices, while low volume indices will remain close to the current state.

By this assumption, a suggestion for sequencing part of orders is proposed. Most orders are large enough to make setup time dismissible in the process. However, in small orders the setup time cannot be ignored. To solve this, a possibility exists for sequencing only orders of a small size, By setting a certain order volume as a limit and sequencing the orders below the limit, the system behaviour will be as if it was a large order. Due to the low frequency of such orders, the sequencing can be performed without occupying additional staff.

5.6 CONCEPTS

An analysis of the concept will be described in the following section.

5.6.1 Concept 1 - Line

The number of operators needed in the line will always be the same independently to the volume produced. At the manual stations needed today the operators vary dependent on the volume of production which makes the system very flexible and Ericsson do not need to have more operators than they need for the current volume. This makes the line not so profitable when the production is low, but on the other hand when the volume is high it will gain even more. It may be possible to reduce the number of operators during the low volume production but the efficiency will likely be lowered.

Producing in batches can result in problems further on in the production flow, during the different tests. The test systems used today consist of equipment that designed for individual products. The number of test stations for the individual products is limited and if a large amount of the same products is produced, the resources in the test station will probably not be enough.

Advantages

- The quality will be higher compared to manual assembly.
- Cost of production is easily predictable, due to static cost.

Disadvantages

- The line concept is sensitive for disturbances. If one of the station is down the complete line will be affected.
- Having one manual station in the middle of the line is not to prefer. But due to the complexity of the operation it is too expensive to automate this station. Today the operators use work task rotation between the different stations in the outdoor production which result in a possibility for changing work task. This makes the manual station at the line acceptable.
- Implementation of a line will take time and also affect the ongoing production.
- There is little volume flexibility due to static machines.

5.6.2 Concept 2 – Automatic screwing cell

The main advantages of this concept are high quality, cost efficiency, and implementing humans and machines at tasks well suited to them. The concept is based around automating the task with the most quality issue, the screwing of components on the product. The task of screwing is not complicated for a human to perform, but the monotony of the task is a great opportunity for error. The human mind must focus a great deal to keep track of which screws are in place when it cannot separate screws as independent events. This makes it a slow process step, or alternately produces a certain amount of errors. A robot, however, is very good at keeping track of what has been performed and what has not, and will possibly never miss a screw placement. This in turn makes the robot significantly faster and more efficient at this task.

As a result of removing the screwing task from the operators, they are now able to spend this time on something a human is much better at; pick and place. Each operator produces two products simultaneously, and chooses varying components for these, If these production steps were to be automated, the costs would be very high. It would also be marginally faster or possibly slower.

Proper task allocation between machine and human provides high quality and cost efficiency for this concept. In addition, by focusing automation on well known mechanical tasks, cost of automation is kept fairly low. This, coupled with the possibility for incremental investments makes this concept very appealing.

As a final note on the concept, it is very attractive in that it has minimum impact on the current production system during the implementation period. The possibility for incremental investments also enables a possibility for incremental implementation. Many of the current process workstations may be kept intact during early implementation of the first screw stations. By doing this during low production periods, it is likely that production dips can be averted altogether.

Advantages

The advantages for concept 2 will here be presented.

Quality improvements

The automated screw station eliminates the need for operators to keep track of screw patterns, numbers and tightening torque. These are tasks that humans in general find difficult. Instead the operators focus on picking and placing components, which is a much more fitting task to flexible humans. By keeping the current scanning system, there is barely any risk of picking the wrong components.

Speed

By eliminating the screw operation from the operator's task list, the time spent per product is greatly reduced. Required production volumes are fully covered by two 2-man stations.

Flexibility

The station works just as well with one operator as with two, providing great flexibility to volume variation. Adding another operator simply doubles the production rate. However, allocating operator time to material gathering must always be considered and assigned to maintain a proper flow.

Reliability

By avoiding complex automated solutions, reliability of the system goes up. The components chosen to automate the task are some of the most reliable components available. Screwdrivers, linear positioners and pneumatic drives are all designed to run continuously for extremely long time in industry settings.

Implementation

The concept has a medium level production rate per station, allowing for partial implementation to lower risk of lowered production during the implementation period. It also allows for easily increasing production with additional investments if required volumes go up.

Work environment

Mechanical parts of the machine are encased, generating less noise for the operator than the current process.

Disadvantages

Concept 2 also has a few disadvantages, presented below.

- There is limited system intelligence; it can only keep track of the screwing quality. Everything else is controlled by humans.
- The concept is very operator reliant; if an operator disappears, the machine cannot produce.

5.6.3 Concept 3 - Robot Cell

To be in line with the modern concept of high reusability and flexibility, this concept takes advantage of highly articulate, reprogrammable industrial robots. The robots fully assemble each product according to an order list. Components are picked automatically from stocked cartridges placed in the robot's reach. Operators simply restock these cartridges when instructed to.

Because each robot cell may produce independently, there is a substantial volume flexibility available. The number of robots in use is simply adjusted to the desired output. It also provides much appreciated redundancy in case one or more robots require maintenance. On the other hand, each robot is limited in its capacity meaning a number of cells are required at high volumes.

Because of the accessible software for programming task sequences for industrial robots, it is very flexible in terms of implementing new products or changing existing sequences. All programs may be programmed and simulated offline, tested and verified on one robot, and then uploaded into all robot cells in the facility. This provides the least amount of downtime when making alterations to product varieties.

Advantages

- With flexible and reprogrammable machines, the investment will have a long lifespan.
- Intelligence in the system ensures high quality control and performance.

Disadvantages

- Currently, there are high costs associated with this level of automation.
- More resources must be spent to ensure the process is safe for operators and maintenance personnel.

5.7 PUGH

In order to decide in which direction to take the semi-automated concept, a Pugh matrix was constructed and scored by the project workers. Four possible solutions are evaluated in comparison to the current system in order to find strong points and weak points. From the finished Pugh matrix it became clear that the shuttle concept and the robotic arm concept were the only ones to be improvements over the current system. These ideas were both realised in concept models.

5.8 KESSELRING

As part of the evaluation process and to provide a strong case for the recommended solution to be implemented, a Kesselring was constructed and scored by the project workers. The system attributes for each concept model were scored on a one to five scale, with five being the value of an ideal system.

Because the concepts were all constructed using the same requirements, it is no big surprise that the Kesselring matrix shows a very similar overall score of all the concepts. Even though the Kesselring matrix shows a single winner, it is only by about 1% that it beats the runner up. The winning concept is also only 10% stronger than the lowest scoring concept. While the Kesselring matrix does suggest this to be the strongest candidate, additional evaluation is required before making a recommendation.

5.9 TASK ALLOCATION AND PRICE DECISION MATRIX

Through the inquiry, the following was established: Ericsson is asking for a system with a high degree of automation, but leaves some tasks for humans to perform.

From the results it is easily distinguishable that all the conceptual solutions comply with Ericsson's requirements fairly well, but one concept in particular stands out; concept 2. This makes it the ideal choice based on this method. The other concepts are slightly over-automated but concept 1 would also readily qualify as a suitable solution.

This method presents a strong case for choosing one of the realisations of concept 2, providing the financial analysis supports this.

5.10 COST

The first impression of the investment costs supplied by the companies is that the investments are somewhat larger than initially anticipated. It is clear that hardware costs are a much smaller factor than assumed, increasing the total cost of the solutions greatly. Nevertheless, as long as the return is as expected they are all still valid possibilities.

By comparing the current cost to the investment and annual costs of the concept models, it is obvious that all the investments have a great potential for saving Ericsson a great deal of money. However, the recommended payback time at Ericsson is as low as one year. This means that every suggestion for a medium production volume is actually over this limit, if only by a small amount. The earliest payback comes from the suggestions based on concept 2. They are the suggestions with the lowest investment costs and were therefore most likely to return money early. However, if one looks at a longer time period the investment of concept 1 will actually return more money, eventually, due to the greater investment cost. The big question for Ericsson will be which to prioritise.

5.11 PAYBACK TIME

As stated in the beginning of the project; the payback time should be less than one year. This can be seen as a very short payback time when it comes to a large investment. The payback time is often set by the product life cycle and a short product life cycle normally results in a short payback time. The product life cycle in this case necessarily does not have to be short but because of technological advances and economic insecurity, the payback is determined to be less than one year. To be able to reduce the necessity to keep such a low payback time, some considerations can be established.

When implementing an automated solution it is very important to have good communication with the construction department. In order to make it possible to automate a product where the life cycle is short it is very important that the automated solution is possible to cope when new or updated products should be produced. It is crucial that the construction department keeps the production flow in mind when new products are developed. The automated cell then hopefully just needs some re-programming and small additional solutions.

Ericsson is a large company that may be able to benefit from having the competence for re-programming robots in-house. This would make it possible to do smaller changes, if required, without using consultants from outside the company.

During the development of the concepts in this thesis, the possibility to adapt to future product variants has always been kept in mind. Introducing the next generation will result in small changes that have already been considered in the concepts.

5.12 SUSTAINABILITY

By considering personal safety over the many iterations of automated solutions, none of the proposed concepts bring increased risk to the operators. In fact, all the concepts should decrease the risk of work related injuries cause by wear and tear in monotonous work tasks. These were mostly caused by the forces involved in the screwing operations and handling of the finished products.

5.13 METHODS

The result of the project is important to discuss, but it is also very important to discuss and evaluate the methods that have been used. DYNAMO++ has been used as a methodology throughout the entire project. It is a structured approach to analyse the potential for automation in an existing system that we have not found elsewhere.

As a complement to the DYNAMO++ methodology methods that normally are used in product development processes have been used. DYNAMO++ do not have any specific methods for how to develop concepts and in order to get a structured way of generating, eliminating and finally evaluate the concepts this was a good solution. The methods are designed for product development but some of them can easily be implemented in the production development process as well.

A lot of effort has been put in to the current situation. But it is an important part of the project, including phase one, two and three in DYNAMO++. The result that is gained from this analysis has been the basis for the project and in order to get a credible result this is an important part and the effort that have been given to this seems necessary.

The evaluation of the system attributes consists of subjective information. The choice of individuals that have answered the questionnaire was made based on their background. In order to get a reliable result it is important to choose people with different knowledge and experience. The result would probably be different if another group of people, having other backgrounds, would have answered the questionnaire. The result is based on professional opinions and therefore it is very important to get a good distribution between professional areas. The persons chosen to participate in this questionnaire seems relevant for this project. In order to get more accurate data the questionnaire should have been answered by a larger population. Input from people with more knowledge about the process has simplified the decision making during the project.

The SoPI method has been a helpful tool when it comes to establishing the framework for designing concepts. The result from the analysis limited the possible solutions which resulted in a more effective concept generation. It was also indicated that the operation where the cables should be assembled were not possible to automate and no resources needed to be wasted on further investigations on that operation. The method helps to suggest an optimal area for further research and time can be saved because the complete area does not need to be investigated.

The concept development process involved different methods that normally are used during product development. The choice of method was convenient because they supported the decision making. The Pugh matrix that was used for screening the concept involved grading done by the authors. The Kesselring matrix used for scoring the concepts also involves subjective grading. A subjective analysis may vary from engineer to engineer but however the judgement seems reliable. The scores from the Kesselring matrix were very similar between the concepts and a decision based on only this analysis is not a good basis for credible conclusions. But the use of complementing analysis method for evaluation of the concept enforces the implications.

The task allocation method, coupled with the Price decision matrix, is a method that has not been addressed in any of the literature initially used. However, it numerically describes a normally qualitative requirement on a system, which is something we desired but did not have a clear method for. The authors believe it is a helpful tool that should be evaluated further by those interested.

There have been some problems with getting costs for the different concepts. The detailed descriptions that were needed on the line, in order to get an estimate of the cost were very time consuming. In the time scope of this project it is not possible to get an exactly cost of the implementation of the different concepts. The cost will be used as an indication. And further research needs to be done to get a more accurate cost, which is vital for an actual business case.

The combination of methods used in the project has generated a result that takes a lot of different aspects into consideration. In order to give a good basis for the recommendation given to Ericsson, this is very important, and the methods chosen seem to be appropriate.

6. CONCLUSION

From all the gathered results and the analysis, the following can be clearly stated:

- Out of the proposed concepts, regardless of which would be chosen, Ericsson will have the benefits of increased productivity and increased quality.
- No concept fulfils the requirement of payback within one year for medium volume production. For certain volumes, concept 2A reaches a lower payback time than one year.
- The benefits of automation become much clearer at higher production volumes, as the continuous costs of the concepts are much lower than the manual process.
- No concept can function entirely without human interaction; due to technical restraints and exponential costs of extreme automation.
- Automation will lower the risk of work related injuries caused by wear and tear in monotonous work tasks.
- The semi-automated concepts bring very little change to the current material flow.
- Sequencing small orders diminishes the impact on system stability.

The advantages of the semi-automated solutions, concept 2A and 2B, outweigh the advantages of other solutions of higher autonomy. Due to the ability to incrementally invest and implement the concept, the risk is much lower if circumstances change.

Hardware is not the only major cost factor in automation investments. If the costs of programming robots could be lowered and the product life cycle could be prolonged without risk, all concepts would look much more attractive to Ericsson Sandlid. By establishing programming competence in-house and directing the construction department to adapt coming products to fit in the implemented production flow, payback times would not be as important as they currently are. Of course, the cost of keeping competence in-house must be weighed against the lowered investment costs.

A semi-automated assembly flow will greatly increase the productivity of the process, lower product rework rates, and improve the working conditions of the operators involved.

For the above stated reasons, it is our recommendation that Ericsson Sandlid invests in semi-automated screw stations for the MINI-LINK assembly process after conducting further investigation in material handling and investment costs, to ensure profitability.

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APPENDIX A: Survey – System attributes

Ten different system attributes will in this study be compared with each other. Two and two they will be prioritised against each other having the outdoor production in mind. A cross will be set at the system attribute that you consider most important and if you consider both of them as equally important a cross should be set in the middle.

<u>Definitions of system attributes:</u>

Investment cost - Cost of the investment
Maintenance cost - Regular reoccurring cost to ensure function
Accuracy - Operating within requirements and tolerances
Uptime - Machine is ready to operate
Product Flexibility - Possibility to reuse the machine for new products
Volume Flexibility - Lower production means lower use of resources
Safety - Personnel safety
Ease of use - Easy to operate
Varied work tasks - Avoiding repetitive work for the operator
Speed - Possibility to vary production rate

Prioritising

		Equal		
Investment cost				**Maintenance cost**
Investment cost				**Accuracy**
Investment cost				**Uptime**
Investment cost				**Product Flexibility**
Investment cost				**Volume Flexibility**
Investment cost				**Safety**
Investment cost				**Ease of use**
Investment cost				**Varied work tasks**
Investment cost				**Speed**
Maintenance cost				**Accuracy**

Maintenance cost				**Uptime**
Maintenance cost				**Product Flexibility**
Maintenance cost				**Volume Flexibility**
Maintenance cost				**Safety**
Maintenance cost				**Ease of use**
Maintenance cost				**Varied work tasks**
Maintenance cost				**Speed**
Accuracy				**Uptime**
Accuracy				**Product Flexibility**
Accuracy				**Volume Flexibility**
Accuracy				**Safety**
Accuracy				**Ease of use**
Accuracy				**Varied work tasks**
Accuracy				**Speed**
Uptime				**Product Flexibility**
Uptime				**Volume Flexibility**
Uptime				**Safety**
Uptime				**Ease of use**
Uptime				**Varied work tasks**
Uptime				**Speed**
Product Flexibility				**Volume Flexibility**
Product Flexibility				**Safety**
Product Flexibility				**Ease of use**
Product Flexibility				**Varied work tasks**
Product Flexibility				**Speed**

Volume Flexibility				**Safety**
Volume Flexibility				**Ease of use**
Volume Flexibility				**Varied work tasks**
Volume Flexibility				**Speed**
Safety				**Ease of use**
Safety				**Varied work tasks**
Safety				**Speed**
Ease of use				**Varied work tasks**
Ease of use				**Speed**
Varied work tasks				**Speed**

APPENDIX B: HTA

The first operation is Place hull and hood, see Figure A.30: HTA for operation "Place hull and hood". Both the hull and the hood are picked up from a pallet close to the assembly station. These are later placed at a fixture.

The next operation is to adjust the cables connected to the hull, according to instructions.
The third operation is to assemble the filter, see Figure A.31. Knallban is generating a packing slip that gives information about what type of filter that is needed for the intended product. The operator gets the filter from the shelves close to the assembly station. The filter is then placed in the hull according to instructions. Then the last task in this operation is to screw the filter in place. This task is divided into additional subgroups and all screw tasks are identified as identical and will be described separately, see Figure A.37.

One of the operations is to get a gapfiller and place it at the correct position on the filter, see Figure A.32.

The first task in the assembly MB operation, see Figure A.33, is to get the MB card. The packing slip says which type of MB should be used and the card is picked from a rack close to the assembly station. The MB card is scanned and further on placed at the correct position. The next task is to collect an EMW screen and place it on top of the MB. The operation is finished after screwing the MB and the EMW screen in place, also here described separately, see Figure A.37.

The assembly of CB card operation see Figure A.34, starts with getting the CB card from a rack close to the assembly station and the packing slip indicates which type of CB card should be used. The next step in the operation is scanning the CB. After that the CB card is placed onto the filter. Finally, the CB card is screwed in place, which is described separately, see Figure A.37.

In the operation where the cables are assembled, see Figure A.35, the first task is to remove the connector protection. The connector protectors are placed on the CB card and are used in earlier stages of the production to make it possible to grip the card without destroying the contacts. The next step for the operation is to get two coaxial cables and connect the MB card with the CB card at two points. A flat cable is picked and the MB card is connected with the CB card at a third point. After that the cables from the base are connected to the CB card.

The MINI-LINK should then be screwed together, see Figure A.36. This operation starts with flipping the MINI-LINK to access the screw threads. Then a screw operation is performed, which is described separately, see Figure A.37.

When the last part at the packing slip is scanned, the UKL label is printed. One of the operations is to place the UKL at the correct position at the finished MINI-LINK. The next operation is to label the MINI-LINK with a sequence number that is generated when the last part in the packing slip is scanned. The last operation is to deliver the MINI-LINK to RauCal, here the operator takes the MINI-LINK and walks to the RauCal station and places it on a carriage. This is the last operation at the station. Afterwards, the operation sequence will start all over again.

All tasks that involve screwing are identified as identical and the first task is to get the screws, and after that place them in correct position. The last task is to screw the screws and this is done with an automatic hand tool, using the correct momentum and with an application that reduces the backlash.

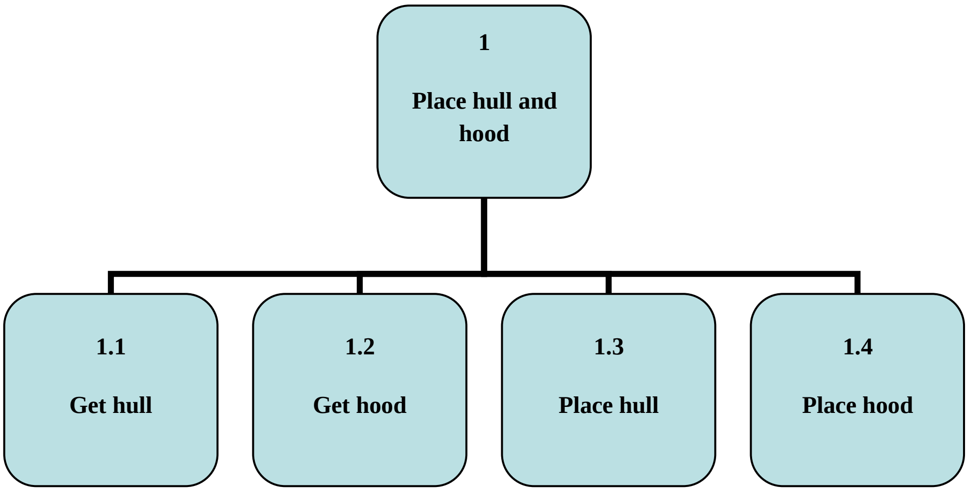


Figure A.30: HTA for operation "Place hull and hood"

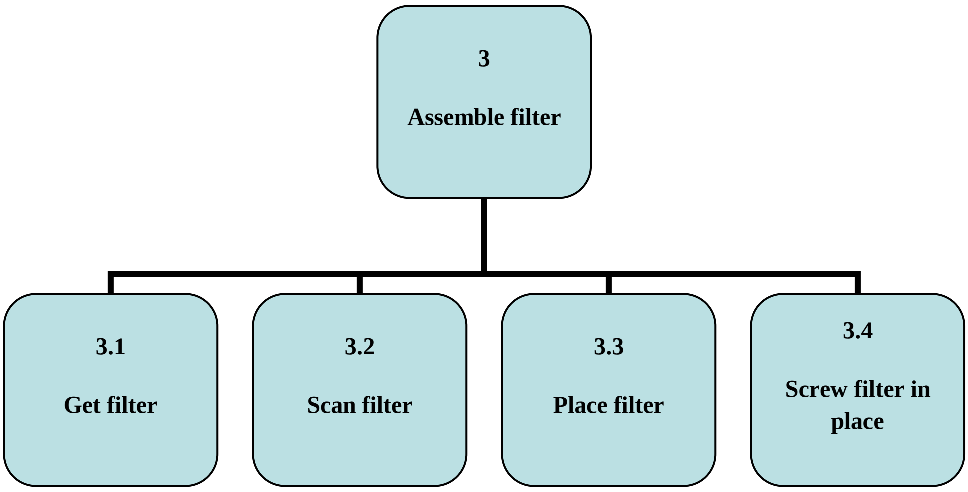


Figure A.31: HTA for operation "Asseble filter"

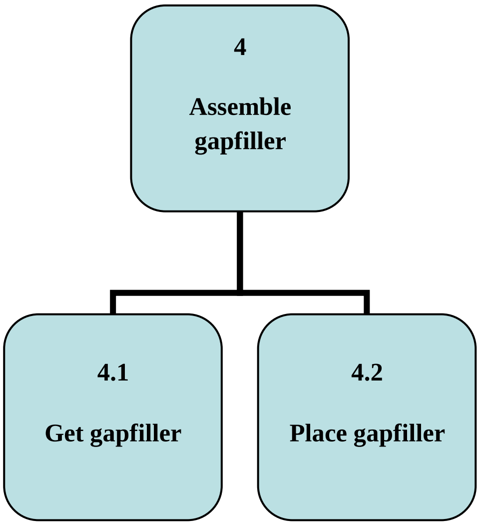


Figure A.32: HTA for operation "Assemble gapfiller"

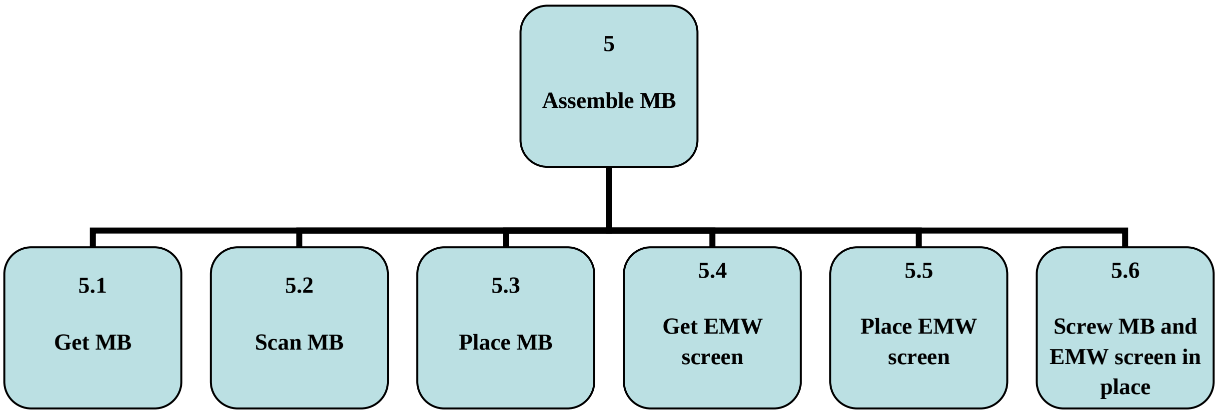


Figure A.33: HTA for operation "Assemble MB"

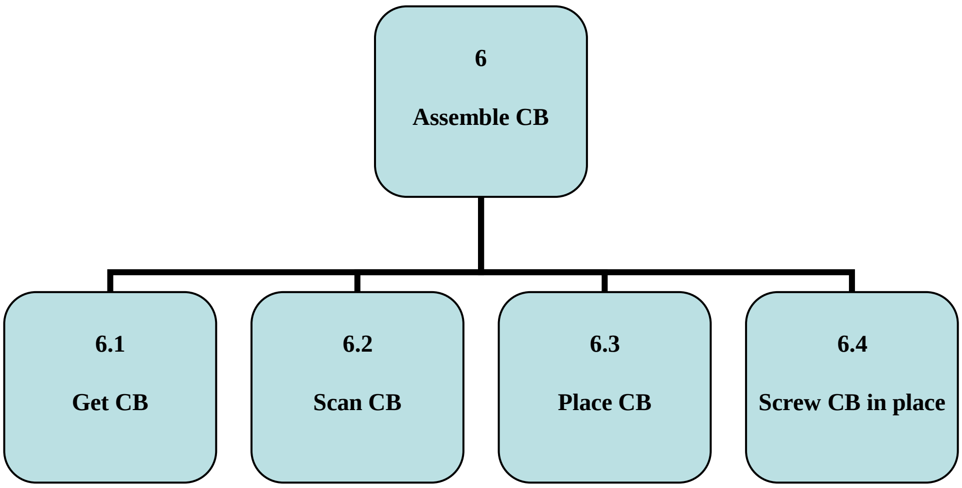


Figure A.34: HTA for operation "Assemble CB"

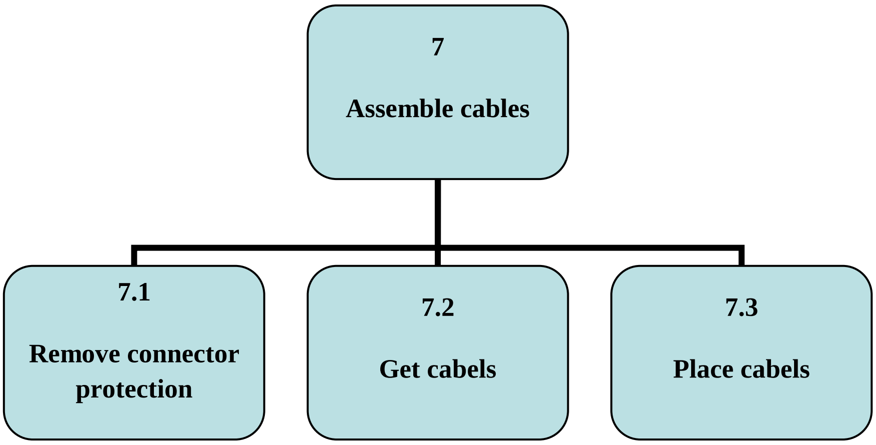


Figure A.35: HTA for operation "Assemble cables"

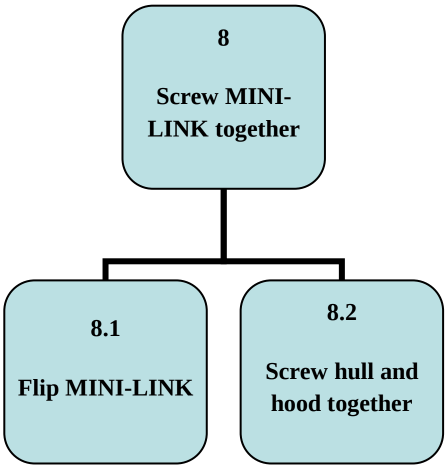


Figure A.36: HTA for operation "Screw radio together"

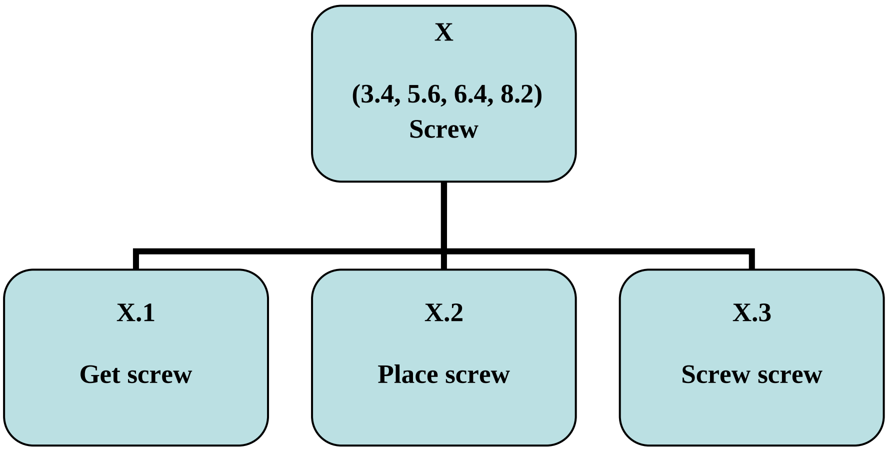


Figure A.37: HTA for operation "Screw"

APPENDIX C: LoA

The LoA score card for each operation is presented below.

Task 1.1 - Get hull	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **2**	Max LoA **6**	Comment: Barcode on each casing in future production
			Min LoA **2**	Comment:

Task 1.2 - Get hood	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **2**	Max LoA **6**	Comment:
			Min LoA **1**	Comment: Only one hood in future production

Task 1.3 – Place hull	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:

Task 1.4 – Place hood	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:

Task 2 – Adjust cables	MEK	Observed LoA **1**	Max LoA **1**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **6**	Comment: 5 mid process, 6 if separated
			Min LoA **1**	Comment:

Task 3.1 - Get filter	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **2**	Max LoA **5**	Comment:
			Min LoA **2**	Comment: Work order for required filter is needed

Task 3.2 – Scan filter	MEK	Observed LoA **4**	Max LoA **6**	Comment: The position of the label is varying depending on filter type
			Min LoA **4**	
	INFO	Observed LoA **4**	Max LoA **5**	Comment:
			Min LoA **4**	Comment:

Task 3.3 – Place filter	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **5**	Comment: Guiding pins, different patterns depending on filter range.
			Min LoA **1**	

Task 3.4.1 – Screw filter in place – See Task X	MEK	Observed LoA	Max LoA	Comment: All screw operations is treated the same
			Min LoA	Comment:
	INFO	Observed LoA	Max LoA	Comment:
			Min LoA	Comment:

Task 4.1 - Get gapfiller	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **5**	Comment:
			Min LoA **1**	Comment: Several types of gapfillers

Task 4.2 – Place gapfiller	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:

Task 5.1 - Get MB	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **2**	Max LoA **5**	Comment:
			Min LoA **2**	Comment:

Task 5.2 – Scan MB	MEK	Observed LoA **4**	Max LoA **6**	Comment:
			Min LoA **4**	Comment:
	INFO	Observed LoA **4**	Max LoA **5**	Comment:
			Min LoA **4**	Comment:

Task 5.3 – Place MB	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

Task 5.4 Get EMW screen	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

Task 5.5 – Place EMW screen		Observed LoA	Max LoA	Comment:
Task 5.5 – Place EMW screen	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

Task 5.6 - Screw MB and EMW screen in place – See Task X	MEK	Observed LoA	Max LoA	Comment: All screw operations is treated the same
			Min LoA	Comment:
	INFO	Observed LoA	Max LoA	Comment:
			Min LoA	Comment:

Task 6.1 - Get CB	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **2**	Max LoA **5**	Comment:
			Min LoA **2**	Comment:

Task 6.2 – Scan CB	MEK	Observed LoA **4**	Max LoA **6**	Comment:
			Min LoA **4**	Comment:
	INFO	Observed LoA **4**	Max LoA **5**	Comment:
			Min LoA **4**	Comment:

Task 6.3 – Place CB	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

Treated

Task 6.4 - Screw CB in place – See Task X	MEK	Observed LoA	Max LoA	Comment: All screw operations is treated the same
			Min LoA	Comment:
	INFO	Observed LoA	Max LoA	Comment:
			Min LoA	Comment:

Task 7.1 – Remove connector protection	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

Task 7.2 – Get cables	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:

Task 7.3 – Place cables	MEK	Observed LoA **1**	Max LoA **1/6**	Comment: Automation achievable? Requires some margin in contacts
			Min LoA **1**	Comment:
	INFO	Observed LoA **1**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

Task 8.1 – Flip MINI-LINK	MEK	Observed LoA **2**	Max LoA	Comment:
			Min LoA	Comment:
	INFO	Observed LoA **3**	Max LoA	Comment:
			Min LoA	Comment:

Task 8.2 - Screw hull and hood together – See Task X	MEK	Observed LoA	Max LoA	Comment: All screw operations is treated the same
			Min LoA	Comment:
	INFO	Observed LoA	Max LoA	Comment:
			Min LoA	Comment:

Task 9 – Label UKL	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

Task 10 - Label Sequence number	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **3**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

Task 11 - Deliver to RauCal	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **1**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

All screw operations is treated in the same way, see task X.

Task X.1 – Get screw	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **1**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

Task X.2 – Place screw	MEK	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:
	INFO	Observed LoA **1**	Max LoA **5**	Comment:
			Min LoA **1**	Comment:

Task X.3 – Screw screw	MEK	Observed LoA **4**	Max LoA **6**	Comment:
			Min LoA **4**	Comment:
	INFO	Observed LoA **1**	Max LoA **6**	Comment:
			Min LoA **1**	Comment:

APPENDIX D: Time study

The time study performed at Ericsson that has been used during the project is described below.

Document: Time Study Protocol No. EAB-09:043492 Uen Rev. PA1
Time study documented: 2009-06-17
Prepared by: Marina Karlsson

The assembly of MINI-LINKs have been divided in different operations. Each operation have been clocked separately and documented in a protocol. The study has been performed using ten samples, where at least one per shift has been clocked. A mean value of the ten samples has been calculated. The division between operations is described below, see Table A.9. The cycle time for the assembly of the radio is [redacted] seconds.

Table A.9: Time study for assemble of Rau2.1.

Operations	**Mean Value [sec]**
Place hull and hood	[redacted]
Inspect hull and hood in detail	[redacted]
Place cables according to picture	[redacted]
Get filter	[redacted]
Put on ESD-bracelet	[redacted]
Get MB & CB	[redacted]
Scan filter, MB & CB	[redacted]
Assemble filter (including beep-test)	[redacted]
Place gapfiller	[redacted]
Assemble CB, MB and EMW screen	[redacted]
Remove plastic guard	[redacted]
Assemble cables	[redacted]
Inspect cables	[redacted]
Flip radio and screw together	[redacted]
Label with UKL-label	[redacted]
Inspect radio in detail	[redacted]
Label with sequence number and sign	[redacted]
Deliver radio to RauCal	[redacted]
Go back to assembly station	[redacted]

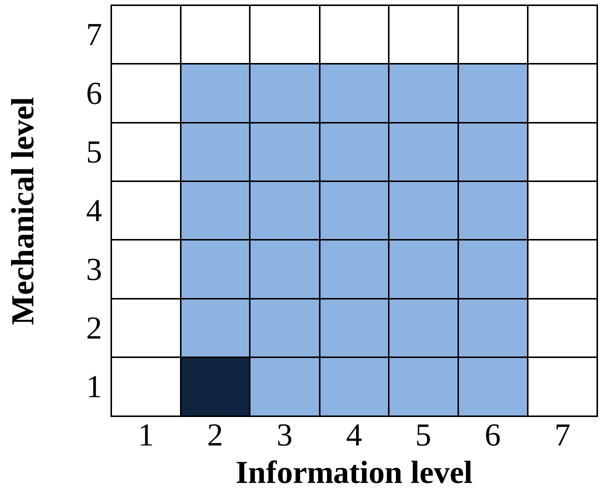
In order to get the theoretical cycle time for the assembly station there is some movements that need to be added to the time it takes to assemble the Rau2.1. The time it takes to handle the incoming material from the kanban train and the time it takes to handle the empty boxes and wrapping from parts included in the assembly. The total time it takes to handle these additional tasks have been calculated and divided between the products produced. The total theoretical cycle time is described in Table A.10.

Table A.10: total theoretical cycle time for the assembly station.

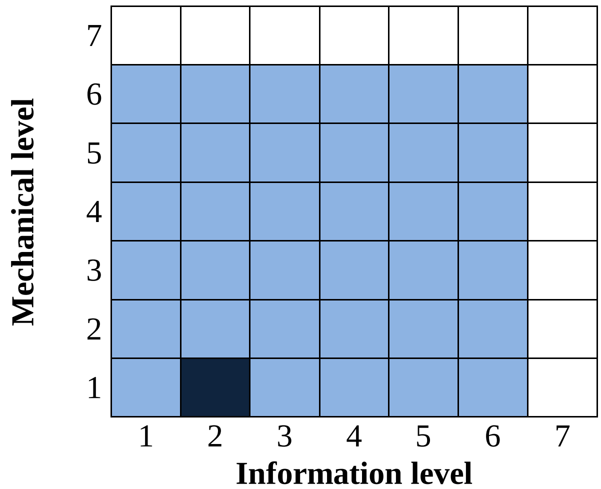
Operation	**Time [sec]**
Assembly of Rau2.1	[redacted]
Material train	[redacted]
Wrapping	[redacted]
Total theoretical cycle time	[redacted]

APPENDIX E: SoPI analysis

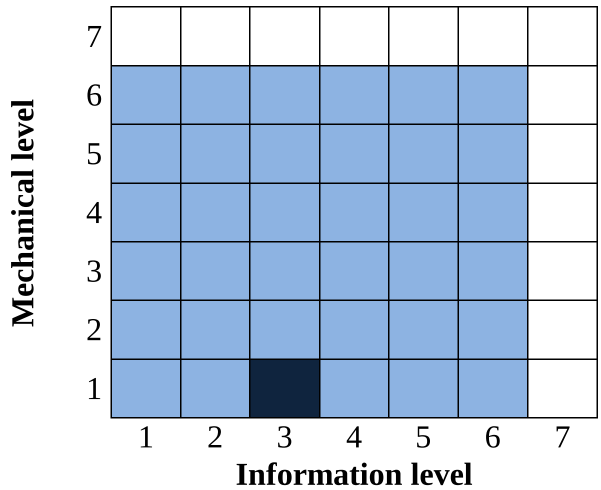
Task 1.1 - Get hull



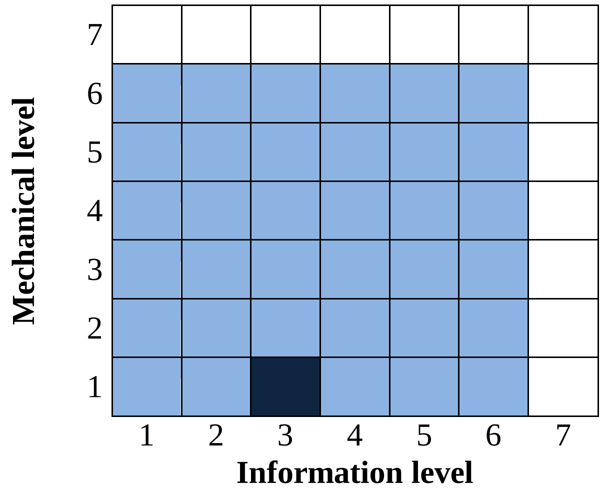
Task 1.2 - Get hood



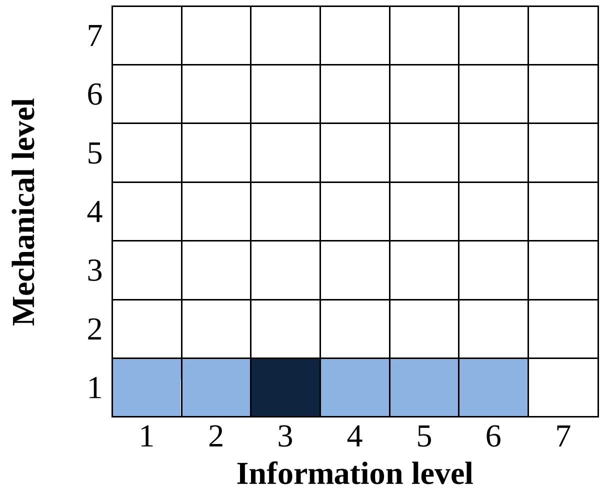
Task 1.3 – Place hull



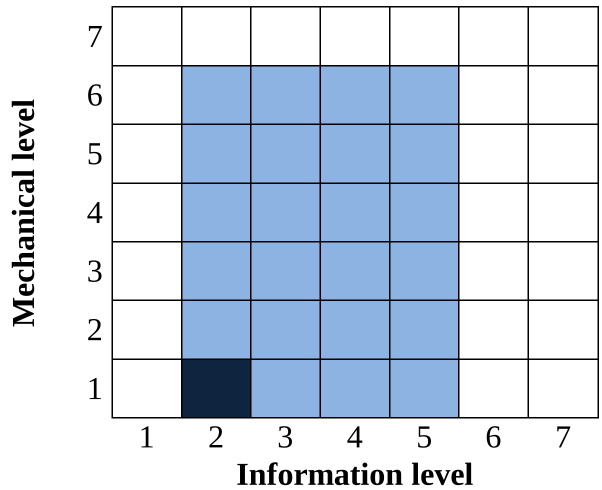
Task 1.4 – Place hood



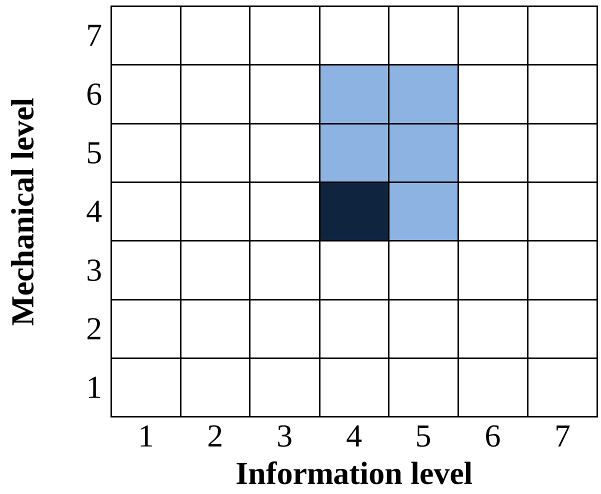
Task 2 – Adjust cables



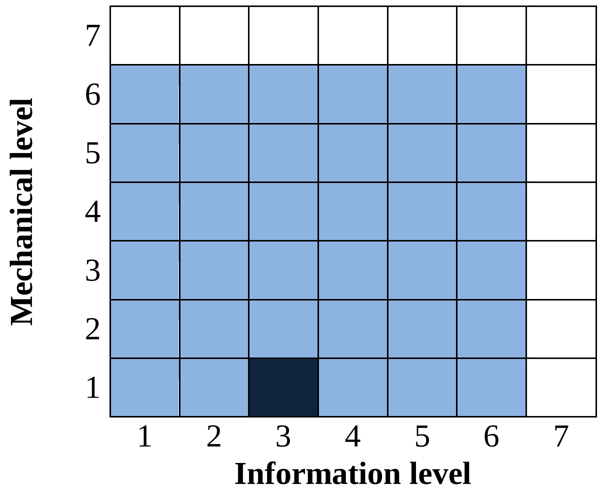
Task 3.1 - Get filter



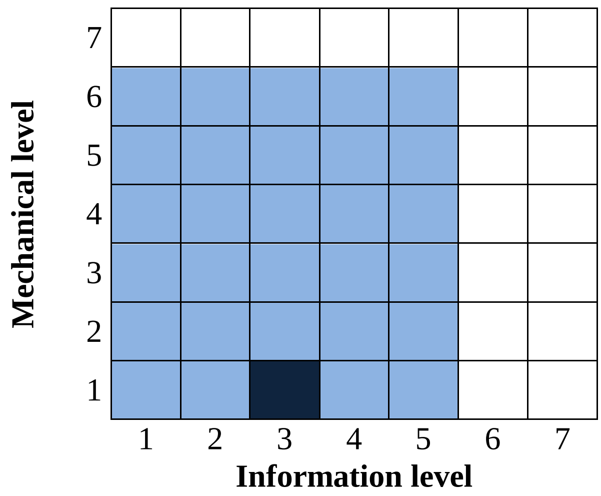
Task 3.2 – Scan filter



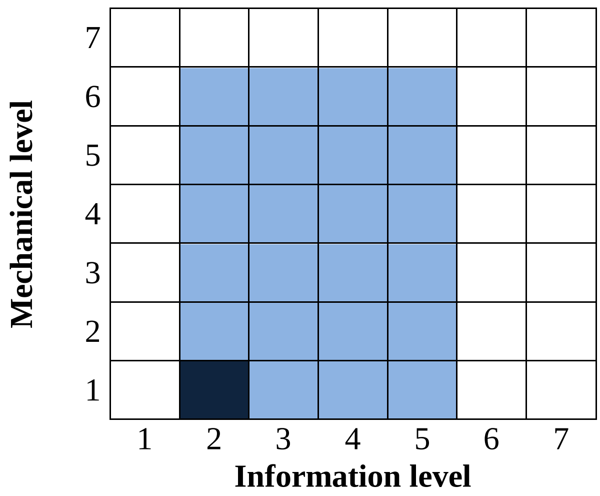
Task 4.2 – Place gapfiller



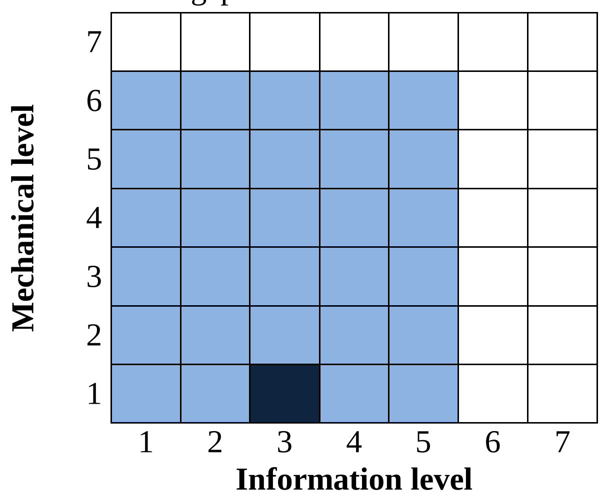
Task 3.3 – Place filter



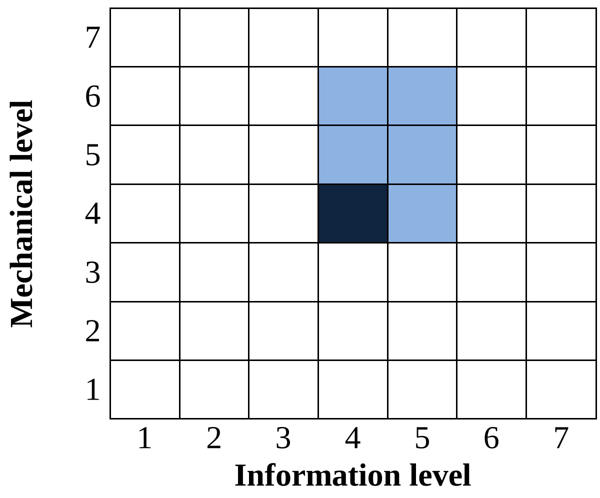
Task 5.1 - Get MB



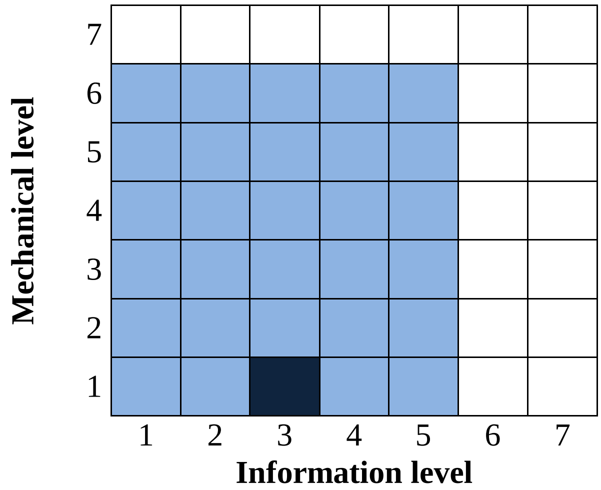
Task 4.1 - Get gapfiller



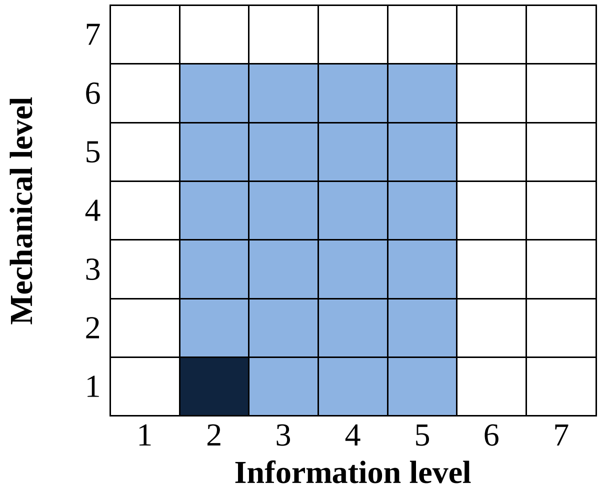
Task 5.2 – Scan MB



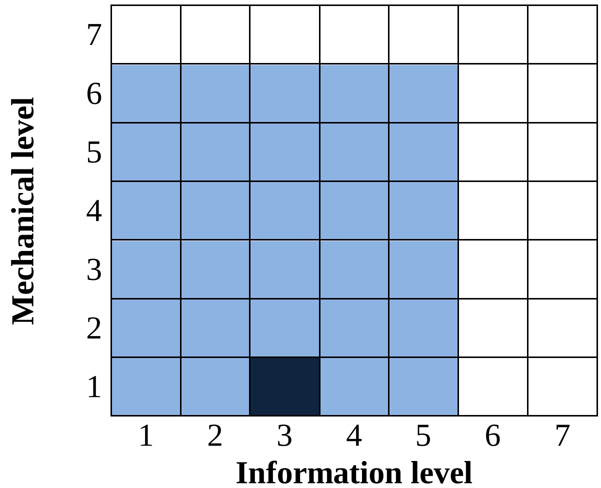
Task 5.3 – Place MB



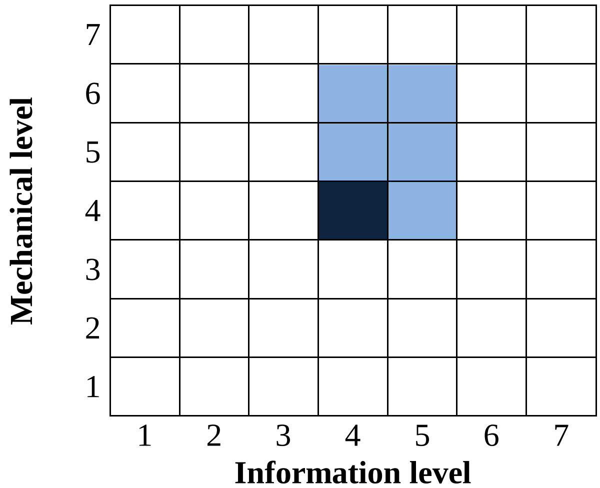
Task 6.1 - Get CB



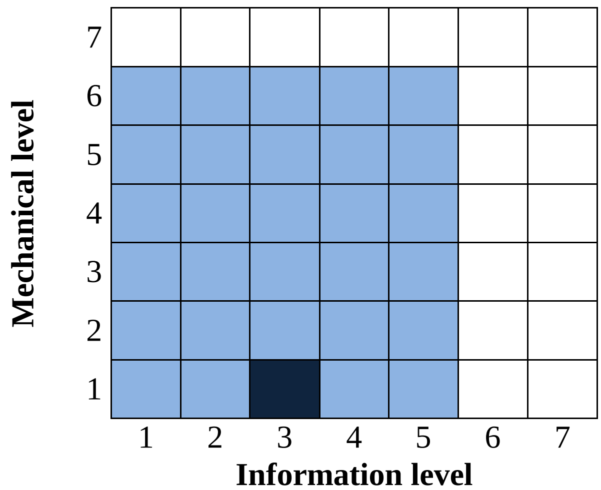
Task 5.4 Get EMW screen



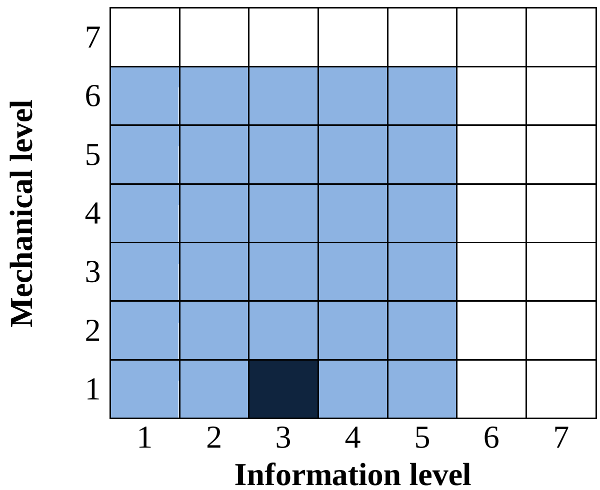
Task 6.2 – Scan CB



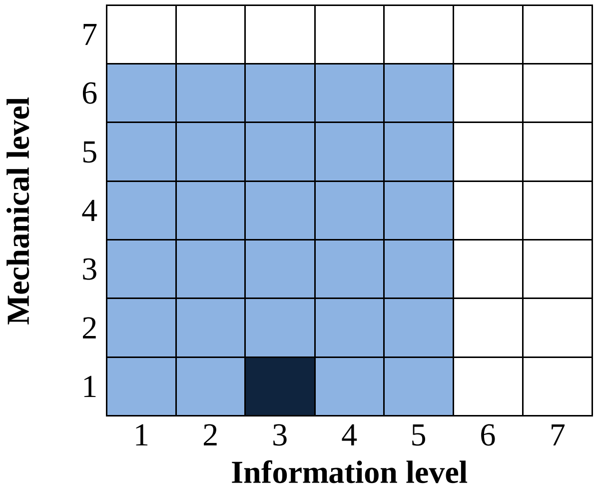
Task 5.5 – Place EMW screen



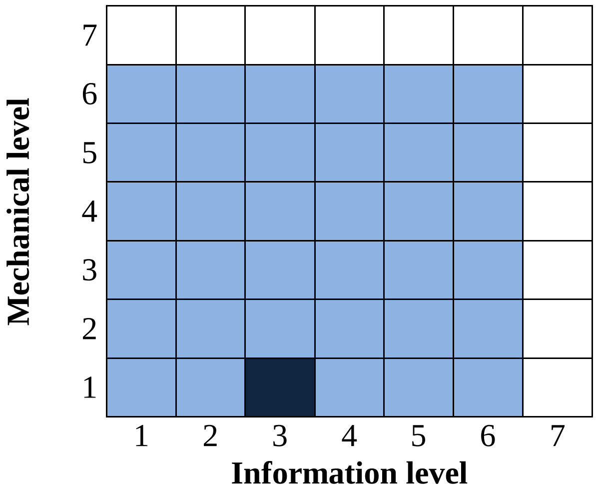
Task 6.3 – Place CB



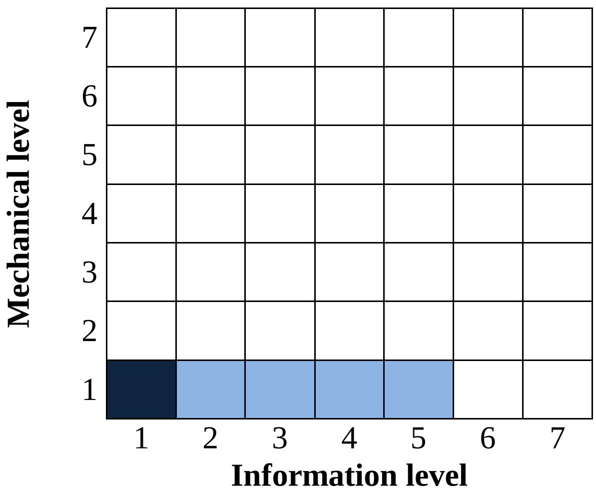
Task 7.1 – Remove connector protection



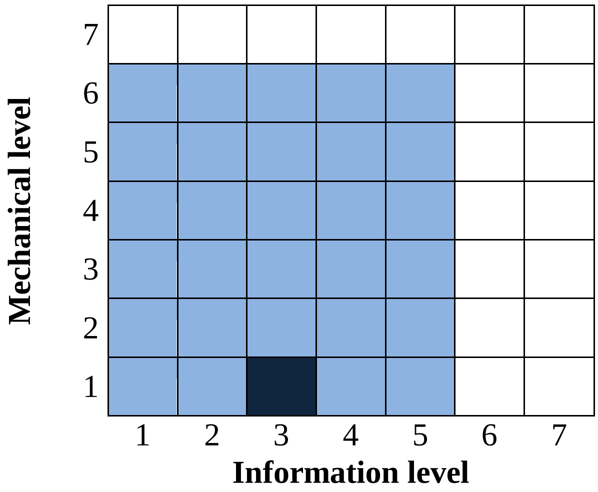
Task 7.2 – Get cables



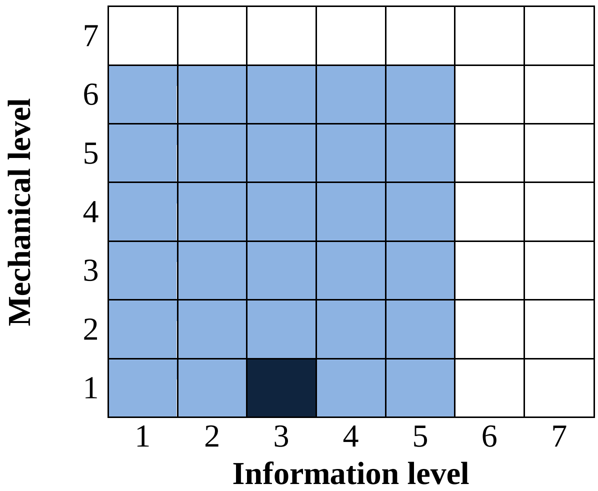
Task 7.3 – Place cables



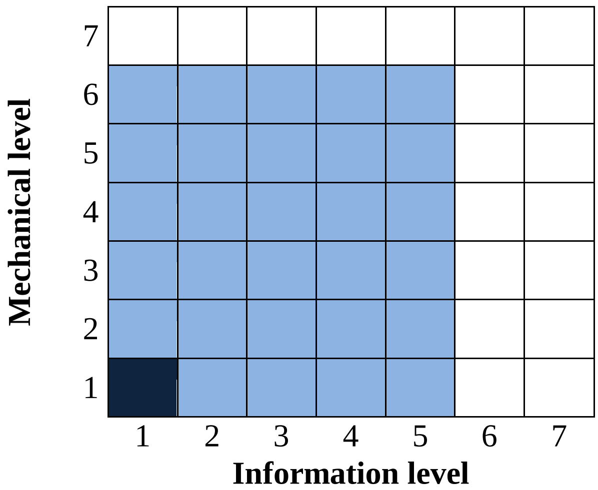
Task 9 – Label UKL



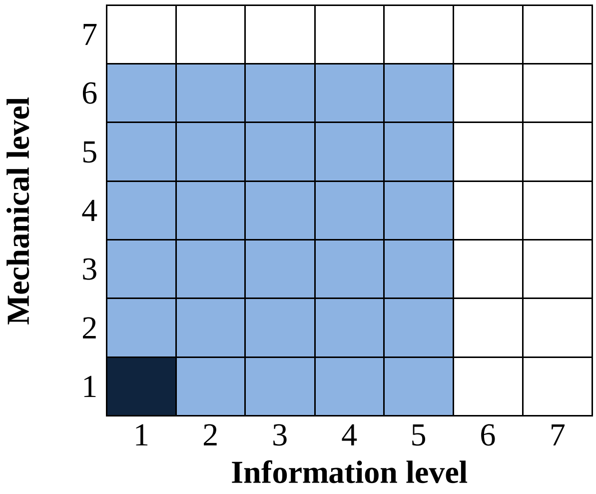
Task 10 - Label Sequence number



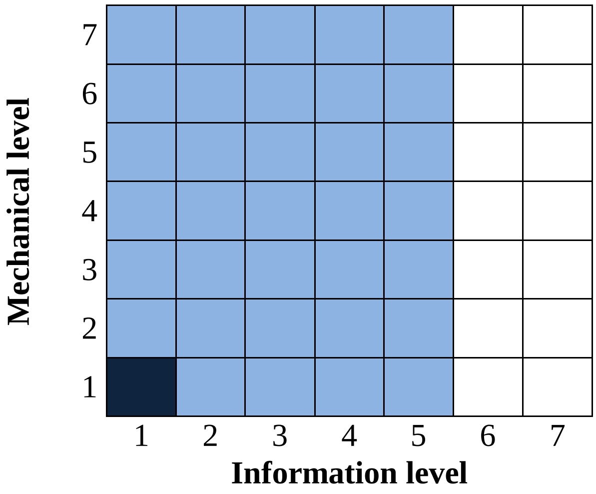
Task 11 - Deliver to RauCal



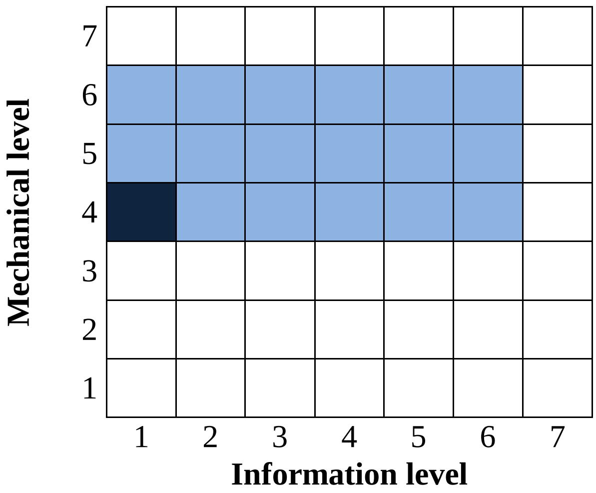
Task X.1 – Get screw



Task X.2 – Place screw



Task X.3 – Screw screw



APPENDIX F: Specification of Concept 1 – Assembly line

Station	Unit	Measure	Quantity	Tool
Station 1	Gravity roller conveyor for the hulls	50x200cm	11	
	6-axis robot	175cm radius to reach hulls		Multi gripper - 2 tools - grip hull and filter
	Vision-system for control of cables and secure positions		1	
	Label robot			
	Conveyor for filter	40cm wide		
	Scanner for barcodes on filter			
Station 2	6-axis robot	55cm radius		Multi gripper - 4 tools
	Cartridge Gapfiller	5x5 cm	2	
	Cartridge EMW-screen	20x30cm	2	
	Conveyor for incoming MB	30cm wide		För kretskort - 2 conveyorband i kanterna
	Scanner barcode MB			
	Feeder Supersorb	20x20cm	1	
	Vision-system to secure positions		1	
Station 4	SCARA-robot	48cm radius		Multi gripper - 2 tools - grip list and CB
	Cartridge for list	20x4cm	2	
	Conveyor for incoming CB	30cm wide		
	Scanner barcode CB			
	Vision system to secure positions		1	
Station 6	Roller conveyor	3m long		

Station 7	XYZ-robot for hood assembly	100x100cm including material feeding		
	Label robot		2	
Screw stations (station 1, 3, 5 and 8)	XYZ-robot with screwdriver	100x100cm	3	
Transport system	Lift for the fixtures	60x60cm		
	Fixtures	40x40cm	40	
	Conveyor for fixture	8.7 + 3.8m (Before and after manual station)		
Buffer of finished products	Buffer conveyor for finished products	4m		Damper is needed - collision between products is not ok
	2-axis robot for transferring			

APPENDIX G: Operations within sequences in concept 2A and 2B

The operations within the sequences for concept 2A and 2B can be described as follow:

Sequence 1:

Manual operation A	Place hull and assemble filter
Screw operation A	Screw filter in place
Manual operation B	Assemble gapfiller, Assemble MB and Assemble EMW screen
Screw operation B	Screw MB and EMW screen in place
Manual operation C	Assemble CB (For RauX add assemble list)
Screw operation C	Screw CB in place
Manual operation D	Assemble cables and place hood
Screw operation D	Screw radio together

Sequence 2:

Manual operation A	Place hull and assemble filter
Screw operation A	Screw filter in place
Manual operation B + C	Assemble gapfiller, Assemble MB and Assemble EMW screen + Assemble CB (For RauX add assemble list)
Screw operation B + C	Screw MB and CB in place
Manual operation D	Assemble cables and place hood
Screw operation D	Screw radio together

APPENDIX H: Task allocation

This appendix states if humans or machines are best at satisfying the system attributes of the system. Due to time constraints, the lowest resolution of scoring is used. This differs from the LoA analysis in the project, where a scale of 1 to 7 is used. Here 1 is representing human and 0 is representing machines. If the machine and the human are equally satisfying the system attributes the number 0,5 is used. The result is summarised and will represent the base coordinates. Table A.11 shows the individual results and the summarised result.

Table A.11: Task allocation analysis on the system attributes for a system where 1 represent the human and 0 represent the machines.

System attributes	Author 1	Author 2	Author 1 & 2 (X)	1-X (Y)
Investment cost	1	1	1	0
Maintenance cost	1	1	1	0
Accuracy	0	0	0	1
Uptime	0	0.5	0.25	0.75
Product flexibility	1	1	1	0
Volume flexibility	1	1	1	0
Safety	0	0	0	1
Ease of use	0	0	0	1
Varied work tasks	0.5	1	0.75	0.25
Speed	0	0	0	1

The coordinates of the Price decision matrix

The base coordinates are further on used to calculate the Ericsson required task allocation. The base coordinates will be multiplied with the weight generated from the questionnaire on pair wise comparison between system attribute, where the performance advantage of each system attribute between humans and machines have been defined, see Table 4.4. These values will defined the X and Y coordinates of each attribute and used to calculate the coordinates of the concepts in the Price decision matrix. By multiplying these coordinates with their respective weights found in quantitative studies, a compounded point for the entire desired system can be defined, see Table A.12.

Table A.12: Calculations of the task allocation according to Ericsson's requirement, between man and machine.

Weight system attributes [%]	Base coordinates X	Weighted coordinates X	Base coordinates Y	Weighted coordinates Y
3.93	1	3.93	0	0
10.11	1	10.11	0	0
17.42	0	0	1	17.42
16.29	0.25	4.07	0.75	12.22
6.74	1	6.74	0	0
8.99	1	8.99	0	0
16.29	0	0	1	16.29
7.30	0	0	1	7.30
3.37	0.75	2.53	0.25	0.84
9.55	0	0	1	9.55
TOTAL		**36.38**		**63.62**

By using the currently implemented system as a reference point, new concepts may be placed along the automation scale. The current system is given a coordinate by analysing the LoA of the involved tasks. Using the same resolution as with the base coordinates, tasks are deemed either automated, halfway automated, or manual. By doing so, 7 out of 27 tasks are found to be halfway automated, found in the scanner or screwdriver tools (level 4 on both the information scale and the mechanical scale).

The amount of tasks performed by the machine can then be calculated and will represent the Y-axis:

$$\frac{Number\ of\ tasks\ performed\ by\ machine}{Number\ of\ tasks}[\%] = \frac{7/2}{27} = 12{,}96\% \qquad \text{(A.5)}$$

$$\text{X–axis} = 100 - \text{Y–axis} = 100 - 12{,}96 = 87{,}04$$

This gives a coordinate of (87.04; 12.96) in favour of manual work. By setting the number of operators in the current system as 100%, the number of operators in the concepts will scale their respective coordinates by their relation to the current system.

The amount of operators needed for the different concept in relation to the current system will give a relative offset. The coordinates for the concept will be translated using this relative offset.

APPENDIX I: Cost and profitability

Cost theory
The cost of the current manual process at Ericsson can be divided in separate elements. For ease of comparison, the costs elements that remain unchanged for the concepts will not be used for calculation. The elements used will be: implementation cost, annual salary and annual maintenance.

Implementation cost includes hardware, software and installation of the concept. Annual salary is the sum of wages of the operators for the required production hours per year. Annual maintenance includes technical maintenance services performed weekly, monthly or yearly. Annual maintenance also includes spare parts. Annual maintenance costs for the concepts are estimated by an experienced technician at Ericsson.

The cost of the current process is calculated by using an expected volume, divided by the production rate, divided by the yearly work hours of an operator, times the yearly cost of an operator. Added onto this is the annual cost of supportive systems.

The required amount of machines differs from concept to concept, but will be calculated to support two shifts of operators per day. Equipment is expected to run constantly, but the takt time will be increased if production rate is too high.

The annual savings are the decreases in annual costs, minus machine write-off costs.

Profitability
Many measurements may be used to indicate profitability in the concepts. The most common at Ericsson are payback time and TK-reduction. In addition to these, the internal rate of return and the modified internal rate of return are calculated as complementary key system attributes. As a more general measurement, return on investment defines the net profit divided by the investment cost, without considering interest.

Annual Operator Cost

Current process

$$\text{Total Annual Operator Cost} = \text{Operators Required} * \text{Operator Annual Cost} \quad \text{(A.6)}$$

$$\text{Operators Required} = \frac{\text{Volume}}{\text{Production Rate per Operator} * \text{Work Hours per Year}} \quad \text{(A.7)}$$

$$Work\ Hours\ per\ Year = Operator\ Annual\ Work\ Hours * Operator\ Shifts \quad \text{(A.8)}$$

Concept 1

$$\text{Total Annual Operator Cost} = \text{Operator Annual Cost} * \text{Operators Required} \quad \text{(A.9)}$$

$$\text{Operators Required} = [\text{Static Optimum}] \quad \text{(A.10)}$$

Concept 2A

$$\text{Total Annual Operator Cost} = \text{Operator Annual Cost} * \text{Operator Required} \quad \text{(A.11)}$$

$$\text{Operators Required} = \frac{\text{Volume}}{\text{Production Rate per Operator} * \text{Work Hours per Year}} + [\text{Material Supplier; 1 in 6}] \quad \text{(A.12)}$$

Concept 2B

$$\text{Total Annual Operator Cost} = \text{Operator Annual Cost} * \text{Operator Required} \tag{A.13}$$

$$\text{Operators Required} = \frac{\text{Volume}}{\text{Production Rate per Operator} * \text{Work Hours per Year}} + [\text{Material Supplier; } 1 \text{ in } 6] \tag{A.14}$$

Concept 3

Unknown

Profitability

Payback Time [Years] (A.15)

$$\text{Payback Time (Volume)} = \frac{\text{Investment Cost (Volume)}}{\text{Annual Savings (Volume)}}$$

$$\begin{aligned}\text{Annual Savings (Volume)} \\ = \text{Current Annual Cost (Volume)} - \text{Concept Annual Cost (Volume)}\end{aligned} \quad \text{(A.16)}$$

$$\begin{aligned}\text{Concept Annual Cost (Volume)} \\ = \text{Total Annual Operator Cost (Volume)} \\ + \text{Total Annual Maintenance Cost (Units\textbackslash Lines)} \\ + \text{Total Supportive Systems Cost}\end{aligned} \quad \text{(A.17)}$$

APPENDIX J: AutoMod

A brief AutoMod simulation model is run on concept 2A to establish that the system has a steady state that proves viability. The model is coded with two parallel processes to simulate two operator flows sharing the same machine resources. The automated screwing time is lower than the corresponding manual time and thanks to clever queuing; there is minimum to no wait time for the operators.

The model has not taken breakdowns into consideration. Instead a generalised efficiency rating will be used for the output.

The simulation shows there is a very brief warm-up time, but the output per operator of the steady state system is equal to concept 2B.

APPENDIX K: Efficiency

The efficiency of a process at Ericsson is defined as model fulfilment. The model fulfilment is used to calculate the additional time required to produce a specified amount of products.

Model fulfilment is defined for a full process flow, meaning the final assembly step does not have a unique model fulfilment. Therefore, another measure must be defined to accurately calculate the manual time in the thesis.

Availability of operators in the current manual process will be defined as the theoretical minimum time divided by the current takt time. Because the takt time takes meeting time, bathroom breaks, equipment problems and material handling into account; this will also be included in the availability measure.

$$\frac{Theoretical\ minimum\ time}{Takt\ time} \approx 70\% \tag{A.18}$$

In addition to this, there is also some system loss which is mainly caused by material supply chain issues. This can be calculated by dividing the summarised production goal over a year divided by actual production. However, to make a sensible comparison to the suggested concepts which will likely have the same issues, this system loss is ignored.