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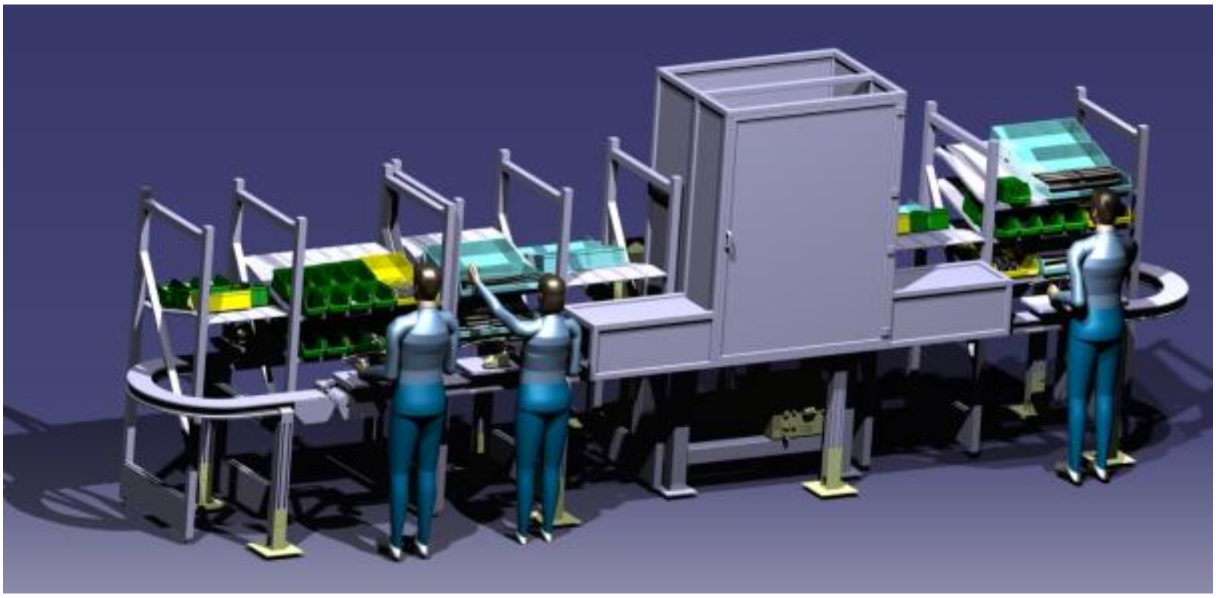

Theory-based design of a manual assembly line in a dynamic environment

Master of Science thesis [Production engineering, PPUX05]

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Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2017

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Cover:
[Picture of a conceptual solution for the production of a new product visualized by a CAD program]

[Chalmers reproservice]
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Abstract

The lighting solution manufacturer TYRI is a company in a period of growth and they are designing a new product to capture market shares. To be able to deliver the new product in time, with good quality and in the right quantities, a new production unit should be developed solely for this specific product.

The purpose of this thesis is to convey academically anchored production principles and ideas on how to design a production system around one of these new products. These ideas are intended to be delivered via a conceptual model to provide valuable input that can be used to facilitate, improve and act as a source of inspiration for TYRI's own ongoing design process. The thesis is delimited to only considering the new product in their factory.

During the later stages of the project changes to the prerequisites critically impacted the applicability of the proposed design. Despite this, the thesis can still fulfil its purpose of providing value as the conceptual solution is a result of production systems theory applied through a systematic methodology. The described course of action used to develop the conceptual solution surfaces structured engineering methods and tools that can influence and inspire TYRI in their own development process.

Keywords: Production development, Disturbance handling, ACD^3, Lean production, Workplace ergonomics, SAM, Line balancing, Line design.

Acknowledgements

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Furthermore, we would like to thank Lars-Ola Bligård at Chalmers for explaining and aiding regarding how the development tool ACD^3 can be used in a production project such as ours. In addition, we would like to thank Peter Almström for providing us with his expert knowledge of SAM.

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Adam Andersson and Jakob Sandström

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1 Introduction

This first chapter will provide the reader with insight into why the thesis was made and what prerequisites that existed. The background and information about the project structure will provide the reader with context. Moreover, the purpose and goal will present what the thesis was expected to achieve, and lastly the scope and delimitations will introduce the frame within which the thesis has operated.

1.1 Background

TYRI is a company specialised at making LED, HID (Xenon) and Halogen lighting solutions designed for heavy vehicle environments such as mining, forestry, construction, agricultural and material handling. They are present at multiple locations all over the world, meaning they offer products globally. USA, Brazil, United Kingdom and Sweden are some of the locations where they are present.

Right now, the company is in an episode of growth and has initiated a collaboration with a new customer. Together they have designed a new product which has been cleared to go into production during early 2017. For TYRI, this project is of the utmost importance as the client is a prominent producer of material handling equipment on the global market. If TYRI can prove themselves and live up to the expectations, it could lead to securing a long-term contract. This contract would in turn mean a twofold increase of TYRI's annual turnover. A lasting relationship with a significant manufacturer could also mean that TYRI receives the rights to produce additional parts to other products as well, further strengthening the relations and the TYRI brand. TYRI now faces a challenge where success would lead to becoming a company at the forefront of lighting solutions.

To satisfy new design demands and at the same time keep up with current production TYRI plans to introduce a new production unit in their factory. Moreover, they plan to expand their current premises and rearrange both their production and storage layout. Consequently, TYRI are investing a lot of resources into this project. Combined with the fact the customer has high demands on delivery precision and quality (see requirement specification in appendix I) the plan represents a risk for the company.

With the objective to design the new production unit and plan the layout inside the new facilities a small project group has been put together at TYRI. The team consists of personnel with experience both from the industry and the company's production system. However, TYRI sees this as an opportunity to improve their way of working and influence the project with new and relevant research. To this goal, a team from Chalmers University of Technology was enlisted to design an alternative solution, derived from an academic standpoint, in parallel to TYRI's own development of the product and the new production system. This team from Chalmers will henceforth be referred to as the thesis team.

1.2 The product

The product in question is the rear lamp of a logistic vehicle (see figure 1) and it consists of three distinct parts, two identical side parts and one middle part. In turn, these parts each consist of four types of subcomponents as can be seen in figure 2. Covers are meant to shield inner components, light conductors direct the light in the correct way, electrical components supply light and power while holders keep important components in the right place. Apart from these there are also several smaller parts like screws and gaskets.

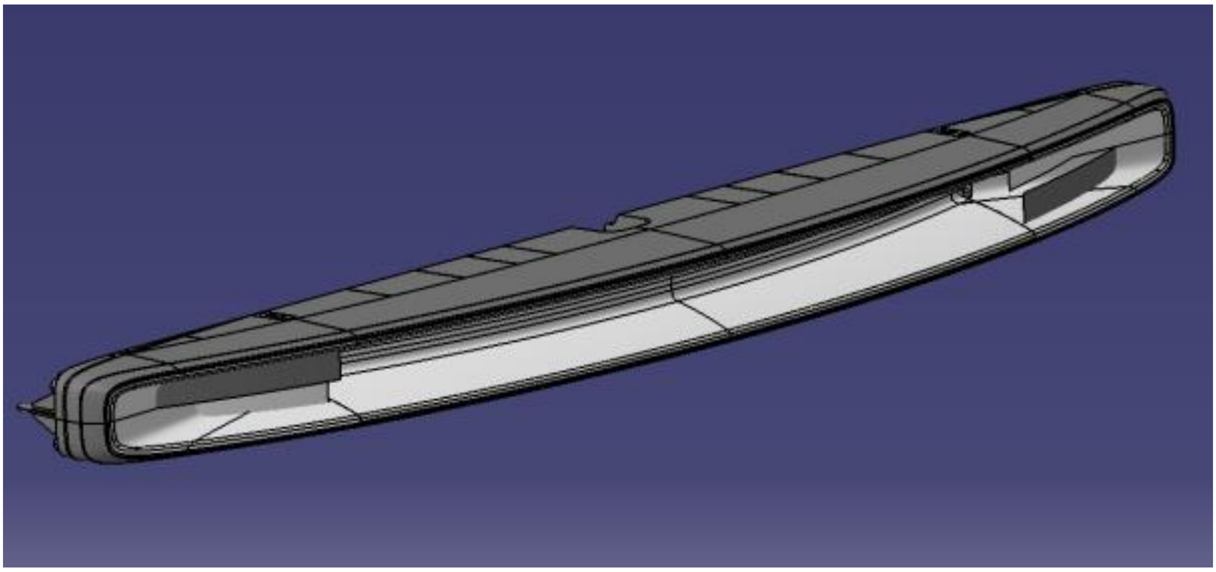

Figure 1. CAD model of TYRI's new product.

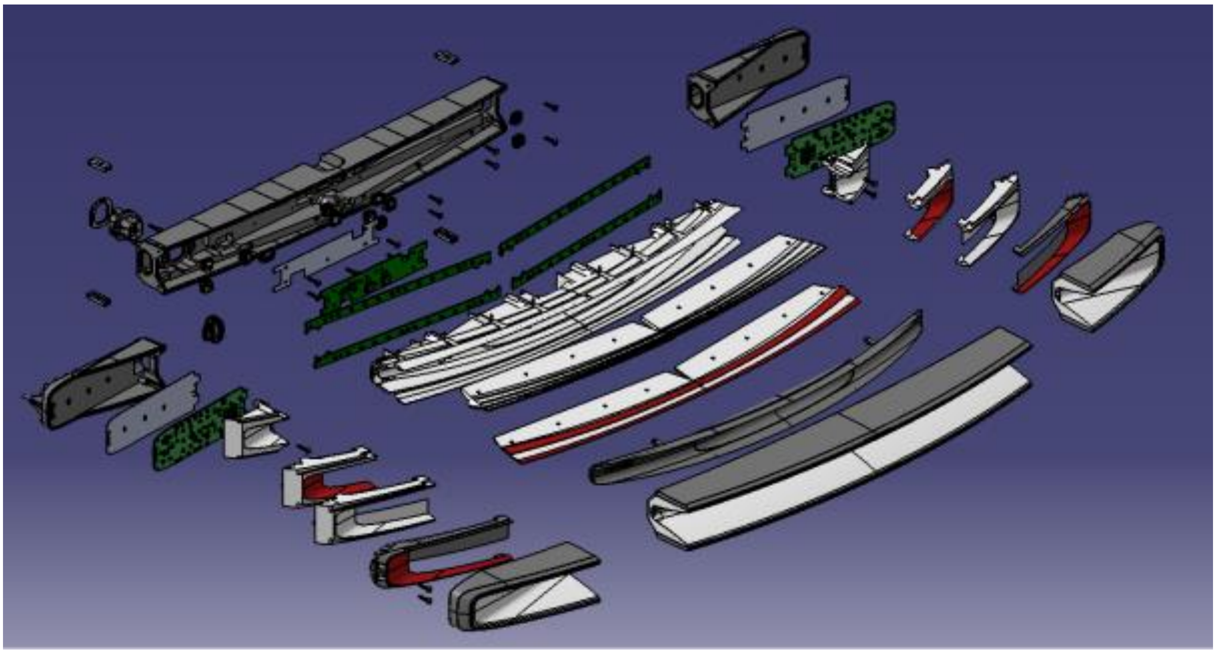

Figure 2. Exploded view of TYRI's new product with the three parts clearly separated.

From an assembly perspective, there are a few parts that are of extra interest. First, the top covers for all three parts need to be glued onto the bottom covers. This process complicates the assembly since it demands a 24-hour hardening period after the top and bottom covers have been merged. Furthermore, the three parts of the product cannot be merged before the glue has cooled since the warm air must be evacuated. Otherwise the components might expand from within and become deformed. Consequently, this creates the need for a storage before the final assembly where the parts can harden. The duration required is also a problem since a storage equal to one day's demand will be bulky.

Another problem area is the cables that connect all the electrical components (cables are not included in the CAD model, see appendix II for explanation). First, cables are generally harder to handle than the other plastic components due to their non-rigid nature and their tendency to flex. In addition, there is also limited space beneath the covers. Different lengths of cables impose different challenges. Long ones will be hard to tuck into their assigned slots while the shorter ones make proper connections difficult due to less leeway.

Lastly, the small plastic clips that are used to merge the three parts of the products (in appendix III) can also prove to be challenging. They need to fit tightly enough to ensure that the product will not break apart but not too tight so that the operator cannot place the clip.

1.3 Project complexity

As stated in the background, the thesis team of this thesis has worked in parallel with a design team from TYRI. These two have worked together closely, keeping up to date with the progress of one another. However, an important note is that as new design decisions were made by TYRI's design team or higher instances in the company, adjustments had to be made to the requirement specification for the thesis team. For instance, when a certain type of robot or line was chosen by TYRI, the thesis team had to take the new information into account to try to reduce the gap to reality. A longer description of how the work has proceeded can be found in chapter 3. Furthermore, from the initiation of the thesis and throughout its course the product development team at TYRI has worked with their customer to perfect the product. This means that the product has undergone changes during the thesis.

The parallel setup of the development work in the thesis has, at times, affected the engineering work process due to alterations of the preconditions. This subject is explained in chapter 5.

1.4 Purpose

The primary purpose of the thesis is to convey academically anchored ideas on how to design a production system around a product for TYRI. This knowledge is intended to be delivered to TYRI though a conceptual solution where theoretical linchpins of production development are surfaced and applied. Secondary to the main purpose is to examine how disturbances to the product development and design criteria affect production development and the subsequent value of existing solutions. Moreover, another secondary purpose is to test and evaluate the Activity-Cantered Design Decision Determination (ACD^3) framework in a production development case in a project with dynamic decision making (Berlin & Bligård, 2016).

1.5 Goals

The goals of the thesis are formulated to fulfil the overall purpose. The deliveries aim at providing TYRI with valuable input that can be used to facilitate and improve their own ongoing production system design process.

- Deliver a conceptual solution of a production system anchored in theoretical knowledge.
- Test a novel production development framework as a base for decision making in a production development case.
- Examine and evaluate what impact disturbances in the product design has on the production system development.
- Examine and evaluate what impact late-stage changes to the goal and effect of the production system has on the development.

1.6 Scope

The master thesis will be conducted at TYRI Sweden AB with the main objective to design an alternative concept for the production line of a new product. The concept will focus on the theories described in the thesis and the thought process of the thesis team. Areas that will be investigated are production strategy, ergonomics, material handling and production layouts. The concept will incorporate three main areas:

- A suggestion for the line including the sequencing of work tasks, balancing of stations and general layout.
- A description of the material stored at each station, how it is replenished and what support functions that exist.
- A simple plan of the layout that shows routing of materials, milk runs (see chapter 4.9) and areas for storage and production.

1.7 Delimitations

To complete the project within the given time frame, delimitations need to be established. The thesis will only consider aspects related to the new product when designing the production system. The potential impact of already existing products and product families will not be considered for the developed solution.

Moreover, the thesis will not consider any aspects related to management. Examples of excluded managerial topics are organisational control, work scheduling, production planning and information systems. Custom equipment design has also been excluded from the thesis such as fixtures and test equipment.

Interviews will not be held with the assembly personnel at TYRI as it was concluded that it probably would not generate enough usefulness in comparison to the time invested. This is derived from the fact that they have little insight into the new product and its production procedure.

2 Theoretical framework

The theoretical framework will provide the reader with the necessary theories and terminology to grasp the thesis and its findings.

2.1 Lean production

Ever since Womack et al. (1990) introduced the world to the concept of lean, companies have tried to mimic what Toyota accomplished during the 50s and 60s. When striving to grasp the concept of lean production, the Toyota production system is thereby a good place to start. The most common starting point in explaining "The Toyota Way" is the 4P model (Liker & Meier, 2006), as can be seen in figure 3.

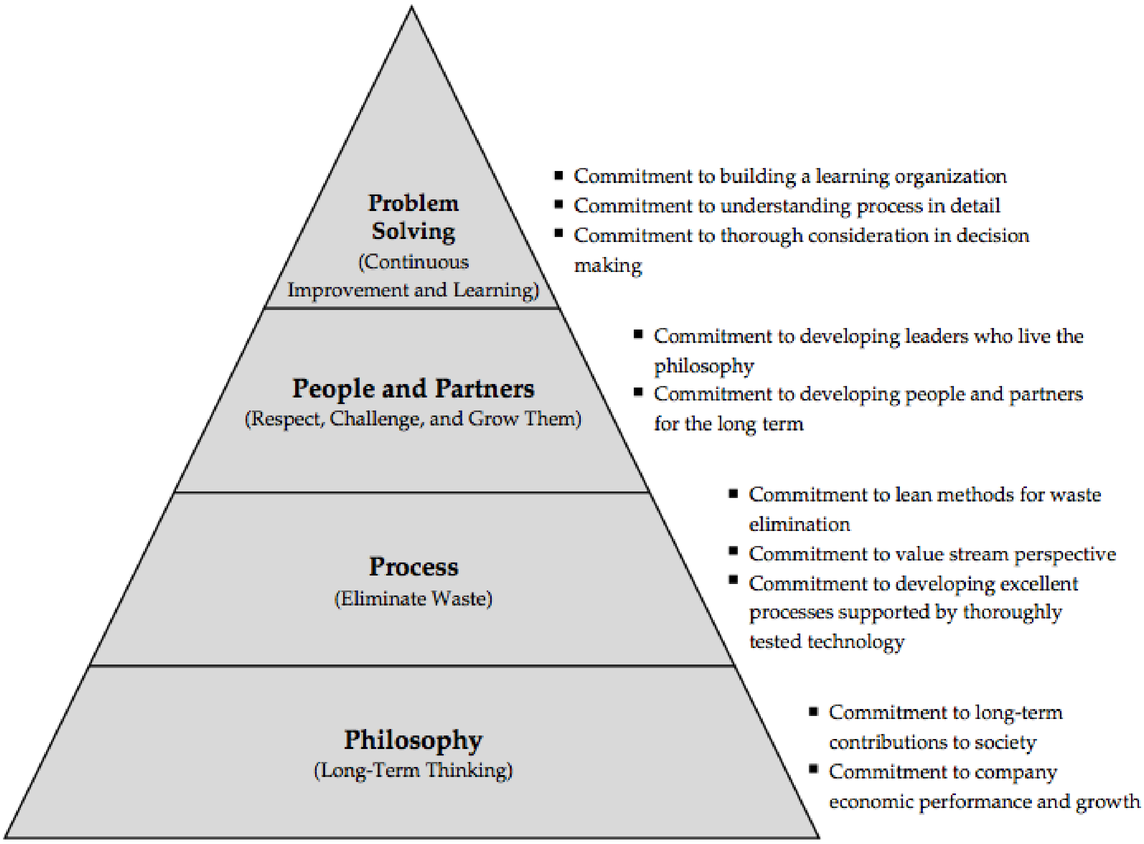

Figure 3. The 4P model (Liker & Meier, 2006).

- **Philosophy.** To Toyota *"The Toyota Way"* it is not only a way of producing products or a business strategy, it is a philosophy and a fundamental part of the company and everyone in it. The goal, according to its leaders, is to add value to customers, society, the community, and its associates.
- **Process.** Perhaps the most characteristic part of The Toyota Way is their renowned processes. However, it is also about truly believing that if you use the right process there will be results and to sacrifice short term financial results for long-term cost reduction and improved quality.
- **People and partners.** At the centre of Toyota's view of its employees and partners is what was once known as the "respect for humanity" system. In this context, it does not mean to create a stress-free and friendly environment. Rather it is a system where problems are brought to the surface, forcing people to

intervene and to make them think of how to eliminate the issue. The goal is to create an environment where people think, learn and grow.

- **Problem solving.** All companies must solve problems on a nearly daily basis. This usually means extinguishing the biggest fire first before moving on to fight the next. However, Toyota has a different approach to problem solving as opposed to the traditional firefighting. Toyota focuses on finding the root cause of every problem, small or big, to prevent any future occurrence of the same issue. This in turns drive so called *"organizational learning"* where every problem is an opportunity to learn something new and grow as a company.

The 4Ps is to some degree a hierarchical model, where lower levels build on higher once. Beneath each P there are principles that further explain the Toyota way (Liker & Meier, 2006). In total, there are 14 principles listed in table 1.

Table 1. The 14 principles of lean production

I. Philosophy as the Foundation
1. Base your management decision on long-term philosophy, even at the expense of short-term financial goals.
II. The Right Process Will Produce the Right Results
2. Create a continuous process flow to bring problems to the surface.
3. Use "pull" system to avoid overproduction.
4. Level out the workload (work like the tortoise, not the hare).
5. Build a culture of stopping to fix problems, to get quality right the first time.
6. Standardized tasks and processes are the foundation for continuous improvement and employee empowerment.
7. Use visual control so no problems are hidden.
8. Use only reliable, thoroughly tested technology that serves your people and process.
III. Add Value to the Organization by Developing Your People and Partners
9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others.
10. Develop exceptional people and teams who follow your company's philosophy.
11. Respect your extended network of partners and suppliers by challenging them and helping them improve.
IV. Continuously Solving Root Problems Drives Organizational Learning
12. Go and see for yourself to thoroughly understand the situation.
13. Make decisions slow and consensus, thoroughly considering all options; implement decisions rapidly.
14. Become a learning organization through relentless reflection and continuous improvement.

2.2 7+1 wastes

Lean means eliminating waste in all parts of the organization. Toyota has identified and defined 7 major types of non-value adding activities and one extra waste connected to employee creativity (Liker & Meier, 2006). In the "The Toyota Way Fieldbook" they are defined as:

1 **Overproduction**. Producing items earlier or in greater quantities than needed by the customer. Producing earlier or more than is needed generates other wastes, such as overstaffing, storage, and transportation costs because of excess inventory. Inventory can be physical or a queue of information.

2 **Waiting (time on hand)**. Workers merely serving as watch persons for an automated machine, or having to stand around waiting for the next processing step, tool, supply, part, etcetera. Waiting can also be a product of having no work due to stock-outs, lot processing delays, equipment downtime, and capacity bottlenecks.
3 **Transportation or conveyance**. Moving work in process (WIP) from place to place in a process, even if it is only a short distance. Another aspect is having to move materials, parts, or finished goods into or out of storage or between processes.
4 **Overprocessing or incorrect processing.** Inefficiently processing due to poor tool and product design, causing unnecessary motion and producing defects. Waste is generated when providing higher quality products than what is necessary. At times, extra "work" is done to fill excess time rather than spend it waiting.
5 **Excess inventory.** Excess raw material, WIP, or finished goods causing longer lead times, obsolescence, damaged goods, transportation and storage costs, and delay. Also, extra inventory hides problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime, and long setup times.
6 **Unnecessary movement.** Any motion employees must perform during their work other than adding value to the part, such as reaching for, looking for, or stacking parts, tools, etcetera. Also, walking is waste.
7 **Defects**. Production of defective parts or correction. Repairing of rework, scrap, replacement production, and inspection means wasteful handling, time, and effort.
8 **Unused employee creativity.** Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to your employees.

Out of these wastes, overproduction is the worst, as it causes other types of waste (Liker & Meier, 2006). Furthermore, it hides problems and does not invite the team to think and solve the problems.

2.3 Flow

From Toyota and foremost Taiichi Ohno we have learned that one-piece flow is the ideal production system (Liker & Meier, 2006). However, in most production situations this is not a feasible alternative due to variance between the workstations, demand from the customer, among other reasons. As described by Liker & Meier (2006):

"Imagine a bucket brigade line where the bucket is passed from person to person one at a time. The ultimate single-piece flow would allow the passing of a single piece from one member directly to the next. This would require perfect synchronicity between all members of the brigade. After handing off one bucket to the following member, a turn is made to the previous member to retrieve another bucket. Unless the timing between the two members is absolutely the same, one of the members will wait on the other, which is a form of waste."

Instead Ohno advocates moving towards, what in lean terms is called "continuous flow". However, achieving this is not the goal but merely a method to surface any problems that would inhibit the flow. This in turn will force problems to be corrected straight away, resulting in reduced waste. Moreover, products that move through the process with minimal waiting time and the shortest distance travelled will lead to the reducing of other types of waste as well.

Achieving flow is a step-by-step process that puts requirements on the production system. Its defined as *"Cutting back to zero the amount of time that any work project is sitting idle, waiting for someone to work on it"*. According to Liker and Meier (2006) there are four criteria for achieving flow:

- First, the capability of the process must be somewhat **stable**, at least on a daily basis.

- To achieve this, application and availability of resources (people, machines and equipment) must also be **consistent**.
- Both the processes and the equipment must be **reliable**. In other words, with regards to; downtime, changeover, simplicity, etcetera.
- The last step is to have **balanced** operation cycle times, with regards to the takt time.

It is important to fulfil these criteria for each operation in the process (Liker & Meier, 2006). If flow is attempted before this, consequences could be catastrophic. The goal is not to aim for perfection but rather to make small improvements that should continue even after the flow has been established. When one operation has been stabilized, you continue with the next, and when the two are at the same level you "connect" or "link" them. This process proceeds until every operation is stable and materials flow with minimum effort. This is when the "big bang" of improvement happens; when parts and products flow smoothly between stations according to the customer demand i.e. the takt time.

2.4 Pull system

When discussing the concept of flow, a common misconception is that it is equivalent with pull or pull systems (Liker & Meier, 2006). This is not true since it is possible to achieve flow without having pull. The difference is that flow defines the state of material as it moves. Pull on the other hand dictates whom decide when material is to be moved and when it is moved.

Another important distinction when discussing pull system is the difference between push and pull. Different authors have different approaches to explain the two concepts. Baudin (2004) adapts a somewhat fundamental explanation; *"In a push system, parts move as soon as they are ready; in a pull system, as soon as the next operation is ready"*. Liker and Meier (2006) is another example and they suggest three characteristic elements of pull that distinguishes it from push:

- **Defined**. A defined agreement with specified limits pertaining to volume of product, model mix, and the sequence of model mix between the two parties (supplier and customer).
- **Dedicated**. Items that are shared between the two parties must be dedicated to them. This includes resources, locations, storage, containers, and so forth, and a common reference time (takt time).
- **Controlled**. Simple control methods, which are visually apparent and physically constraining, maintain the defined agreement.

In essence *"*pull*"* is a system that drives material through the process when triggered by downstream consumption (Baudin, 2004). However, a pull system does not consequently mean that a company must make-to-order and even Toyota make cars that they have not sold yet. The trigger usually involves some sort of visual signal that in turn is triggered by a part movement or consumption. This means that the next operation in the process is ready to receive a new part and as Taiichi Ohno (1988) describes it, *"the downstream operation comes to take away the materials"*.

However, this is not everything that is required to establish a "pull system". It is an aggregation of several elements that if combined correctly will become the new system. These consist of among others: the kanban system (see chapter 2.11), visual control and standardized work (Liker & Meier, 2006)

2.5 Workplace ergonomics

When thinking of a production line or production in general, it is easy to imagine a mechanised system that just keeps on going. Each machine does its work days on end with little need for attention or care. However, many times this is not the case. Modern production still involves lots of humans who function rather differently from machines. Humans vary in performance, and everyone can be affected by plenty of factors that affects his or her daily form. People can also be subject to both physical and mental deterioration should the work task be poorly designed. To capture innovation, problem solving and flexibility it is essential to design workplaces that are ergonomically correct so people stay healthy (Berlin & Adams, 2015). In turn, this will enable the system to maximise its performance in the long run. Apart from the obvious physical design parameter, both psychosocial and cognitive design variables need to be included to create a workplace that is sustainable from all perspectives.

The different perspectives on ergonomics will be described below to create a basic understanding for how each category affects a person in a production environment.

2.5.1 Physical perspective

This perspective focuses on the bodily related part of the ergonomics term; i.e. how human bodies are affected by the work environment. The physical loading of the body is affected by factors such as work posture, force and exposure time. These factors can affect the body in an intertwined manner and amounts to the total strain. Berlin and Adams (2015) describe the relationship as:

$$Physical\ Strain = Posture \times Forces \times Exposure\ Time$$

- **Posture** describes what position the body is in when conducting a task and the resulting strain on the body. Bending, reaching and leaning are examples of different postures that have different effect on the total physical strain.
- **Forces** are consequences of external loading on the human body when it is working. Lifting, pulling and pushing are basic examples of actions that generate a force that needs to be overcome by the operator.
- **Exposure time** considers the frequency and the time the body is loaded from work. Repetitiveness is a typical factor included in this parameter.

The cube model (Sperling, et al., 1993) can be used to visualise the formula presented above. This model further facilitates the understanding for how the different components of the formula affect the total physical strain. In the model, each factor is given a value depending on whether the requirement to fulfil a certain task is high or low. The goal is to design work stations where the total product is as low as possible, as that means the combined strain is acceptable. This is illustrated in figure 4 by the light grey coloured cubes. As factorial demand increases, so does strain and the risk of injury. Work tasks in medium grey are conditional, meaning each case needs its own ergonomic evaluation to determine if the movement pattern can be accepted. Black cubes on the other hand signify a high risk of injuries and these activities needs redesign.

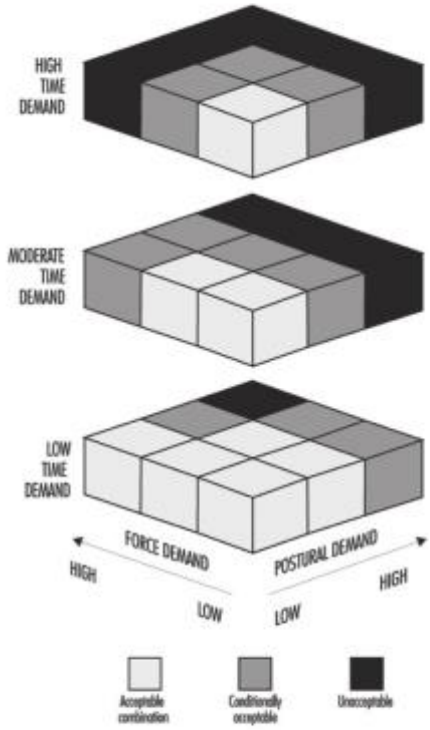

Figure 4 The cube model (Sperling, et al., 1993).

Other guidelines related to correct ergonomics are described by the VASA model (see figure 5), which provides recommendations about certain bodily movements. The height and the depth of component placement are measured and classified according to the ergonomic impact. The model is an accepted method used in Swedish industry by companies such as Volvo (Backman, 2008). The placement of materials or tools should be coordinated in a sense so that the objects used most frequently are placed in or near the green zone. Items rarely used should naturally be placed as close to the green zone as possible as well. However, these items should have lower priority as they are not used to the same extent. The seldom performed movements generally cause less overall harm and can therefore be placed in less advantageous places. The Swedish Work Environment Authority, advocate a similar arrangement in terms of working height as shown in figure 5 (Arbetsmiljöverket, 2012).

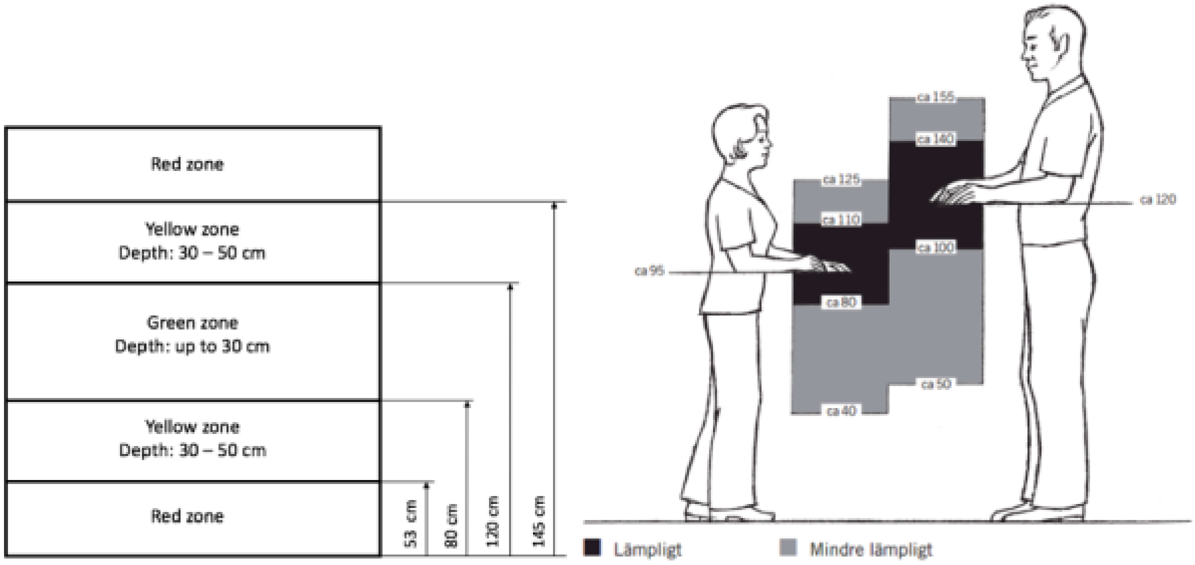

Figure 5 The VASA model and Work Environment Authority model for appropriate working heights (Backman, 2008) (Arbetsmiljöverket, 2012).

Apart from the VASA model, which focuses on height and width, the horizontal ergonomics should also be considered when designing the workstation. Placement guidelines are shown in figure 6 below (Arbetsmiljöverket, 2012).

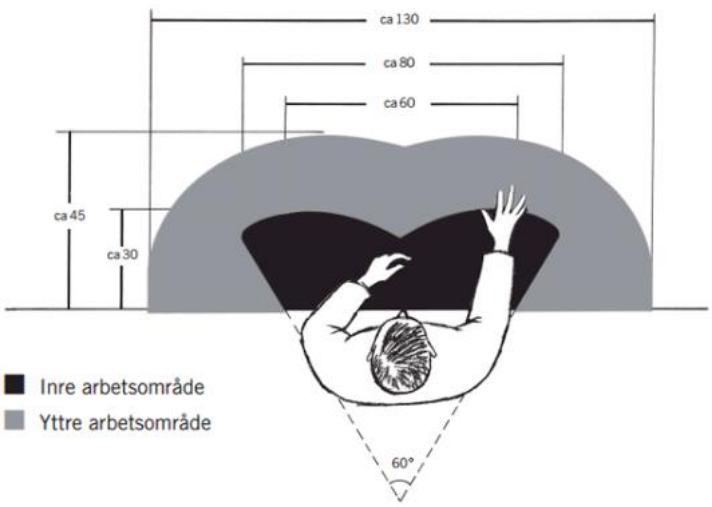

Figure 6 Arbetsmiljöverket's model for appropriate reaching distance during work (Arbetsmiljöverket, 2012).

2.5.2 Cognitive perspective

Cognitive ergonomics is about the mind and the senses and how these interact to interpret and screen information about the surroundings (Berlin & Adams, 2015). The information extracted is what forms the very base for choices and actions. The mental capacity, i.e. cognitive performance, is dependent on a wide variety of factors. These include age, genetic factors, skills, recognition, patterns, memory, experience, ability to concentrate and sorting abilities along with physical well-being.

Human mental performance is closely linked to the physical state (Berlin & Adams, 2015). A relatable example is when an individual is trying to solve a complicated problem when exhausted. It is well known that mental capacity deteriorates dramatically. A cognitively well designed system can reduce the risk for stress, wrongdoings and injuries as the senses are less prone to become fatigued over time.

2.6 Planning a manufacturing unit

Richard Muther (1996) suggests a well cited six-step method for planning a new production unit:

1. Orient the project
2. Classify the parts
3. Analyze the process
4. Couple into cell plans
5. Select the best plan
6. Detail and implement plan

The complete description of this approach can be found in the booklet *Simplified Systematic Planning of Manufacturing Cells* (Muther, et al., 1996).

2.6.1 Step 1 - Orient the project

The first step, is to organize the project and establish what effects it should have on the company. Objectives, goals and desires are formulated and clearly defined. External actors and the context should be noted and accounted for. However, problems, opportunities and questions that also need to be addressed during the project are listed. Finally, a plausible project plan is decided upon, specifying all necessary tasks and their deadlines.

2.6.2 Step 2 - Classify the parts

In the second step, the products and parts that are to be processed in the production unit are listed. Depending on the number of parts and product families this step becomes complicated. Moreover, this step specifies known characteristics for each part. It includes both physical characteristics like quality level, tolerance, size and shape, but also quantity or volume of demand, and routing or process sequence.

2.6.3 Step 3 - Analyze the process

Step three starts by mapping and visualizing the sub-groups of the part. Several different methods, graphs and charts are at the planers disposal, some of which are described in chapters 3.6 and 3.7. The result can then be used to calculate the numbers of machines and/or operators required to satisfy the demand. This process is most commonly known as line balancing and can be read about in chapter 2.9.

2.6.4 Step 4 - Couple into cell plans

In this step, the different solutions that are going to be evaluated in step 5 take their shape. Four things need to be established before the planner can proceed to the next step:

- The layout of operating equipment (physical)
- The method(s) of moving or handling parts and materials (physical)
- The procedures or methods of scheduling, operating, and supporting the cell (procedural)
- The policies, organizational structure, and training required to make the cell work (personal)

A good place to start is with the output from step 3. The charts and diagram of the process can be turned into a sketch of the layout. The planner should start with the machines, stations and the general layout. Next, any storage methods and material handling is visualized, followed by the equipment, containers and areas dedicated to these activities. Lastly all support equipment missing from the layout are added. These include: inspection areas, supply storage, trash bins, desks, computer terminals and printers, etcetera. More information about this can be found in chapter 3.10.

When the physical aspects of the cell plans have been determined, it is time to address the procedural and personal (3rd and 4th point above). According to Zandin (1996), procedural and personal aspects are more important than the physical ones in the design of a successful production unit. Procedures and policies for staffing, scheduling, maintenance, quality, training, etcetera needs to be established, presented and approved by the management.

2.6.5 Step 5 - Select the best plan

Now it is time to compare all the different suggestions and choose the best one. A common approach is to decide upon the most important factors for the company and weigh them against each other. Then the concepts are evaluated against each other with regards to the factors. Common choices are utilization of floor space, effect on quality, flexibility, investment costs, etcetera.

2.6.6 Step 6 - Detail and implement the plan

Lastly the plans that were selected in step five are implemented. This is where details are added to the solution. A scaled plan should be produced to visualize the workplace by showing:

- Normal operator working position
- Location of tooling, gauges and controls
- Parts containers, fixtures, and workplace handling devices
- Utility drops and connection points
- Door swings and access points
- Position of overhead lighting

This is also the step where eventual 3D computer models or life-size mock-ups are created to highlight certain parts of the production unit. Depending on the type of production different options might be of interest.

The most important tasks should be identified and assigned to the best suited individuals. Time and resources are estimated for each task and put into a schedule. Once a detailed cell plan has been established it will be the output from this step.

2.7 ACD^3 - Activity-Centered Design Decision Determination

The Activity-Centered Design Decision Determination or ACD^3 is a framework used in development processes to help identify the scope, organisational positioning and the impact of certain design decisions (Berlin & Bligård, 2016). The tool is intended to be used to address problem solving at the right level of detail in companies, resulting in design solutions that address sought after system performance. Originally, the framework has been developed for product development processes.

The core functions in the ACD^3 framework are the abstraction levels and design perspectives (Berlin & Bligård, 2016). A more detailed combination of these perspectives is what forms the solution. Also, the perspectives connect stakeholders with different views on the problem which thereby enables them to come to a mutual understanding about desired effects and outcomes.

2.7.1 Abstraction levels

The abstraction levels describe the levels of detail that the production system consists of (Berlin & Bligård, 2016). The span ranges from high-level questions affecting the entire organisation to low-level details with a precise and narrow focus. The spectrum is covered by five different levels, each focusing on different parts of the system. The different levels and corresponding core questions are listed below.

- **Effect**: What kind of impact should the system achieve?
- **Operation**: How should the functions be performed to achieve the wanted effects?
- **Architecture**: How should resources be distributed to achieve the technical function to reach the desired performance?
- **Work**: How should the system's resources carry out the work and how should they respond to the environment?
- **Tool/Information**: What support do the resources need to complete tasks?

2.7.2 Design perspectives

The design perspectives are about what detail level the system are viewed at when decisions are to be made. By doing this, decision-makers are aided when determining a suitable approach for problem solving. Just as the abstraction levels, the design perspectives are divided into five subgroups for a more tangible approach.

- **Problem**: The desired outcome that drives the process forward.
- **Structure**: Sub-components of the system and how they are related to each other.
- **Function**: The capabilities which the system needs to offer.
- **Activity**: The tasks carried out by the human resources in the system.
- **Realisation**: How the system is made concrete in terms of technology and resources.

2.7.3 ACD^3 matrix

Combining the two perspectives results in a matrix which visualises topics for discussion in a development process. Where and how should something be planned, specified and implemented to achieve the change? The matrix is meant to be followed in a hierarchical manner by following a top-down approach. By continuously specifying the elements of a design decision from a holistic view to a precise one, each stage is fed with input to continue to build on for a tangible solution. An overview of the matrix with descriptions of the different levels is shown in figure 7.

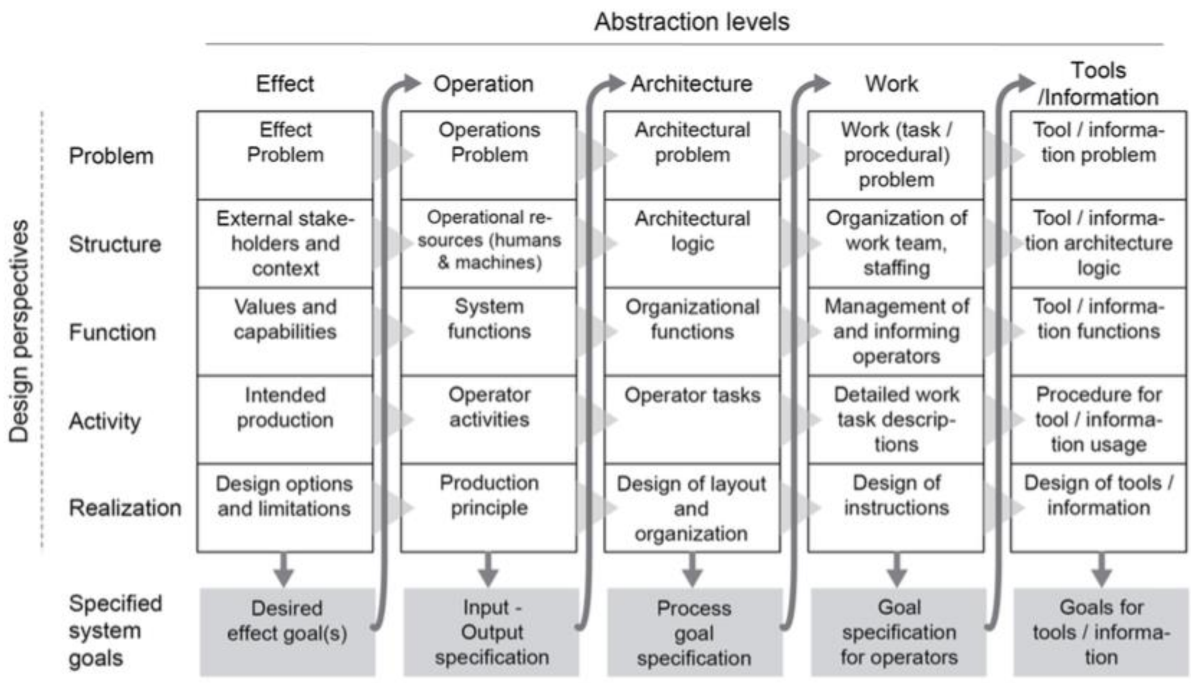

Figure 7 The ACD³ matrix.

2.8 PTS – Predetermined time systems

In all time studies the time values of all operations and elements are measured in one way or another (Zandin, 2001). Examples of techniques to take measurements can be by film or the more traditional stopwatch. However, one important issue remains; how to measure the effort level, i.e. performance rating of the operators. In fact, there are several factors that are yet to be accounted for after this initial phase of a time study. These include day-to-day variance of cycle time, the skill level of the operator, etcetera.

There are many different types of predetermined time systems, all with the same main function: *"to provide information about manual work cycles in terms of basic human motions"* (Zandin, 2001). However, it also allows for visualization of the work and even establishing of a standard even if the task is still in the planning phase. There are also additional uses of PTS even when the production system is in the planning stage. It provides information about learning times and the development of learning curves. On the other hand, one of the disadvantages of PTS occurs when *"machine-paced operations"* are involved. Most of the systems were designed solely for human motion times and not machines. This is an important consideration when applying the systems.

2.8.1 SAM - Sequential Activity - and Methods Analysis

SAM is a PTS method used for calculating and describing the motions in an assembly operation performed by a human resource. The purpose for using SAM is to enable the user to design work methods for high productivity, document work methods for reproduction of the method and to establish norm times for the production based on documented methods (IMD, International MTM Directorate, 2004).

SAM originates from the idea that manual movement of objects always follows a simple sequence: *"GET an object and PUT the object into a planned final position"*. The system works at a *"norm performance level"*, defined as: *"the performance level most people are working at when carrying out manual tasks"*. A good reference can be the fact that if a performance incentive system is implemented the SAM norm level is usually exceeded by 10-20% (IMD, International MTM Directorate, 2004). The norm performance level corresponds to a norm time. In other words, the time it takes to perform a task according to the norm performance level. The special unit of time measurement used in SAM is called factor and the system is structured as follows:

- 1 hour = 20.000 factors
- 1 second = about 5.6 factors
- 1 minute = about 333 factors

Time factors are in turn associated with certain movements and their complexity to describe the time it takes to complete it. For SAM to be able to describe a set of motions, the system is based on a listed number of activities that can depict any manual task. These activities are listed in figure 8.

Type	Activity
Basic activity	GET and PUT
Supplementary activities	APPLY FORCE
	STEP
	BEND
Repetetive activities	SCREW
	CRANK
	TO AND FROM
	HAMMER
	READ
	NOTE
	PRESS BUTTON

Figure 8 SAM activities.

As with many theoretical methods, the underlying assumption of SAM is that the production system itself highly developed. In an immature environment, i.e. one where the operations are planned and organized in a poor manner or the workstation have tools and fixtures not adapted to the task, the norm times can be hard to achieve.

2.9 Line balancing

When in the process of balancing a line the main objective is to *"establish a sequence composed of the minimum number of element groupings, each with combined task time Less than or equal to a fixed cycle time"* (Buxey, et al., 1972). The process of balancing a line starts with an identification of the work elements needed to complete the final product. In turn, these elements are distributed on several stations based on certain criteria, such as a logical precedence order or a design decision (Zandin, 2001).

In today's competitive market, the basics of line balancing tend to revolve around matching the cycle time of the work stations in the production system to the customer demand (Townsend, 2012). The most common approach to this challenge is to equate the cycle times of the stations to the takt time, i.e. the average level of demand for products by the customers. This basically means each work station in the production system aims at completing a product as often as a customer needs one. Another objective of the balancing is to create an even flow across all the stations to avoid under or overproduction (Liker & Meier, 2006).

When balancing a production line, there are different approaches available. Below, three common approaches are presented.

2.9.1 Precedence diagram

Most classical line balancing starts off with the construction of a precedence diagram (Buxey, et al., 1972). It is a tool used to visualise activity relationships, thereby facilitating scheduling (de Werra et al., 2015). The diagram provides information about the duration of each activity while also providing the user with critical information about the critical path and the float. The critical path is the longest sequence of activities in the diagram which in turn determines the shortest amount of time it takes to complete a service or product.

2.9.2 Largest candidate

The largest candidate method is a straightforward method where work elements are assigned to stations in a sequence determined by the length of each work element. In the largest candidate method, the longer the work element, the higher the priority. For an element to be viable at a workstation, it must not violate precedence requirement nor make the station exceed the cycle time.

2.9.3 Kilbridge Wester

The Kilbridge Wester's Method is a heuristic method for balancing production lines. The principle of the method is to assign work tasks to stations based on the task's placement in the precedence diagram (Kilbridge & Wester, 1961). This means work element occurring early in the precedence diagram will occur in early workstations. Essentially, the method encourages the user to follow the natural order of assembly along the stations.

2.9.4 Ranked positional weight

The ranked positional weights (RPW) method calculates a value for each work element. The calculation is based on the length of the work element, the total time for the subsequent production path and the element's position in the precedence diagram. Having completed this stage, activities are then assigned to stations according to the activities' individual ranked positional weight value (Helgeson & Birnie, 1961). Activities are assigned to stations in a descending order.

2.9.5 Disturbances and allowances

In an ideal production line, all the operators at each station work exactly as long as the cycle time without deviation. However, this is seldom the case in the real world as things tend to be subject to some variation.

Balance losses occur when the distribution of work among the stations is uneven. Uneven distribution leads to situations where some stations are slower while others are faster. The consequences of this are the phenomena known as blocking and starvation. Blocking occurs when station A is faster than station B, thereby making A unable to send products onwards. The only option A has is to simply wait for B prior to sending the product onwards, which results in a loss of capacity at station A. When the relation is the opposite it is called starvation and this occurs when station B is faster than station A. In such a scenario, the operator at B must wait as he or she cannot do any value adding work as no product is yet available.

An important, yet easily forgettable aspect of line balancing is planning for activities that are not directly task related. These supplementary non-directly task related activities are gathered under the name allowances (Zandin, 2001). Typical non-working activities are: resting to overcome fatigue, bathroom breaks, talking to colleagues/supervisors/management and waiting for parts/instructions. A common way to deal with allowances is to add a few percentages of extra time to complete tasks to compensate for unavoidable delays, personal fatigue and personal needs. The percentage levels normally depend on the intensity and strain associated with the job. Usually the levels span from 12-15% for light industrial work (Zandin, 2001).

Apart from human allowances, the balancing must also consider losses that affect the entire system, also known as system losses. These include setup, downtime, maintenance, varying work rates, breakdowns, changes in production schedules and changeovers between product groups or individual components (Zandin, 2001). Much like the allowances, system losses need to be acknowledged and compensated for in the system planning.

2.10 Material handling

Material is defined as the handling of raw materials, products or various material containers through production and storage areas (Stocker, 1951). Nowadays, material handling and logistics is a central aspect in the world of production and over the course of time certain truths have been established by industrial engineers and practitioners (Zandin, 2001). Zandin (2001) list principles as the starting point for capturing problems and working out needs and subsequent solutions. An excerpt of these are presented below.

- **Planning**. The material handling should come because of a thorough plan where needs, performance objectives and functions are already specified. It is crucial for the plan to include people from different levels and background. This will contribute to successfully improve the system from a wide variety of perspectives while simultaneously avoiding sub optimisation.
- **Standardization**. One of the most important principles of material handling is standardization (Stocker, 1951). This is due to the economic beneficially of being able to increase the usage of already existing methods and equipment. However, the standardization must not become too rigid as that would lead to incompatibility with modularization and flexibility.
- **Work**. This certain principle aims at optimising the handling by maintaining service levels and productivity but reducing material handling activities. Stocker (1951) also state that the more efficient the operation, the better flow and lower cost. Key components to succeeding in improving the work principle are combining, reducing, shortening and eliminating movements and/or actions associated with the handling of materials (Liker & Meier, 2006).
- **Ergonomics**. During the material handling design phase one must keep physical and cognitive ergonomics in mind to ensure a safe and effective workplace. Poorly designed material handling system puts operators at risk for exceeding the accepted strain levels or being subject for falling loads (Mital, et al., 1997) (Arbetsmiljöverket, 2012). The effects of these often result in chronic injuries and great costs, both physical and economic, of direct and indirect nature (Mital, et al., 1997).
- **Unit load**. One should strive after moving individual components as a single conglomerated unit, such as a pallet, container or barrel. Which form and size the single entity should have is determined by the needs of the stage in the supply chain. Reduced effort and handling times are generally key benefits in using unit loads opposed to transportation of single parts.
- **Space Utilization**. It is evident that the available resources such as space and is in an effective and efficient manner to fully capture the potential of one's premises (Tompkins & Smith, 1988). Flexibility, storage density and plant accessibility must constantly be balanced to achieve the end goal.
- **Automation**. Improving one's material handling process can be achieved by robotic elements in certain areas to improve responsiveness, efficiency, consistency, reduce cost and prevent the risk of injuries (deSpautz, 1994) (Bourbonniere & Yuvin, 2006).

2.11 Kanban

Kanban is an inventory control system used to manage the supply chain of the system. The idea of the kanban system is to be responsive to demand and act according to the behaviour of the demand. This means that any given process is to act based on the actions or signals of its customer(s), not on forecasted usage (Gross & McInnis, 2003). The essentiality of kanban is that some sort of signal controls what needs doing. Well planned kanban environments have clear visual indicators, revealing the scheduling status of things to the beholder in an instant (Liker & Meier, 2006). Apart from the clarity of the signal it must also be simple, manageable, unmistakeable and only trigger a single course of action (Gross & McInnis, 2003).

A kanban card in a process is an example of a physical representation of a demand signal. The card signifies the consumption of products, sub components or inventory levels in the system and in turn activates replenishment of the recently consumed object (Cimorelli, 2013). The card should also provide information to the upstream operations. Common information on kanban cards include: item number, quantity, location off pickup/drop-off and the timing, if not immediate (Baudin, 2004). Note that the kanban signal does not have to be triggered a physical card, another object can fulfil the same role. An example of a kanban "card" application is having a two-bin system for parts at a workstation. When one container of the pair is empty, it is placed in a certain location which turn signals to the supporting functions that material has been consumed and that station needs restocking.

2.12 Production layouts

There are several different production layouts that are suitable for different production situations. Many methods and visual tools have been developed to define and visualise these layouts. Muther (1999) suggest that there are primarily three characteristics that affect what type of layout that should be used. Characteristics of the parts (P), quantities (Q) and the routing (R) through the process. Depending on the relationship of these three, different layout types should be chosen. However, Hayes & Wheelswright (1979) suggests a more fundamental definition which they call the product-process matrix. It is based on the two-dimensional relationship between process and product. This means the different formats a process can be adapted to, from a flow layout to a systematic one, depends on how big the product volume and variance is. A version of the matrix is presented in figure 9.

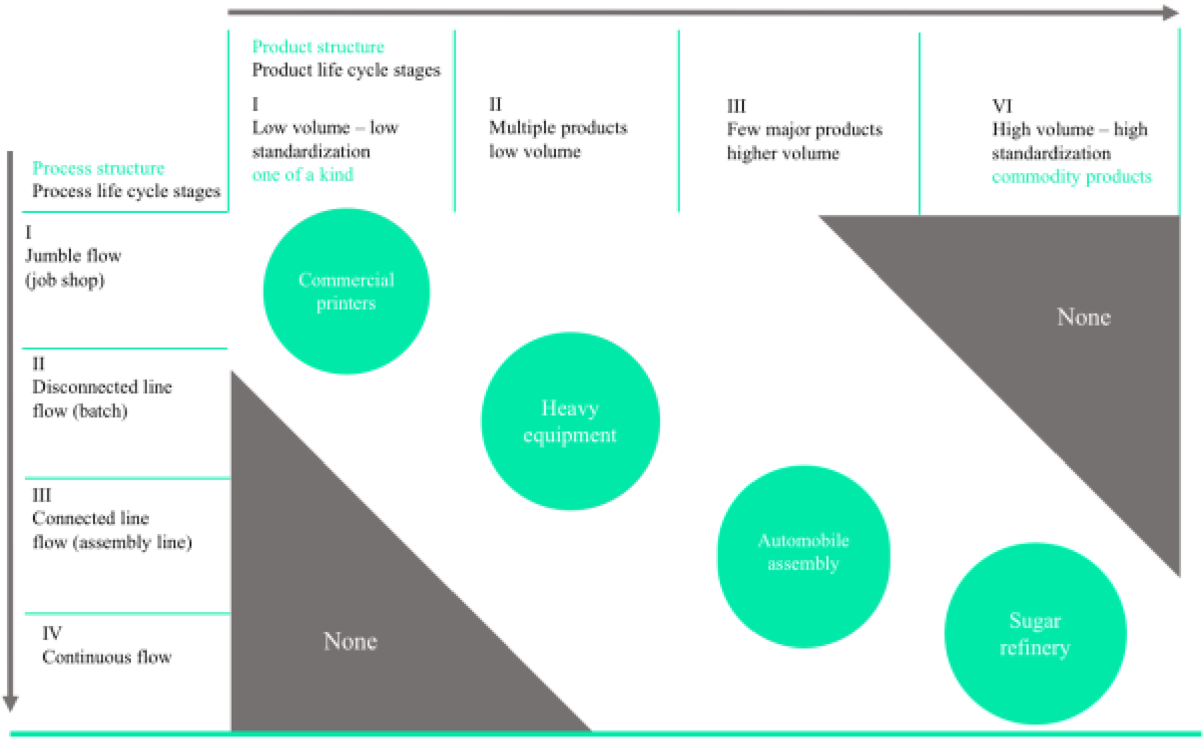

Figure 9 The product - process matrix.

Companies generally place themselves on a diagonal going from the top left to the bottom right corner. Exceptions do exist where companies have placed themselves either above or below the line. This has resulted in varying degrees of success; however, it is safe to say that companies should avert from straying too far from the diagonal without having a clear plan in doing so (Hayes & Wheelwright, 1979). The further away from the line, the further away a company is from its competitors. This can both be a good and a bad thing, but should only be sought after with intent.

At the top of the diagonal the process structure is called job shop or jumbled flow. Processes and machines are organized by their function rather than product family or application. Furthermore, their functions are general purposed instead of being dedicated. Products and parts must be moved between the different processes and wait for their turn before being processed. This results in longer throughput time than the labour time invested. Industries that can benefit from this kind of structure could for example be a machine shop that produce custom parts for other industries. The orders are usually small or medium sized and can be completely unique every time.

Further down the diagonal the structure is called disconnected line flow. In this part of the matrix a customer may even be allowed to order customized units from a selection of basic products with different options. Products or batches move irregularly through different stations in a flow like pattern.

In the next part of the matrix we find connected line flow or assembly lines, iconic for the car industry. Volumes are high and production units are dedicated to one or a few products. Hence companies in this area adapt mass production techniques like high-speed automation, progressive assembly lines, or transfer machines (Muther, et al., 1996).

The last production structure is continuous flow and its most common application is different types of refineries like sugar or oil processing (Hayes & Wheelwright, 1979). The product is usually a commodity and the process continuous.

The top right and bottom left corners are not included since they consist of product-process combinations that do not exist and that are not feasible in today's industry.

2.13 In-house transportation

Within any production layout there are a lot of products, components, tools, etcetera that need to be transported between the different parts of the factory. Adapting a suitable in-house transportation system will in most cases present many opportunities for big waste reductions. Within every operation within such a system four things need to happen (Baudin, 2004).

1. The minimum transportation quantity must accumulate at the point of origin.
2. The parts need to be prepared for transportation, which may entail, for example, placing them in bins and palletizing the bins.
3. A vehicle needs to come and pick up the parts, for example a forklift.
4. At the destination, the parts must be prepared for production - that is, removed from pallets and bins and possibly placed on lineside shelves.

Finding the best solution for each of these steps, customized for the current production situation is key for an effective production system. It is important to not only focus on reducing transportation distances since these improvements usually have small impact. The focus should instead be to integrate transportation for multiple destinations eliminating transportations completely.

First, the shop floor should be organized into "manufacturing islands", some dedicated to operating personnel where vehicles and material carriers are prohibited. Between these there should be aisles reserved for vehicles. This will both keep transportation routes free of extra materials, pallets, fixtures, etcetera as well as a better working environment for the operators. Secondly, assigning and aligning drop-off and pickup location is another important consideration. Lastly, the operator responsible for refilling material should be provided with a pushcart or use a material train. Forklifts and similar transporting equipment are in general a poor fit for the repetitive movement of materials between two locations, and should be avoided.

3 Methodology

This chapter describes how the work has been conducted throughout the thesis. The method will present each step along the way in a chronological order to facilitate understanding of how the thesis team developed the proposed production system.

3.1 Structure

The thesis has been structured around a specific task and a given period. As a prerequisite for beginning to work on the actual thesis, time was invested in creating a plan of what was to be done throughout different stages of the project. This plan was done independently from the company's own internal structure as the thesis team itself had to narrow down scope, delimitations and the areas the thesis would encompass in general. A study of production development methodology was also carried out to determine an appropriate work sequence during the thesis. Richard Muther's methodology was chosen and formed the basis for the overall method described in figure 10. More on this methodology can be found in chapters 2.7 and 3.3.

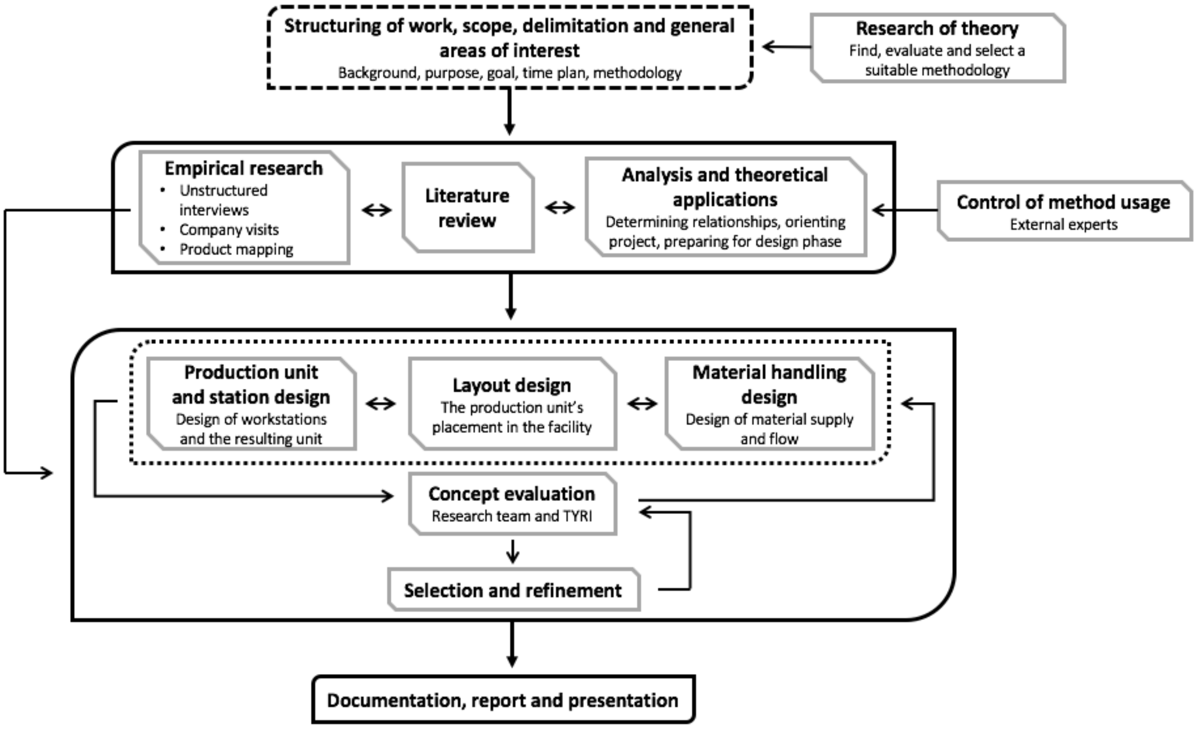

Figure 10 Methodology of project with the different phases encircled.

The first step in the project revolved around learning as much as possible about the product, the plans/objectives/goals and desires of the company, constraints and useful theory. Information was gathered through a literature study and parallel meetings with TYRI. In turn, the acquired knowledge was sorted and classified in the ACD^3-matrix according to the effect of the design decisions. The literature review and empirical research were carried out iteratively throughout the project. This was done to be able to focus on subjects related to the phase the thesis team was in (see appendix IV). This step corresponds to Muther's first step, "Orient the project", which focuses on establishing a foundation on which to build. As data and information was being obtained, several analyses were carried out to determine essential product and production system relationships crucial for the design phase. More on this can be found in the chapters 3.5, 3.6, 3.7 and 3.8. The analysis conducted corresponds to Muther's second and third step, "Classify the parts" and "Analyze the process". More on this can be found in the chapter 2.7.

In the design phase, different concepts of the production unit, its layout and the associated material handling system were drafted to capture various solutions to the identified challenges. The process was of iterative nature to filter and improve ideas. The iterative design process also involved TYRI who provided new aspects and qualified feedback. The topics mentioned in this paragraph are presented in chapters 3.9, 3.10 and 3.11. The design phase of the thesis corresponds to Muther's fourth and fifth steps, "Couple into cell plans" and "Select the best plan".

During the last phase of the thesis, the emphasis was on documenting the project process, results and areas of improvement in text. Also, time was spent preparing a way to present the outcome of the thesis to the stakeholders of the project.

3.2 Literature review

Production system development is a topic subject to a great deal of research due to its many perspectives. Therefore, the purpose of the literature review was to gain theoretical knowledge which would help the project members make qualified decisions based on research. Moreover, the study also supports arguments, claims, results and discussions about the result (Ridley, 2012).

The study was initiated at the early stages of the thesis and was continuously supplemented when the thesis team encountered situations where additional information was deemed necessary.

Theoretical data was obtained from sources such as websites, journals, books, reports, theses, videos or similar works. The sources were primarily acquired from various internet libraries such as Chalmers library, Google Scholar, Science Direct, Emerald Insight, Scopus or similar sources. To find information on these web libraries for the project, the following keywords are examples of what the thesis team used in different combinations of each other when looking for information.

- Planning
- Layout
- Design
- Production
- System
- Sequencing
- Work station
- Material
- Flow
- Handling
- Assembly
- Balancing
- Precedence
- Method
- Lean
- Principles
- Philosophies
- Layout
- Diagram
- Tool

Apart from using literature obtained from databases, course literature from the Production Engineering master programme at Chalmers was also used.

3.3 Empirical research

To get to know as much as possible about the conditions surrounding the product, constraints, factors, and the company the thesis team continuously had meetings with TYRI's development team. Empirical research of this type continued throughout the entire duration of the project. To get hold of answers to the questions, the thesis team used two different approaches depending on the required type of information. Phone calls and email were the communication channels used to answer simple questions. However, more complex questions were answered by TYRI's development team during meetings at their headquarters. This was done to make sure that question, context and answer was properly understood by the involved parties. Face to face meetings were held weekly or every second week.

3.4 ACD^3

To structure information and facilitate decision making in the project, the thesis team used the ACD^3 framework for development processes. The framework helped to identify the scope, organisational positioning and the impact of certain design decisions. The framework was chosen as it seemed to provide a delimiting structure in an ever-changing process with plenty of aspects. Another appealing side to the use of the framework was that the developer Lars-Ola Bligård was based at Chalmers, thereby giving the thesis team the opportunity to properly understand and use the matrix.

As advocated in theory, the thesis team followed the top down approach when conducting the mapping. In other words, the team started at the top left part of the matrix and filled in relevant information for that perspective (see figure 7). Then each box was filled in further down the column of that level of the production system. At the bottom the "specific system goals" formulate the problem perspective for the lower level.

Throughout the project, the ACD^3 matrix was continuously filled with additional information that emerged during the development of the product and the production system. The continuous compilation of knowledge over time was important for the thesis as the nature of development work is dynamic. The information gathered revolved around requirements, wishes and/or other relevant pieces of information which potentially could have had impact on design decisions.

During the work of acquiring and filling the matrix with knowledge, the thesis team began narrowing down the areas of interest for the thesis. The team investigated which abstraction levels and design perspectives that were in line with the purpose and goals of the thesis. The information boxes under the relevant abstraction levels and design perspectives were in turn targeted as potential areas for decision making. Due to the dynamic nature of the project, these boxes were screened continuously over time to evaluate what was to be included in the thesis.

The collection of information led to the matrix being used as a constant sounding board for what needed to be acquired, done or decided. Apart from information, the matrix was also filled with decisions already taken to remind the thesis team of what was already decided. The final output of the ACD^3 matrix can be found in appendix V.

4 Results

In this chapter, the result from the development process is presented and described. The findings are organised into sub-categories to facilitate the description of the different aspects of the proposal. These sub-categories aim to describe how each aspect of the suggestion functions. Furthermore, an extra category exists to explain and motivate design decisions.

4.1 Product mapping

A prerequisite for designing the production system was to have proper understanding of the relationship between the components that form the end product. Knowledge about the order of assembly was obtained in two steps. First, the thesis team studied exploded view schematics to get an overview of the problem. The exploded view schematics gave basic insight in how many parts that made up the end product and how they were connected to each other. The study of the schematics also provided knowledge about different assembly strategies for the product. After having obtained a basic understanding, the thesis team also sat down with the development team at TYRI who explained the sub components and their specific traits in a detailed manner. From all this a draft of the necessary activities needed to assemble the product could be established (appendix VI).

4.2 Precedence diagram

To generate logical assembly plans for the product in a structured and methodical manner, the thesis team chose to make a precedence diagram. The diagram was created to surface the critical relationships among components and activities. These relationships are turn the ones that dictate the logical order of assembly. This approach to the challenge was chosen as the thesis team had successful experiences of using the method during previous occasions.

To make the diagram, the knowledge acquired from the product mapping was used as a foundation for the work. This was done as the previous step in the development work provided the thesis team with information about the sequential relationship among tasks. This in turn was the key for how the end product could be put together.

First, the different sub-components, i.e. sides and middle, were analysed separately to observe the different precedence options to screen out noise from surrounding work elements. This was first done by listing the possible order of components and operations in spreadsheets in a text based format. The spreadsheets in turn acted as support elements for the thesis team during the visual representation of the relationships. The precedence diagrams can be seen in figure 11 and 12

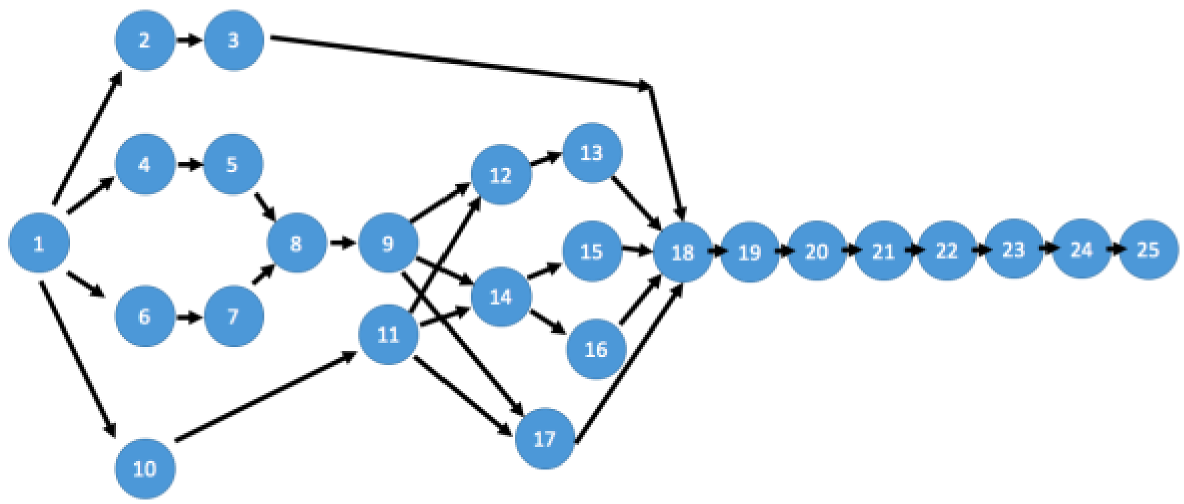

Figure 11 Precedence diagram of the middle part of the product.

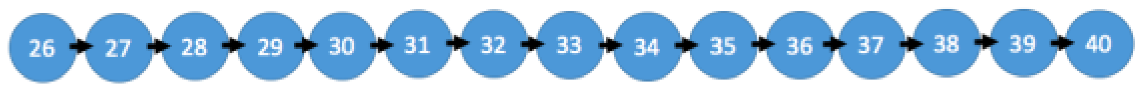

Figure 12 Precedence diagram of the side part of the product.

4.3 SAM – Sequence activity – and methods analysis

When designing a production system, it is crucial to know how long it takes to produce a product in the system. With a known sequence of work, the next step in the project was determining the time it would take to put the components together. To accomplish this, it was decided to use some form of engineered labour standards. Engineered labour standards were chosen as they provide a scientific approach to what could realistically be expected, both from a management and employee point of view. Predetermined time systems were chosen to get a theoretical frame for the work tasks related to the production. The predetermined time system chosen was SAM. This method was chosen as it was the most detailed predetermined time system the thesis team encountered and had been used by the team on previous occasions.

Based on the knowledge obtained from the work with product mapping and precedence diagram, corresponding times could be assigned to assembly activities. Since there was no production system present at the time of the SAM-analysis, several assumptions about the placement of equipment and tools had to be made. As the thesis team envisioned a working environment that followed ergonomic guidelines about workplace design, tools and parts were assumed to be in the accepted zones as described by figure 5 & figure 6. Furthermore, the glue robot was not part of the analysis since the method does not support automatic processes and the robot itself does not influence the manual assembly.

Having modelled the production activities in SAM-sheets, these were presented to Peter Almström a SAM-certified professor at Chalmers to check whether the usage of the method was correct. In cases of wrongdoings, the recommended corrective actions were taken. The complete SAM-sheets can be found in appendix VII.

4.4 Balancing

The balancing procedure was initiated to see how the production could be planned given the previous findings from the product mapping and precedence diagram. The first step of the work with line balancing was translating order levels and order patterns into daily and hourly production demand, thus signifying the takt of the production. The takt time also corresponded to the maximum cycle time for the workstations.

At this point the number of workstations needed to be established and what work tasks that should be performed at each station. To accomplish this, the thesis team applied the three balancing approaches and compared their results. An important note is that the glue robot was treated as a constant factor during the balancing, due to it being an automatic process. After adapting different balancing methods, it was concluded that the best result was achieved with the Ranked positional weight method. The result from the balancing gave the thesis team a good place to start and it can be observed in figure 13. The calculations that the balancing is based on can be found in appendix VIII.

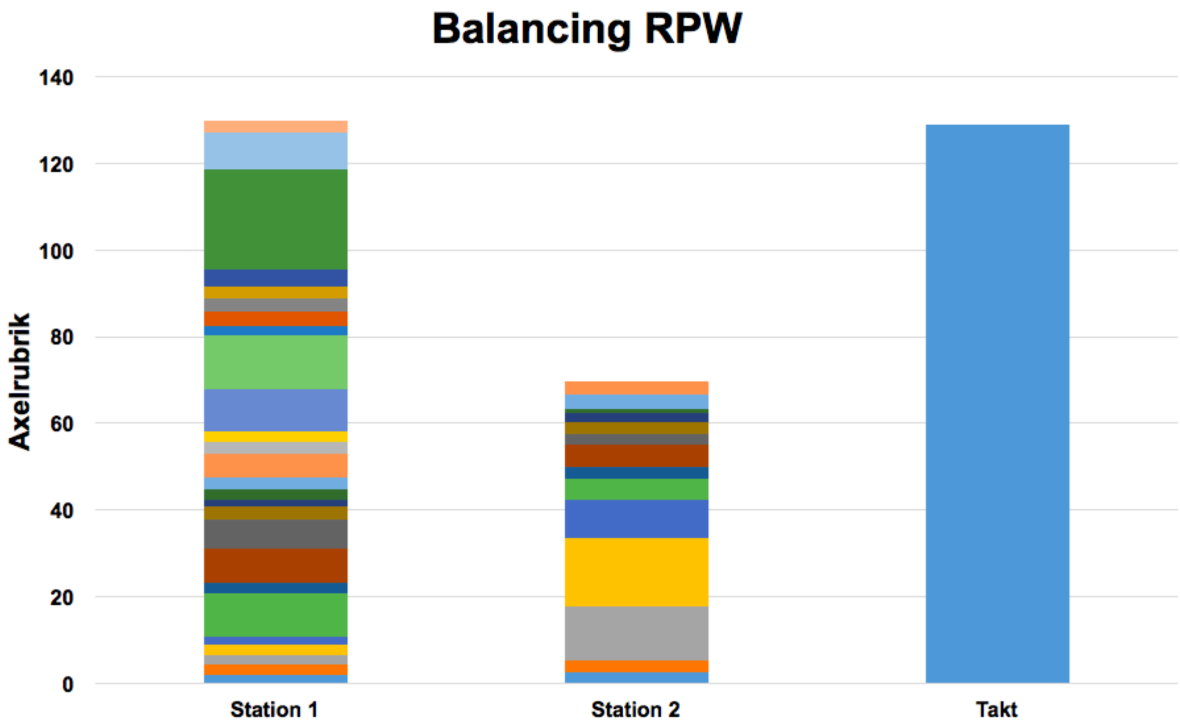

Figure 13 Balancing of stations based on the RPW-method.

4.4.1 Challenges

A problem with the output from the RPW with the established takt time, was an uneven workload between the different stations (see figure 13). This would inadvertently lead to stations becoming blocked and/or starved. Consequently, this would mean that the workload would vary from station to station. Some operators would constantly be occupied with tasks while others would experience long periods of time without any work.

Another issue was the utilisation of the robot, due to the robot working faster than the takt time. As the robot meant a significant investment for the company it would not be economically viable for it to stand idle most the time.

Yet another problematic area was the sequencing of work tasks. The method did not take the characteristics of the work tasks into account, only their duration and preceding tasks. Thereby, all stations had a jumbled mix of work tasks to perform. This would increase the cognitive load on the operator and demand more tools to be available at multiple stations.

Since the glue robot is one of the last activities in the assembly sequence it creates a problem as it disrupts the manual assembly sequence. This would create a situation where an operator would assemble for a while, then wait for the robot, before proceeding to put the final components into place. This would create an unacceptable idle time.

Sequencing of the production also created problems due to a difference in assembly times for one side part compared to one middle part. The relationship between these two was roughly 3-2, i.e. 3 side parts were produced in the time it takes to make 2 middle parts. Since you need 2 side parts for every middle part this creates issues with regards to changeover times and production scheduling. The problem is further amplified by the fact that both parts need to be produced on the same production, and requires an individual 24h drying period before proceeding in the process.

Lastly, the strict requirements on delivery precision consequently meant that a safety margin between the cycle time and demand would be required. Another important consideration is with regards to allowance. This also requires extra time between the takt and cycle times. However, the margin and allowance needed to be balanced against overproduction, which still could become a problem.

4.4.2 Countermeasures

Most of the imbalance of the production phase was eliminated by changing perspective of how the product could be made. Instead of viewing sides and middles as distinct parts in need of separate assembly, the thesis team saw the potential of assembling them simultaneously on a single production pallet. To deal with the increased cognitive strain of mixing the two product types in the assembly, work tasks of similar nature were in turn redistributed to certain workstations to the greatest possible extent.

To increase the utilisation for the robot, the takt time was set to a value closer to the robot's cycle time. This would result in more time for allowance and greater delivery precision as well as allow more usage out of the robot. On the downside, it could also lead to overproduction, which we know from Liker (2006) is the most severe of the different types of wastes. However, delivery precisions and return on investments were deemed to be more important factors in this case. The extra time would also allow for TYRI to ramp up their production and deliver more products to a customer than what was initially required.

To compensate for the robot's late appearance in the sequence, the thesis team shifted some of the activities from the last station to the first. In other words, the first station would first finish the last few steps of one product and then initiate new once. Intuitively this can be challenging to understand therefore a secondary precedence diagram with the stations highlighted was created (see figure 14 and 15) to assist the reader.

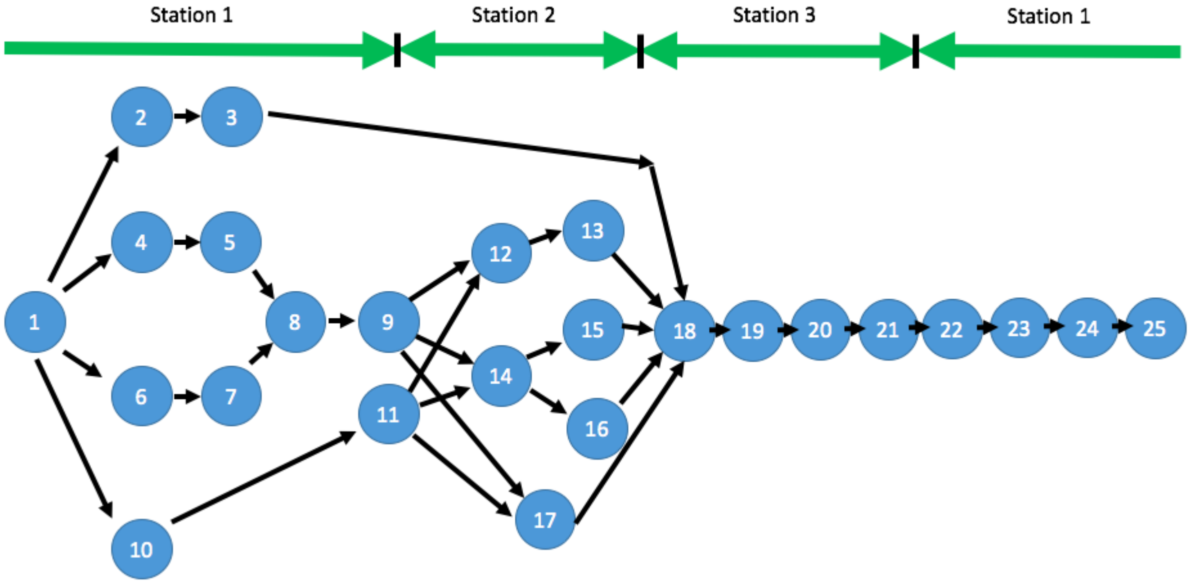

Figure 14 Precedence diagram of the middle part with stations highlighted.

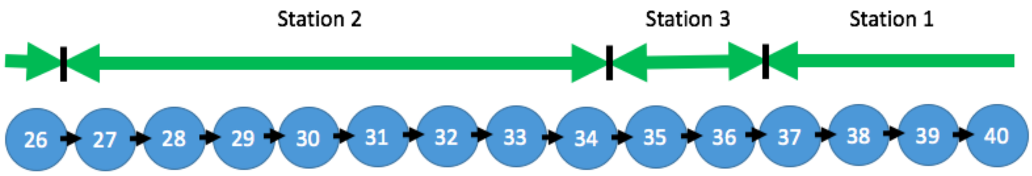

Figure 15 Precedence diagram of the side part with stations highlighted.

For the final balancing with countermeasures applied can be found in figure 16.

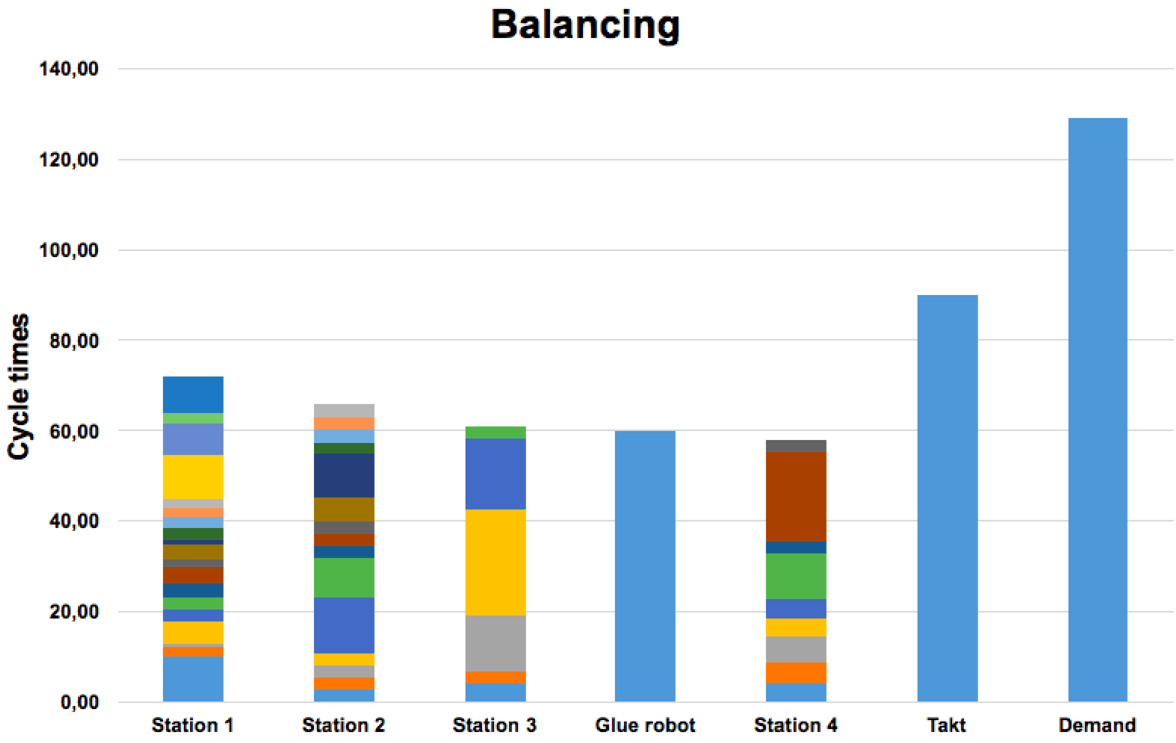

Figure 16 Balancing of workstations.

4.5 Line design

Having learned about the underlying pre-requisites for the design, the thesis team began drafting conceptual solutions to the problem. Each solution was in turn discussed to examine the validity of the sub-components and the concept. Good ideas were kept and polished while the ones deemed to be subpar were scrapped. Three conceptual ideas were remained after the initial screening process. Based on the criteria and wishes given during the discussions with TYRI the pros and cons of each concept were in turn listed. The pros and cons also provided the thesis team with a ranking system for the base concepts.

The different suggestions were in turn brought back to TYRI for discussion. The primary purpose of this session was for TYRI to raise questions about the concepts and for the thesis team to understand challenges from their point of view. Additionally, TYRI also presented their basic ideas of how to tackle issues which gave the thesis team a more practical perspective on the matter.

Having completed the mutual exchange of thoughts and solutions to problems, the thesis team shifted focus back to the concepts with freshly acquired information and insight. This time the thesis team decided on a single concept to continue improving. This was done as that concept performed better than the rest given both old and new insight. The following period was spent on making the chosen base concept get better and grow more detailed. At this stage, the project was now being visualised in 3D environments to simulate how well the ideas would work in an environment with palpable physical constraints. The production line was modelled and evaluated in the CAD software Catia V5.

4.6 Layout design and material handling

Having drafted the basic design and function of the production line itself, the attention shifted to the surrounding supporting systems and the production environment. To get an overview of the material flow and overall process through the entire factory a flow chart was created and can be found in figure 17. To incorporate the new aspects into the concept the team started from the most significant parameter at the time i.e., the production unit. As the workstations of the production unit were known, so were also the material needed at each workstation.

Next, the storage capacity of each component at the workstations was calculated. This procedure was done in two steps. First, measurements of components were obtained from CAD models of the product. Secondly, these measurements were used in calculations to compare the size of individual components to different storing options like boxes and bins. This provided an approximation of how many components the different options could keep at the workstations.

In parallel, the thesis team investigated how to adapt the design of the stations' storage units to the material handling procedure. The market was scanned for already existing solutions and to keep the degree of custom equipment to a minimum. After the search, the thesis team selected a type of shelving system which had shelved inclined towards the operators and a return chute for empty material containers. With this system, both full and empty containers could be loaded and unloaded from a single side which would facilitate in-house logistics. This also inspired the thesis team to a kanban way of thinking where the operators at the line would signal to the material handlers as soon as material has been consumed. Holding on to this thought, the thesis team modified the drafted line layout so that all material shelves would face the same direction to make replenishment easier. Having decided on this type of shelving system, the thesis team checked how well the different storage options would fit into this solution. Shelves, bins and boxes were modelled in Catia V5 to examine what would work by checking geometries and space utilisation. Apart from that, the time it would take to deplete critical component types (not ones that come in bulk such screws or gaskets) was calculated by comparing storage levels to cycle times (see table 1). The concept with the best match was eventually chosen and refined.

Table 1 Replenishment calculation.

Station	Product	Size of product	Size of container	Products/container	Containers/shelf	Quantity	Coverage time (s)	Coverage time (min)
1	Side cover	55x64x158	100x267,5x193,75	14	3	42	1509	25
	Housing middle cover	56x90x508	100x194,95x537,5	6	3	18	1294	22
	Middle bottom	55x55x510	100x194,95x537,5	6	3	18	1294	22
2	Base plate side	56x63x160	100x267,5x193,75	14	3	42	3019	50
	Section 4	47x42x60	125,5x160,4x100	10	3	30	2156	36
	Section 3	46x26x102	125,5x160,4x100	16	3	48	3450	57
	Section 2	46x27x135	125,5x160,4x100	16	3	48	3450	57
	Section 1	47x23x160	125,5x160,4x101	16	3	48	3450	57
3	Holders mid	45x87x251	100x194,95x537,5	8	3	24	1725	29
	Middle cover	30x31x489	100x194,95x537,5	12	3	36	2587	43

Having adapted the production line to the principles of material handling, attention was shifted to development of the activities that would supply the line. Influenced by kanban and lean theory in general, the thesis team developed a conceptual idea of having support personnel making milk runs with material carriers. These rounds would be based on visual signals from the line, i.e. empty containers in the return chutes, and a schedule based on the consumption rate at the workstations. Physical ergonomics was also considered to reduce uncomfortable positions and unnecessary wear. The VASA-model, the Swedish work environment authority's guidelines and the cube model formed the basis during the design process, for example when designing shelves and storage areas.

As a next step in the development work, the concept for the supporting functions needed to be introduced into the factory layout. The main challenge at this stage was placing the new

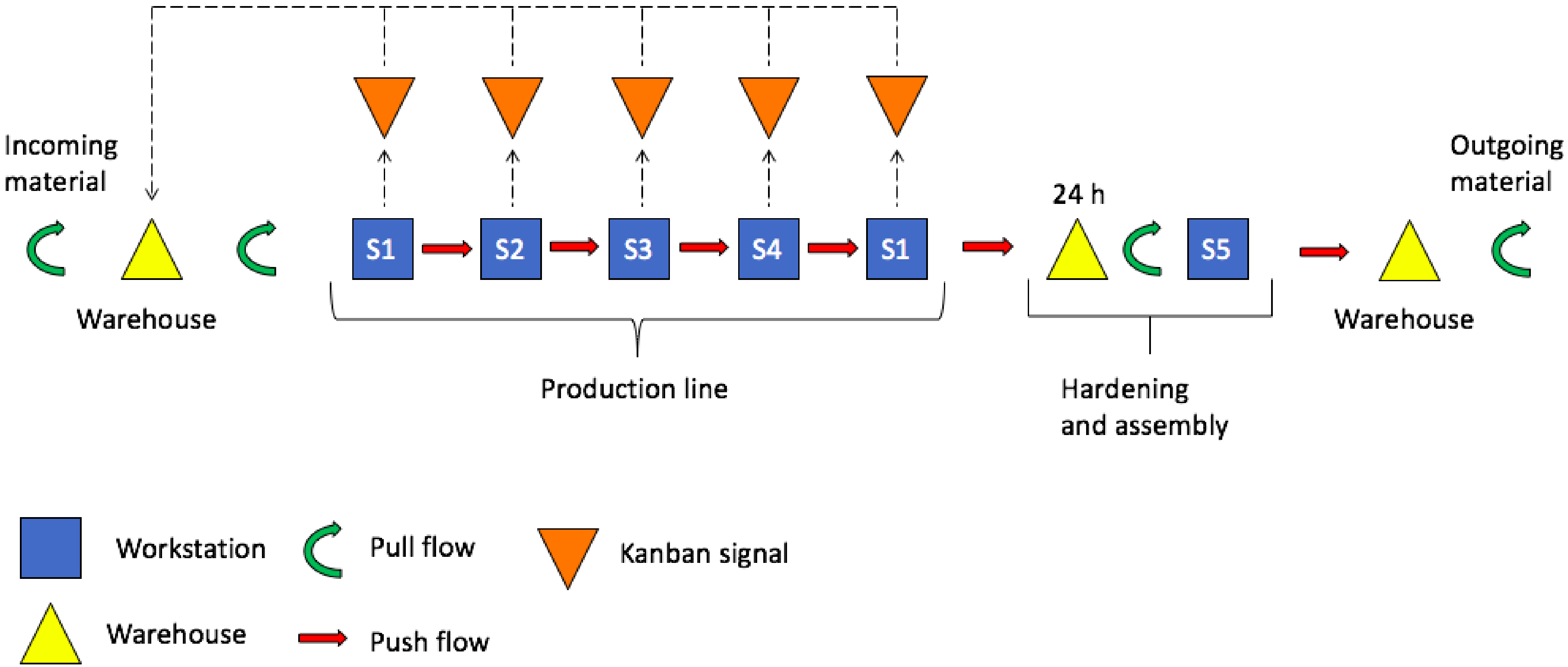

Figure 17 Flow chart, highlighting material flow and process

production unit in the facility layout in a smart manner. Fortunately, this situation was facilitated by the knowledge that one of the prerequisites of the project was that the post reconstruction layout was to be considered. As the post reconstruction layout was not planned yet, the thesis team had a large degree of freedom in the layout design. During the design work, the thesis team put focus on factors related to material flows, accessibility and safety. Just like in previous design phases, the thesis team also emphasised lean principles. The layout design procedure revolved around brainstorming and sketching sessions to quickly conceptualise ideas and solutions. The work was of iterative nature where the learnings from one case were brought along to the subsequent ones.

4.7 The production unit

To visualize the production unit, the thesis team used an existing line design that the team from TYRI has developed. The developed unit design is influenced by the lines already existing at TYRI. Much like the existing lines it is made up by a conveyor belt that transports component pallets around the line with stops at each of the four stations (see figure 18). To fulfil the requirement for the application of glue (see appendix I) one of the stations consists entirely of a glue robot. TYRI was considering to purchase a specific robot and therefore the characteristics of that model were used in the unit design. The last part of the line highlighted in figure 18 is the buffer for the line. The CAD model of the line can be found in figure 19 (the buffers are highlighted in appendix IX).

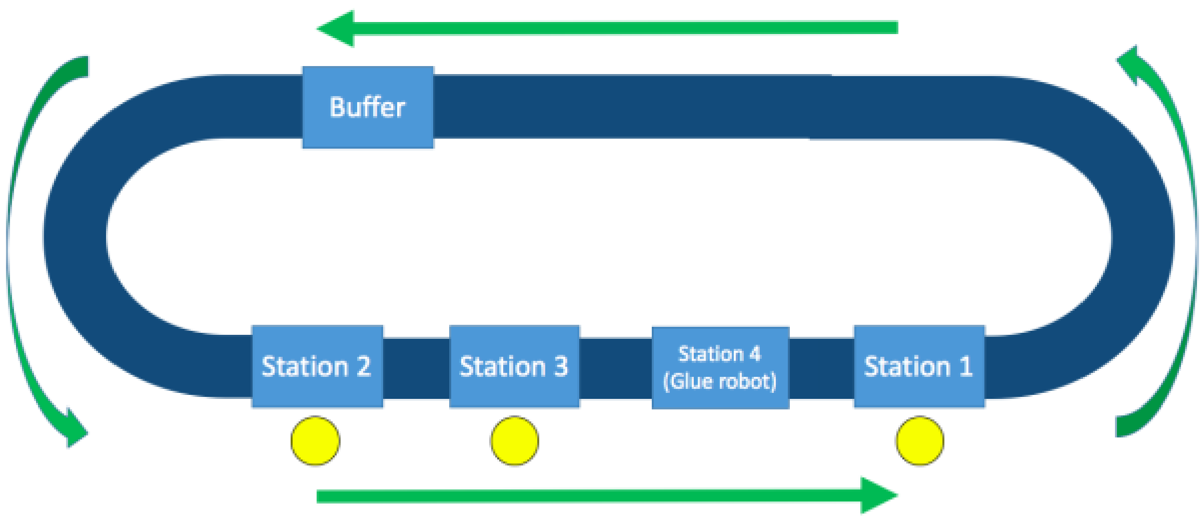

Figure 18 Schematic picture of production line.

Station one is the station that puts the bottom parts into the fixture and initiates new products. At the same time, it is also the station where the finishing assembly operations takes place and subsequently the removal of complete products from the component pallets on the line. These are in turn placed in pallets for storage during the period it takes for them to harden. Naturally, the completed products cannot harden in their pallets by the line as that area would quickly become crowded. To facilitate the pickup and transportation of hardening pallets, station one has been located at one end of the line.

The line uses a one-piece flow in accordance with the requirement specification (see appendix I) and a takt time of 90 seconds. The use of one-piece flow is also advocated by theory, as can be seen in chapter 2.3. The set takt is based on the operation time of the glue robot and the desire to achieve a somewhat even balancing between the stations (see figure 16).

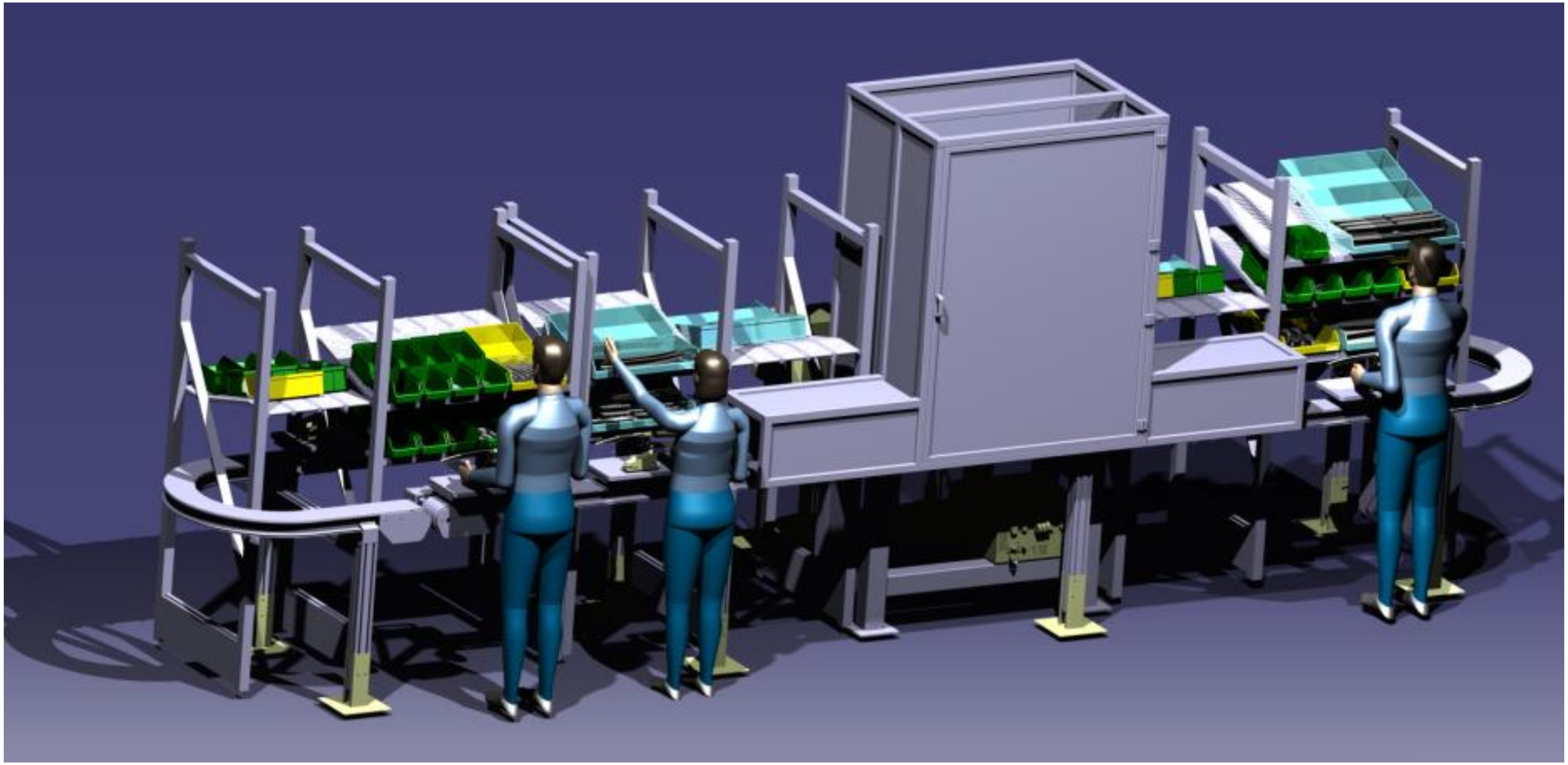

Figure 19 CAD model of the production line.

As one can observe, the line cycle times in the balance are not equal to the calculated demand. Even after adding allowances and making eventual adjustments to certain elements of work, there will still be a time gap. This gap has been planned because of certain criteria in the requirement specification.

Yet another benefit from having a higher production rate compared to the takt is the increased equipment utilisation. The glue robot represents a considerable investment cost and not trying to optimise its use would be wasteful. Therefore, the cycle time of the glue robot influenced the cycle times of the work stations to maximise its use while still achieving an even work flow.

In total, there are four operators working in the production unit. These operators are distributed among station 1, 2 and 3 and they assemble different stages of the middle and side parts. Additionally, there is a 4th operator on station 5 who is responsible for the marriage of middle and side parts of the product. However, since the glue applied by the robot requires 24 hours to harden, station 5 is an independent workstation disconnected from the line itself. This means the station has no limitations in terms of placement, however it is beneficial to place it en route to the outgoing warehouse as all products are eventually going there. The logical arguments made the thesis team place the two in between the line and the outgoing warehouse to make the flow of products intuitive and efficient.

On each pallet in the line there are slots for one middle part and two side parts. In other words, the subcomponents of one complete product are built directly on the pallets. All three parts are assembled in parallel on the line, with a few steps completed on each part at every station. A picture of the component pallet can be found in appendix X.

Compared to TYRI's existing lines, the concept has stations with long cycle times. This in turn could be a risk for increased cognitive load for the operators. To counteract this, the activities of the stations have been arranged not only with regards to duration but also the nature of the work. Similar operations such as using a screwdriver or connecting cables have been grouped together to make the work at the stations intuitive.

4.7.1 Station 1

From the operator's point of view, the work cycle begins with a component pallet arriving on the conveyor from the glue robot (station 4). The pallet holds a set of almost complete parts, more specifically one middle part and two side parts. When the pallet has arrived at station 1, the stationed operator inspects the applied glue joints before picking up top covers and placing them on the corresponding bottom pieces. At this point in the production, one middle part and two side parts are now finished. Subsequently they are lifted off the conveyor pallet and placed into a EUR-pallet. When full, the EUR-pallet is sent off to a separate area where the components harden for 24 hours before they are ready for marriage at station 5 (more on this in chapter 4.3).

The operator then initiates a new work cycle on the now empty component pallet by starting on a new middle part. First the bottom cover is inserted into the fixture on the pallet. Several components are put into the bottom cover before being attached with screws. For a more detailed description of the assembly procedure at the station, see appendix XI.

4.7.2 Station 2

The operator continues working on the middle part by finishing the work with the electronic system in the middle part. This consists of connecting cables to the different electronic components in the middle part. Once completed the operator turns their attention to the side part and start to assemble both. First, the bottom covers are put into the fixture follow by several light conductors that are either placed on pins or attached by screws. For a more detailed description of the assembly procedure at the station, see appendix XI.

4.7.3 Station 3

The last two covers are first attached to the middle part. Mainly however, the work will consist of placing screws into all three parts and fasten them. This opens the potential for investing extra in equipment for fastening the screws. For a more detailed description of the assembly procedure at the station, see appendix XI.

4.7.4 Station 4

All the work conducted in this station is performed by a fully automated robot. When a loaded pallet enters the station, the robot applies a string of glue into moulded grooves in the bottom pieces of middle and side parts. The glue is what makes a merge of top and bottom possible. When the string is applied, the pallet is in turn sent onwards to station 1 where an operator is waiting to place the top covers and initiates another cycle.

4.7.5 Station 5

After spending 24h in storage for hardening the three parts of the product arrive at station 5 on pallets. The operator then should unpack them, connect the contacts and lastly merge the three parts using clips (see appendix III). The assembly of the clips is the most complicated as discussed in chapter 1.2. Having completed the merge, the operator conducts a function test on the assembled product. This means attaching the product to some sort of testing equipment like a test fixture and then running a test program. However, the design of custom equipment such as this has not been included in this thesis (as stated in 1.7). Due to the simplicity of the assembly steps on this station only a normal working table is required and can be placed adjacent to the hardening storage (see chapter 4.3). Once the products have been tested it is placed back into a pallet and later sent to finished goods storage. That completes the process for one product. For a more detailed description of the assembly procedure at the station, see appendix XI.

4.8 Material handling and flow of materials

Identification of materials in need of replenishment is accomplished by checking the return chutes of each station at the line (see appendix XII). In case the operator at the station has used all the material in one of the component boxes, the operator proceeds to place the empty component box in the return chute. A component box in the chute in turn signals that there is a demand for material to the supporting functions, triggering the resupply operation. Having observed a single or multiple signals, a support operator makes his or her way to the station and collects the empty items on the resupply carrier. The support operator then moves the carrier to the pallet racking area and proceeds to fill the boxes with their corresponding component. The components are in turn stored in EUR-pallets that are located on the floor at the bottom of the storage shelves. Preparatory actions such as opening cartons and transferring materials to corresponding plastic boxes are carried out by the support operator to prevent value adding time at the line from being consumed by small tasks. The full boxes are returned to the station as soon as the refilling process is completed. The replenishing procedure with push carts is done in a predetermined circular manner to create a logical flow through the factory.

Due to physical restrictions on the designed shelves, the number of components that can be stored at each station is restricted. Small components can be kept in great surplus as they are space efficient whereas large ones can only be kept in limited quantities at any given time. As a result, from this, different materials have different needs for replenishment frequency. The amount of time each component lasts can be seen in table 1. These numbers are based on calculations where container and component dimensions are compared, as mentioned in chapter 3.10.

To make this system work, the supporting functions must also be supplied from somewhere. That underlying task is carried out by the forklift drivers who manage the inbound and outbound shipping of materials at the loading bay. Inbound material is unloaded from the forklifts before being transported into their specific location in the factory's multi-layer racking system for pallets. The forklifts are also used to lift down pallets of raw material from inaccessible areas in the pallet racking, thereby supplying the supporting operators who refill the line. Outbound products are also handled up by forklifts. These are collected from a drop off zone at the outbound end of the production area. Safety stock pallets ready for storage are also picked up in the same zone.

The movement of products between the line and the hardening storage is handled with pallet trucks. This is done by hand as the production area is a pedestrian zone to reduce risk of injury. Pallet trucks are also used to move products from hardening storage to station 5 and ultimately to a special drop off zone for finished goods.

4.9 Production layout

Figure 20 represents the conceptual layout drafted during the project. In the following paragraphs, the layout and the thoughts behind the design will be explained. The layout has been included into the new facilities that TYRI are planning to build.

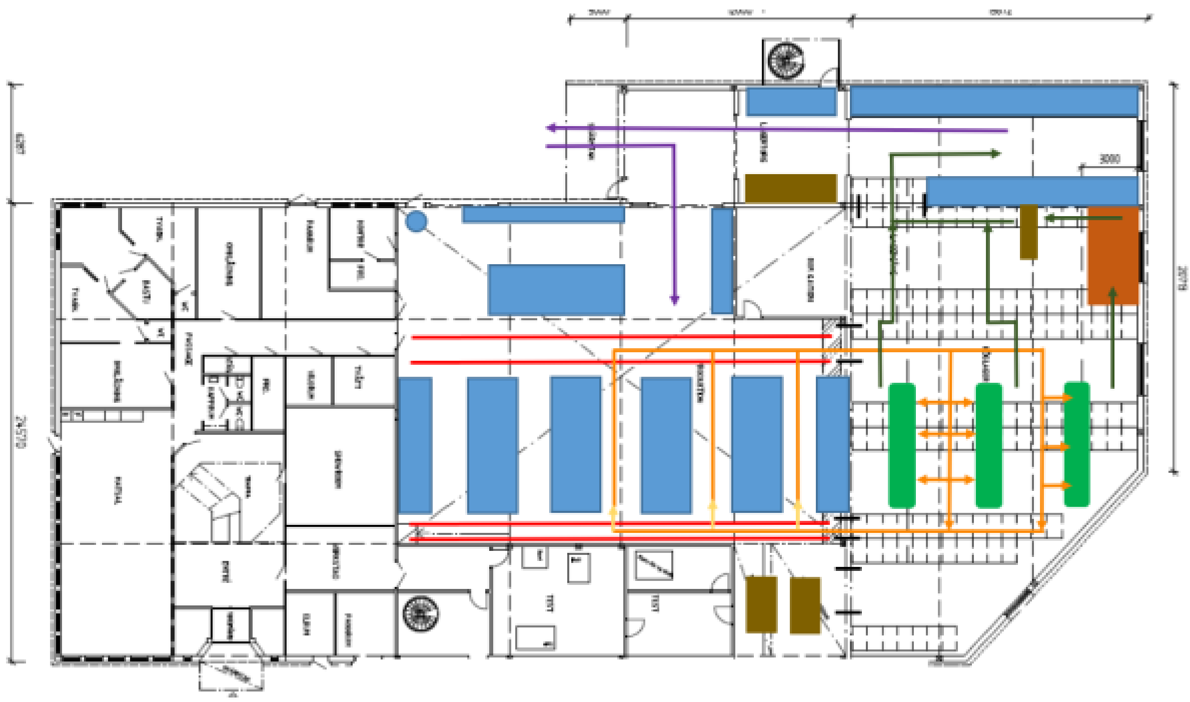

Figure 20 Layout plan with material and personnel flow.

Storage units in the layout are represented by the blue rectangles and they are primarily located in the leftmost area of the plant as depicted. The placement of the main warehouse is a consequence of demands set in the requirement specification. However, the rest of the structure of the facility was planned by the thesis team to allow for logical and systematic transportation routes for forklifts, material carriers and personnel. This resulted in the secondary warehouse, which holds outbound products and safety stock, being placed in the top right corner and the production area in the bottom right.

The transportation routes were in turn predetermined to incorporate standardisation into the system. Forklifts are allowed in the storage areas where their service is necessary to move things, i.e. the primary and secondary warehouses and the loading dock which ties them together. They are restricted to these areas to reduce heavy vehicle traffic among employees, thereby lessening the risk for injuries. The suggested areas where the trucks can move can be seen in figure 21. In the storage areas and the loading dock, the forklifts are responsible for moving inbound and outbound material as well as managing the movement of parts and products in and out of the multi-level storage racks. The movement pattern for the forklifts is exemplified by the purple arrows in the figure 21.

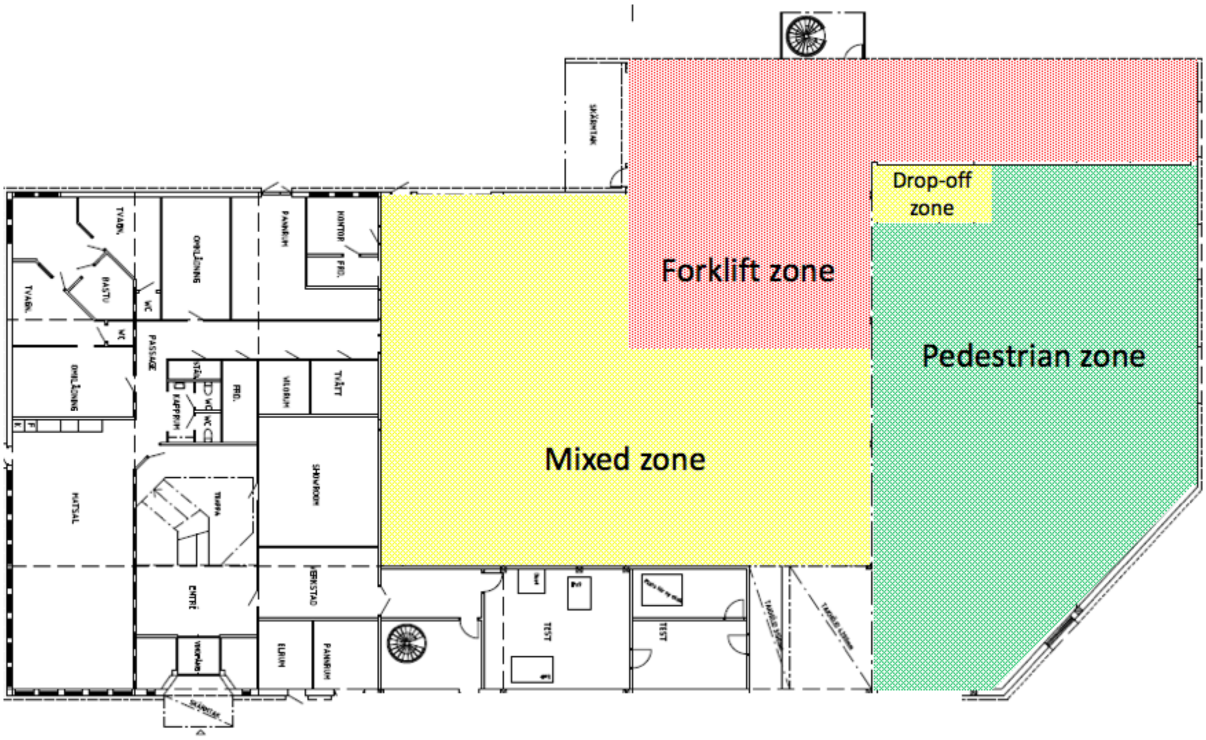

Figure 21 Layout plan with restriction zones.

When it comes to material carriers, their movements are depicted by the orange arrows in figure 12. Material carriers are pushed by operators in a clockwise movement around the system, alternating between going through the component warehouse and production area. The clockwise movement is part of the standardisation and helps forklift drivers and material handlers alike to predict behavioural patterns. This reduces the risk of crashing into one and other. Examples of different milk runs can be observed in appendix XIII.

The material handling personnel are responsible for identifying and subsequently refilling the stations in need of new material. For this to be completed as efficiently as possible, the loading side of the stations are facing each other to the greatest possible extent. This leads to a quick identification of materials that need replenishment and a reduced need for movement. Having identified the needs, operators with material carriers access the component warehouse through the walking aisle, indicated by the bottommost red parallel lines in figure 21. After the correct components have been collected in the carriers they are brought to the lines via the top walking aisle, also indicated with red parallel lines. The lines are indicated by the green rectangles in the picture.

When the operators at the assembly line have put together the middle and side parts, these are placed on a EUR pallet which is taken to a hardening storage when full. As the hardening storage is located next to station 5 in the production area where forklifts are prohibited, the transport is carried out with pallet trucks. This transport is depicted by the dark green arrow going from a green rectangle (line) to the orange rectangle (the hardening area) in the picture. Here, the sides and middles rest for 24 hours, letting the glue harden properly.

Following the hardening process, the pallet is transported to station 5 where the marriage and function test take place. Upon completion at this stage, full pallets are taken to the drop off zone at the border between the second storage and the production area. From here on, forklifts take over the handling of the finished goods.

5 Disturbance handling

Due to new requirements and design changes late in the process the project has experienced some disturbances throughout its duration. This chapter has been added to give the reader an overview of when the disturbances have occurred and how the thesis team adapted to the new situation. Furthermore, the result has been evaluated to evaluate what parts that are valid and can be adapted by the company.

5.1 Information flow

During the project the thesis team has worked side by side with TYRI's own development team to come up with a plausible suggestion for how they should produce the new product. As previously mentioned, the thesis team aspired to come up with a relevant suggestion based on up to date information. To fulfil the desire of coming up with something useful, the thesis team chose to attend regular meetings with TYRI to gather interesting information that would affect the design space. The development work thereby was based on the latest information. However, the dependency on up to date information would cause disturbances in the thesis team's development work.

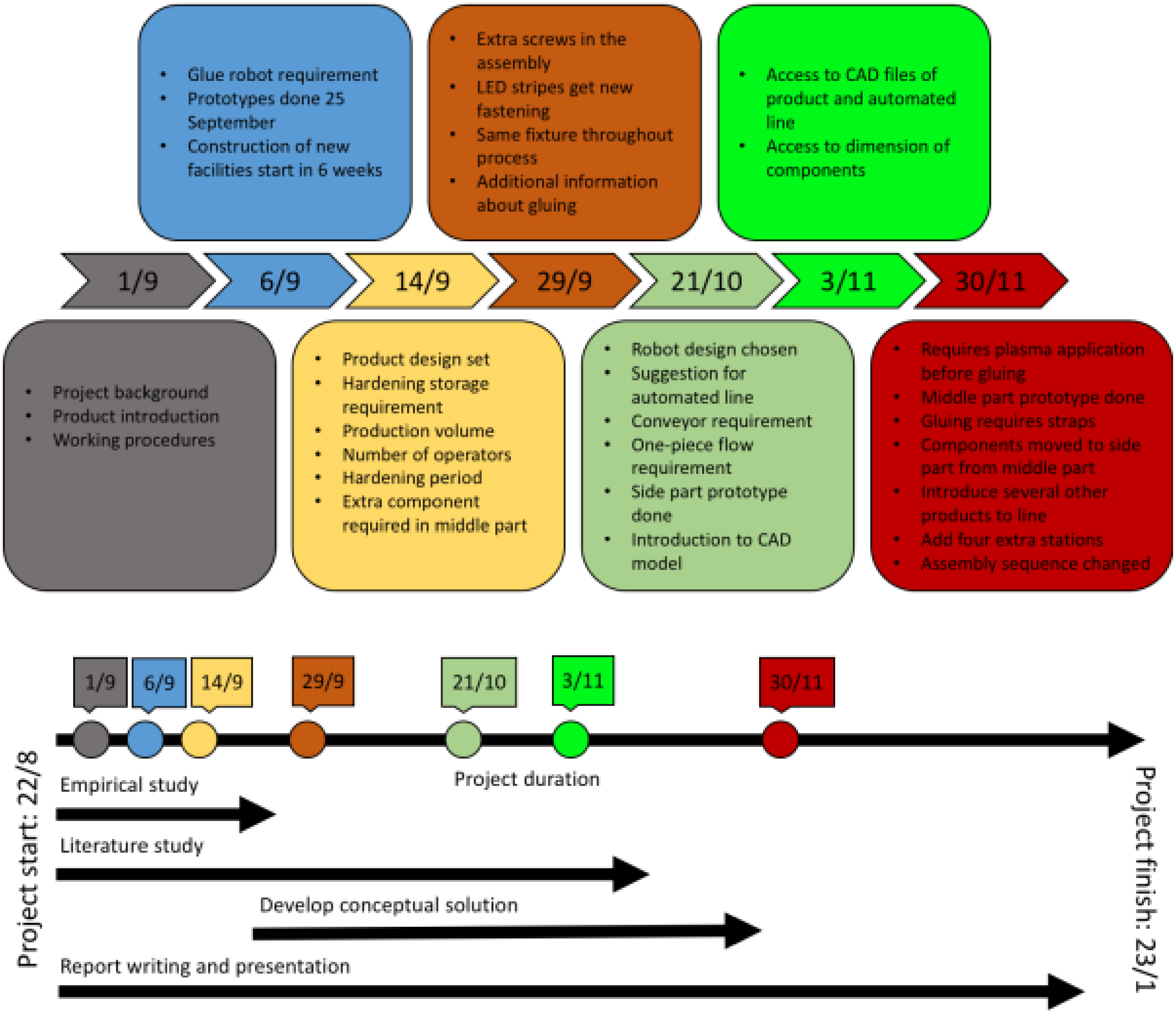

Figure 22 Information flow with adjacent timeline.

Figure 22 depicts the addition of project affecting information in a chronological order. At the bottom of the picture several timelines can be observed, illustrating the different phases which the project has undergone. Here, the addition of information can be seen in relation to the overall project timeline. For a more descriptive timeline see appendix IV where the exact scheduling can be observed on a weekly basis.

During the first weeks of the project, plenty of the work revolved around orienting the situation and laying down the foundation for the work, hence the frequent check-ups with TYRI. The information obtained from the initial talks was what the thesis team assumed would be valid throughout the duration of the project. For example, the thesis team assumed the product would not change, prototypes would come at early on and that the line would be dedicated to the product type. Given this, the thesis team in turn formulated a detailed plan of what was to be done during each week.

Throughout the project, the plan and some of its deliverables has had to be updated due to the occurrence of new information regarding the product and the production system. The addition of new information over time has both been both helpful and obstructive. Sometimes, the project was driven forward as more factors helped the thesis team make qualified decisions. At other times, the thesis team experienced setbacks when new information proved previous assumptions or decisions to be no longer relevant. These setbacks occurred when assumptions or decisions had to be made in an earlier stage to drive the project forward, even though no information had been available.

5.2 Coping with disturbances

To adapt to the dynamic situation, the thesis team had to handle changes to the product and/or the prerequisites for the production unit in a smart manner. To this end, the ACD^3 matrix came in as a useful tool for managing the changes in information. The matrix was primarily used as a place to store potentially useful information as soon as it was obtained, even if it was not relevant for the current phase of the project. Information that, after new updates, proved to be obsolete was discarded to avoid it getting used in decision making. This procedure facilitated keeping track of current information that would help the thesis team move forward in the project. Furthermore, the hierarchical structure of the matrix helped the thesis team assess what areas that potentially would be affected after a certain change. Thereby, the impact of a change could quickly be identified which meant swift corrections could be made accordingly.

5.3 Result evaluation

The biggest change in the project occurred at the very end of the project. (30/11 in figure 22). The need for a plasma treatment on the surfaces that are glued together was introduced. This had big bull-whip effects on the rest of the project as the new investment was not planned for. Due to increase in cost it was decided that the company needed more payback from their investment and therefore needed to produce more different types of products on the line. As can be expected, this change had significant impacts on the direct usefulness of the drafted concept solution. As a result, from the sudden changes to the prerequisites of the project, the remaining work of designing and refining detailed solutions was halted in favour of evaluating what parts that still could be of future use for TYRI.

At this point it was decided to make an updated analysis of the design space that followed due to the new information. Like previously, this was done with an ACD^3 matrix (see appendix XIV). The new and the old ACD^3 matrices were then compared to each other to surface differences and similarities between the two scenarios. This provided an overview of how the prerequisites had changed and how they affected more detailed solutions further down the hierarchy. From the comparison, it was concluded that few of the questions and requirements in the matrix had changed when more products were added to the line. In fact, most of the old questions at the problem level were still valid for the new environment as well. The changes that did happen occurred primarily in the leftmost column in the matrix, i.e. the effect column. This is due to the new goals of the production unit set by management. The new goals in turn opened the design space, leading to questions and uncertainty related to the operation, architecture and work columns of the matrix. The mentioned columns concern information that is vital for the planning and design work. Summarily, the changes to the effect shifts the preconditions which dictates how the system should be designed to fit into the overall purpose.

Fortunately, the method and considerations described in this thesis can still be applied to the new situation. The same ACD^3 approach can be used again to map the uncertainties and procure answers to important questions. Furthermore, the literature, theories and the reasoning are still relevant both for the new production unit and TYRI as a company. On the downside, the result cannot be implemented in its current form due to the change in the basic requirements. Despite this, the result can serve as an example of applied theories and methods, making them easier to comprehend.

6 Discussion

In this chapter of the thesis, the thesis team will bring up thoughts and reflections that have emerged during the project. The chapter is divided into four major topics that each cover the span of considerations. The debated topics are general discussion, analysis of the work method, recommendations and sustainability aspects.

6.1 General discussion

On the first meeting with TYRI it was somewhat uncertain exactly what the scope of the thesis would entail. During the first interview with our supervisor at TYRI, Jimmy Nordén stated the quote below that explains the situation well.

"Complete as much of the line as you think you can manage, we will need to do the rest" - Jimmy Nordén

From that point, it was agreed upon that the focus would be on establishing a theory-based conceptual suggestion for a new production line. Furthermore, an overview perspective would be adapted rather than focusing on perfecting one part of the system. The reason behind this was that both the product and production development was at such an early stage that it seemed unlikely that a perfected niche could be implemented without complications. Instead, the focus has been on establishing methods, principles and ideas on all parts of the system that can be adapted or provide inspiration.

Because of late project changes, an addition to the goals and purpose was introduced as disturbance handling and result evaluation. The reason for this is that some of the late-stage changes had considerable impact on the developed result. It was believed that TYRI would benefit more from an evaluation of the result as opposed to detailed concept that they cannot adapt. Furthermore, since similar development situations are likely to occur, future developers might find use in the conclusions and methods presented in this thesis.

It is evident that the idea of designing a production system in parallel to the product development complicated the development process. The risk for rework or investing time into ideas and concepts that will not work increases. On the other hand, conducting parallel development of both product and production system means the total development time could be decreased. As a result, money can be made faster thereby making the project more profitable. For this project, it would have been beneficial to either put a design stop on the product at an earlier stage or postpone the production development phase. This would create less conflict between the two phases and ensure a less unpredictable process for both teams.

At the time of drafting layout proposals for the factory, the thesis team knew TYRI was going to rebuild their production area within a year. A consequence of this would be that the plans made by the thesis team risked being rendered obsolete by future changes of unpredictable nature. This knowledge and the experience from having changes made to the product during the thesis made the thesis team to put less emphasis on the layout and the material handling system. Given those circumstances, the goal of those parts of the thesis instead aimed at providing ideas and principles that can be carried along to a next future state. The thesis team is confident that the ideas and the reasoning behind the suggestion can be recycled and used when the reconstruction is complete and the dust has settled.

The customer expects TYRI to be able to deliver top quality products always. Failing to live up to these criteria of utmost importance could lead to serious consequences for TYRI. Therefore, to ensure that the system would be able to satisfy those criteria the thesis team built the system to have additional capacity in case something goes wrong. The extra capacity would also assist TYRI in fulfilling their vision to become a top tier supplier, one you can trust to handle additional orders on short notice in case their customers makes mistakes. This status would become extra important as the new product has potential to open new doors for the company.

The thesis only considers the production line which the thesis team designs, yet the production layout and the material handling system would affect other production units in the factory. For the layout and the material handling to be optimal, all the parameters in the factory need to be included which has not been the case. Therefore, there is a need for continued work with the proposal to evaluate whether the ideas presented are applicable in their existing system.

A central topic in the thesis is the handling of information, the assumptions made and how new information has been processed. A fair point for critique might be that the thesis team was overly optimistic in making certain design assumptions early on even though the product was not finished. Early design decisions are a shortcoming in the project and it is unquestionably preferable to base important decisions on information that has been confirmed. But as the thesis is limited to a set span of weeks, the thesis team had to make decisions prematurely to be able to proceed with the project. In longer projects the developer should always base decisions on facts.

6.2 Methodology analysis

More empirical data could have been obtained from companies working with similar operations for increased understanding of assembly operations in general. Production designers, planners, managers and operators could all have provided the thesis team with meaningful information for the project. Because of doing a survey at companies, perhaps the thesis team could have reduced the risk of becoming narrow-minded in terms of coming up with creative solutions to problems.

One of the goals of the project was to assess the ACD^3 method in a production development project. The primary benefit of the framework has been that it made the thesis team consider several different aspects that otherwise might have been overlooked. By just going from top to bottom in the matrix and try to fill out as much of it as possible, a lot of insight was gathered early in the project. Also, the tool has been helpful for mapping decisions and how they affect each other through the hierarchical structure as discussed in chapter 5. A negative aspect of the usage has been the invested time in comparison to the actual output. However, this might just be a consequence of the thesis team spending more time on the method than was necessary. Furthermore, the ACD^3 framework has been developed primarily for product development, and it has not been tested in production development cases. This means that in its current form it can sometimes be somewhat non-intuitive to use.

A shortcoming in the methodology has been the lack of physical validation during the development. Even though theory and virtual tools provide a good basis, new insights will always be revealed when testing it. From the start of the project the thesis team planned to conduct experiments with prototypes and real components. The results would be used to validate and analyse the activities and assembly sequence of the product. Unfortunately, the prototypes were completed too late in the project and subsequently there was no time perform the analysis. However, the thesis team recommends future projects to experiment with prototypes or physical models as early on as possible.

When reviewing the balancing methodology, it is important to shed light on possible flaws which the thesis team are aware of. The overall approach is not based entirely on mathematical arguments, but instead on considerations and logical reasoning. This means the solutions might not guarantee the most optimal solution present in the findings, especially when no physical validation was possible. But given the initial assumptions, the thesis team is confident that the balancing probably is close to the overall optimum. This belief stems from a great deal of work put into the analysis and the considerations made when the balancing was conducted.

6.3 Recommendations

As the concept presented in the thesis became less relevant for TYRI due to the changes in direction for their overall project, the main recommendations will be aimed at what they can take with them from this thesis. For TYRI's future work, the theories (chapter 2) and the methodologies (chapter 3) presented could provide them with a systematic way of working based on research. This would aid them in making decisions about the design that are made in a motivated and logical manner and where each step in the development process builds on the previous one. This approach will also make sure that design decisions are actively made by the developers and not by circumstance.

The goal and purpose of the thesis (see chapter 1) has been to develop a suggestion heavily influenced by research about production development. Therefore, it is recommended to view the concept as an exemplification of how all the research can be applied in a real production situation. Furthermore, rather than viewing the concept as something to implement it is recommended to consider it more as a goal to strive towards. As a start, focus on the most relevant parts of the result and gradually improve from there. Avoid making companywide changes right away. Deliberate and controlled changes will generate the most gain in the long run (Liker & Meier, 2006).

When TYRI moves into the implementation, evaluation and improvement phase of their own project, it is vital to include factors that have been excluded from this thesis. It is recommended to include the operators and other shop floor personnel into the development process as they interact with the different parts of the concept daily. Therefore, their experiences from the user perspective is vital for the development and it is important to harness as much of it as possible (see chapter 2,2). Moreover, as stated by Hackman & Oldham (2005), including the operators in the development can help facilitate the acceptance for changes and increase the motivation of the workforce.

According to Baudin (2004) the biggest improvements to the in-house transportation system are not found in shortening distances but rather when combining transportations for different products and destinations. As the scope had to be narrowed down in the thesis, this important piece of information was hard to apply to its full potential. But as TYRI will have to consider all their operations in their factory during their development processes, this knowledge is food for thought.

In Muther's (2001) fourth step for developing a production it is stated that the procedural considerations like scheduling, maintenance and quality are the most important when the cell plans are coupled into existing system. Thereby it is recommended to put extra effort on these areas when the implementation plan is put together.

6.4 Sustainability aspects

The research has aimed to develop a theoretical concept on how production systems should be developed for a new product. The theories and methods has been selected to give a systematic and robust way of planning and designing the unit in an early stage of the product development phase. Thereby the tools have been provided to design an up-to-date production system influenced by lean and other relevant philosophies. This in turn aim at reducing wastes within the company and creates a more sustainable way of producing products and enforcing market position.

For the operators at TYRI the result and considerations has aimed at providing an ergonomically adapted workplace to reduce the risk of injuries or strain. When the health of people is ensured the company also mitigates costs related to sick leaves. Both factors contribute to social sustainability for both employer and employee alike.

7 Conclusion

This section of the thesis presents the conclusions of the work. The conclusions relate the conducted work in relation the purpose and goals of the thesis.

As stated in the introduction, the main purpose of the thesis has been to convey academically anchored ideas on how to design a production system through a conceptual solution that can serve as input for their continued work. The theory, the thought patterns and the methodology presented in this thesis are elements that will remain useful and relevant for other design cases, hence it is believed that part of the purpose has been fulfilled. A conceptual solution anchored in theoretical knowledge has also been developed. However, the concept turned out to be misaligned as the prerequisites for the system were changed in a late stage of the project.

The severity of the disturbances has been dictated by the scale of the change, what was affected and when the change emerged in the development process. Small alterations to the input of the production system design have generally been fixed easily, even in cases when they pop up late. These rarely have any effect whatsoever on the validity of the result. Major changes or changes to fundamental assumptions on the other hand, such as the switch in production philosophy from single-type to multi-type line, come with considerable consequences unless they are made early on. Major changes risk rendering existing solutions obsolete and in need of updating efforts. The same can be said about changes made to the product or products which the system is built for. Tiny alterations to dimensions and shapes can lead to production engineers having to redesign assembly orders, the tasks at workstations and at times even redesign station layouts to properly adapt them for the new needs. Therefore, it is advantageous to include production engineers in the process of designing products to reduce the risk of this happening.

The usage of the ACD^3 framework in the project proved to provide an easy way of creating an overview of the different decisions, interests and criteria involved. It was also helpful when determining how different stakeholder's criteria influenced each other. The work with ACD^3 was rewarding in the initial phase when the thesis team focused on laying down the foundation for the remainder of the project. Furthermore, the method encourages the developer to consider many different aspects of the project and what stakeholders that are connected to each part of the matrix. However, in its current form the method can sometimes be unintuitive to use, which results in unnecessary amounts of time being committed with low payoff.

In the following paragraphs, each individual goal will be addressed and summarized.

Deliver a conceptual solution of a production system anchored in theoretical knowledge.

The thesis team managed to deliver a theory-based conceptual solution of a production system to TYRI. The idea behind the concept was to provide TYRI with a detailed description of how to overcome the production problem and to suggest the design of supporting functions. However, one can argue about the value of the result due to it becoming misaligned with the new prerequisites. The direct use and relevance of the concept is probably limited in its present form but it can provide support for understanding theory and methodology, thereby acting as a support for TYRI's own development process.

Test a novel production development framework as a base for decision making in a production development case.

During the project the thesis team tested the ACD^3 framework, which originally was developed for product development, in a production environment to see if it could provide the user with any assistance. As concluded, the framework facilitated the process of determining the foundation of the work by visualising the design criteria and hence the decisions that needed to be made. However,

Examine and evaluate what impact disturbances in the product design have on the production system development.

Changes made to the product risk leading a situation where the production department should reconsider assembly orders, work sequencing and in a worst-case scenario even the workstation design. The reason for this is the chain reaction of consequences that can build up through all layers of complexity.

Examine and evaluate what impact late-stage changes to the goal and effect of the production system has on the development.

Late changes to the desired goal and the effects of the line has had a significant impact on the development work. Changing those criteria in a late stage leads to a considerable step backwards in the development process due to previous design assumptions becoming invalid. This in turn triggers a need for new analyses of the situation and redesign of concepts.

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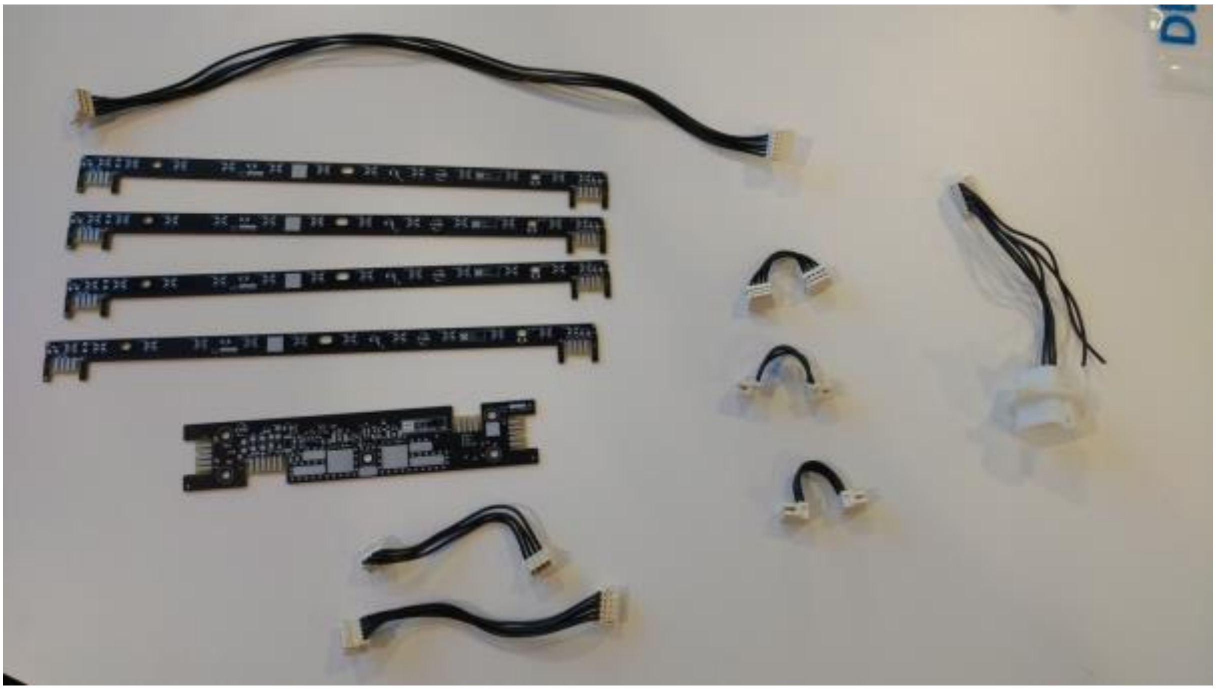
Appendix I – Requirement specification

Aspect	Specification	Weight	Comments
Production rate	Produce 50 000 products yearly (45 weeks)	5	Takt time = 129 s
Deliverability	Always deliver to customer on time	5	Even and predictable demand
Quality	Lights musn't be scratched	5	Scratches alter light emitting abilities
	24 hour hardening of glue joint	5	
	Tight seals	5	
Product cost	Maximum of 100 SEK	5	Primarily based on operator cost
	Less than 50 SEK	3	Primarily based on operator cost
Ergonomics	Adapt work stations to physical ergonomics	2	
	No unecessary tear on operators	2	
Material handling	Influenced by lean production	2	
	Use one pallet in producing system	4	
	Eliminate middle storage	1	
	Components in plastic boxes at work stations	3	
Production type and layout	Production Line	5	Familiarity from existing lines
	Conveyor belt based system	5	
	One Piece flow	5	
	Dedicated to one product	5	
Production equipment	Glue robot	5	
	Glue operation takes 60 seconds	5	
Work force and scheduling	3-8 people working in the production system	5	
	Even number of operators	3	Facilitates downpacing
	Work at 100% or 50%	3	
Ethics			
Storage and shipping	EUR-pallet based	5	
	Storage located in old part of the factory	5	
	Designated storage area	5	

Appendix II – Cables and electrical components



Appendix III – Marriage point clips

Appendix IV – Time plan

	Activity	Milestone	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4
			Weeks																					
1	**Project plan**																							
2	**Literature study**	ACD3	■																					
3		Lean production	■	■	■																			
4		Ergonomic workplace design	■	■	■																			
5		Predetermined time systems				■	■																	
6		Balancing						■	■	■	■													
7		Layout and material flow						■	■	■	■	■	■	■										
8		Material handling										■	■	■										
10	**Emperical study**	Interview stakeholders	■	■	■	■	■																	
11		Test assembly of electronics							■															
12		Assembly of prototype								■														
14	**Devlop conceptual solution**	Sequential Activity - and Methods Analysis			■	■	■																	
15		Decide prodution system type					■	■																
16		Balance work tasks					■	■	■															
17		Develop work stations						■	■	■														
18		System layout						■	■	■	■													
19		Material flows										■	■	■										
20		Material handling										■	■	■										
21		Factory layout												■	■									
22		Develop complete conceptual solution													■	■	■							
24	**Factory visits**		■	■	■		■																	
25	**Project presentation**																	■			■	■	■	■

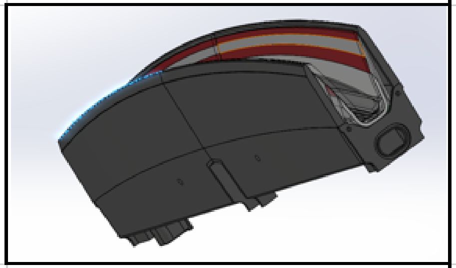
Appendix V - ACD^3 matrix

Design perspectives	Abstraction levels				
	Effect	Operation	Architecture	Work	Tools and Information
Problem	Assemble high quality products efficiently	How do the components flow	Assemble and glue	Support function personnel	
		How much to keep in storage	Takt vs. assembly times	What tools are needed?	
		Where to place storage	Size of hardening storage	Cables below electronics, difficult	
		50k yearly spread evenly	Material handling equipment	Even glue joint, hard to reach	
		Non damaging production design	One line pallet/fixture	Quality responsibility, who?	
			Prefer full/half paced work		
			24h hardening, storage issues		
			Utilize glue robot for multipe stations		
Structure	Supervisor/examinator	Custom material boxes from suppliers	Pack finished products in EUR-pallets	3-8 people initially approximated	Glue on bottom parts
	Customers	Components in, products out	Number of operators		
	Suppliers	Glue robot	Number of robots		
	Tyri	Machines	Number of stations		
	Arbetsmiljöverket	People			
Function	Deliver on time	Transport of material	60s glue operation	Control glue joint	
	High quality products	Components in, high quality product out	Pack, move, assemble, glue		
	Pleasant working environment				
Activity	Design of product	Move components and products	Inspect glue joint	EUR-pallet shipping, sheets	
	Design of production system	Click, screw, glue components	Function test		
	Design of supporting functions	Pack products	Quality check		
	Installation of production system		Pack products in pallets		
	Installation of supporting functions		Connect electronics		
			Assemble subcomponents		
Realization	Space restrictions	Production line (straight, U-shape)	Final storage and shipment on pallets	Grooves to place cables	
	Incorporate into existing solutions	Functional layout (functional line)	Glue robot specifications required	Screw component to prevent rise	
		Cell layout	Kanban shelves	Technical help for inspection	
		Conveyors		Operators, quality responsibility	
		Flow (one piece, parallel)		Angled glue nozzle	
Specified system goals	Space restrictions	Defined flow of components and products	Support functions	Demand: 100 SEK/product (operator cost)	
	50 000 products in 45 weeks	Chosen production principle/layout	Balancing of stations	Wish: <50 SEK/product (operator cost)	
	High quality requirements, few defects		Layout planning		
			Material flows		
			Work sequence		

Appendix VI – List of activities

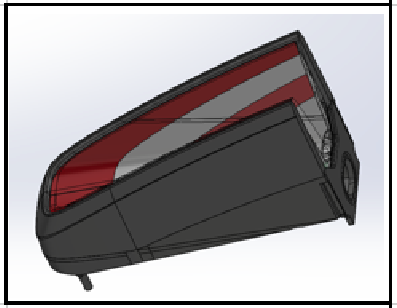
Task	Activity
1	Get bottom and put in fixture
2	Get tool and remove membrane from paper
3	Get membrane and put onto hole
4	Get rubber washer and put around hole
5	Get contact and put on rubber washer over hole
6	Get control board and put on bottom
7	Get heatpad and put on bottom
8	Get 3 screw and put on control board and contact
9	Get screwdriver and tighten screws
10	Get 4 led lights and put on table
11	Get 4 led lights from table and put on bottom
12	Get 3 short cables and put on table
13	Get 3 short cables and put on control board/led lights
14	Get 2 medium cables and put on table
15	Get 1 medium cable and put on control board/led ligh
16	Get 1 medium cable and put on control board/led ligh
17	Get 1 long cable and put on control board
18	Get 2 light holders and put on control boards and light
19	Get 8 screws and put on light holders
20	Get screwdriver and tighten screws
21	Get midcover and put on light holders
22	Inspect glue joint
23	Get top and put on bottom - part 1
24	Get top and put on bottom - part 2
25	Get finished product and put in buffer
26	Get two bottom parts and put into pallet
27	Get two circut boards and put in bottoms
28	Get heatpad and put on bottoms
29	Get two section 4 and put on circut boards
30	Get 4 screws and put in both section 4
31	Get screwdriver and tighten screws
32	Get two section 3 and put on section 4
33	Get two section 2 and put on section 3
34	Get two section 1 and put on section 2
35	Get 4 screws and put in both section 1
36	Get screwdriver and tighten screws
37	Inspect glue joint
38	Get top and put on bottom part 1
39	Get top and put on bottom part 2
40	Get finished product and put in buffer

Appendix VII – SAM analysis



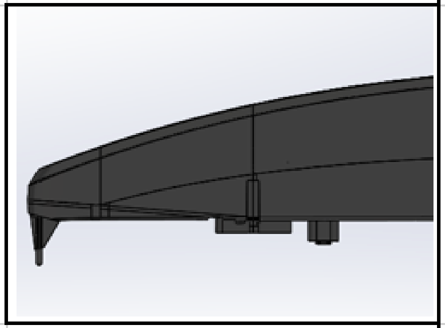
	Object: Middle part headlight	Get					PUT							USE						RETURN PUT							SUMMARY OF FACTORS				
		Step	GS			Add. For handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke, prip etc			Apply Force	Weight > 5 kg	Step	PD			Add. for Precision	Apply Force	Bend+Arise				
		S	80	45	10	-H	AW	S	80	45	10	-P	AF						AF	AW	S	80	45	10	-P	AF	B				
Row	Activity description	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	Code	3	2	3	5	4	2	3	3	12	F	f	Total (Factors)	Total (s)
1	Get bottom and put in fixture			1						1		1					0													11	1,96
2	Get tool and remove membrane from paper			1	1						1	1											1	1						17	3,04
3	Get membrane and put onto hole				1						1	1																		7	1,25
4	Get rubber washer and put around hole			1						1		1	1				0													14	2,50
5	Get contact and put on rubber washer over hole			1						1		1	1				0													14	2,50
6	Get control board and put on bottom			1						1		1					0													11	1,96
7	Get heatpad and put on bottom			1						1		1					0													11	1,96
8	Get 3 screw and put on control board and contact			1		1				3		3		4	3	2	24													55	9,82
9	Get screwdriver and tighten screws			1						3		3	3			4,48	4,48													38,48	6,87
10	Get 4 led lights and put on table			1		1				1							0													14	2,50
11	Get 4 led lights from table and put on bottom			4						4		4					0													44	7,86
12	Get 3 short cables and put on table			3	3					3							0													30	5,36
13	Get 3 short cables and put on control board/led lights			3	3					3	3	3	3				0													54	9,64
14	Get 2 medium cables and put on table			1	1					1	1						0													12	2,14
15	Get 1 medium cable and put on control board/led lights			1	1					1	1	1	1				0													18	3,21
16	Get 1 medium cable and put on control board/led lights			1						1		1	1																	14	2,50
17	Get 1 long cable and put on control board			1	1					1	1	1	1				0													18	3,21
18	Get 2 light holders and put on control boards and lights			2						2		2					0													22	3,93
19	Get 8 screws and put on light holders			1		1				8		8		4	8	2	64	SA7												130	23,21
20	Get screwdriver and tighten screws			1						8		8	8			4,48	4,48													88,48	15,80
21	Get midcover and put on light holders			1					1			1	1				0													15	2,68
22	Inspect glue joint																0													28	5,00
23	Get top and put on bottom - part 1			1						1		1					0													11	1,96
24	Get top and put on bottom - part 2										1	1					0													5	0,89
25	Get finished product and put in buffer	2	1						1								0													16	2,86
	Calculation:																			**Total net time (factors)**										697,96	124,64

Object: Side part headlight



		Get					PUT							USE						RETURN PUT							SUMMARY OF FACTORS				
		Step	GS			Add. For handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke, prip etc			Apply Force	Weight > 5 kg		PD			Add. for Precision	Apply Force	Bend+Arise				
		S	80	45	10	-H	AW	S	80	45	10	-P	AF						AF	AW	S	80	45	10	-P	AF	B				
Row	Activity description	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	Code	3	2	3	5	4	2	3	3	12	F	f	Total (Factors)	Total (s)
1	Get two bottom parts and put into pallet			1	1					1	1	1																		15	2,68
2	Get two circut boards and put in bottoms			1	1					1	1	1					0													15	2,68
3	Get heatpad and put on bottoms			1	1					1	1	1																		15	2,68
4	Get two section 4 and put on circut boards			1	1					1	1	1					0													15	2,68
5	Get 4 screws and put in both section 4			1		1				4		4		4	4	2	32	SA7												70	12,50
6	Get screwdriver and tighten screws			1						4		4	4			4,48	4,48	MT												48,48	8,66
7	Get two section 3 and put on section 4			1	1					1	1	1					0													15	2,68
8	Get two section 2 and put on section 3			1	1					1	1	1					0													15	2,68
9	Get two section 1 and put on section 2			1	1					1	1	1					0													15	2,68
10	Get 4 screws and put in both section 1			1		1				4		4		4	4	2	32	SA7												70	12,50
11	Get screwdriver and tighten screws			1						4		4	4			4,48	4,48	MT												48,48	8,66
12	Inspect glue joint																0													28	5,00
13	Get top and put on bottom part 1			1	1					1	1	1					0													15	2,68
14	Get top and put on bottom part 2			1	1					1	1	1					0													15	2,68
15	Get finished product and put in buffer	2	1		1				1		1						0													20	3,57
Calculation:																				**Total net time (factors)**										341,96	74,99

Object: Marrige point

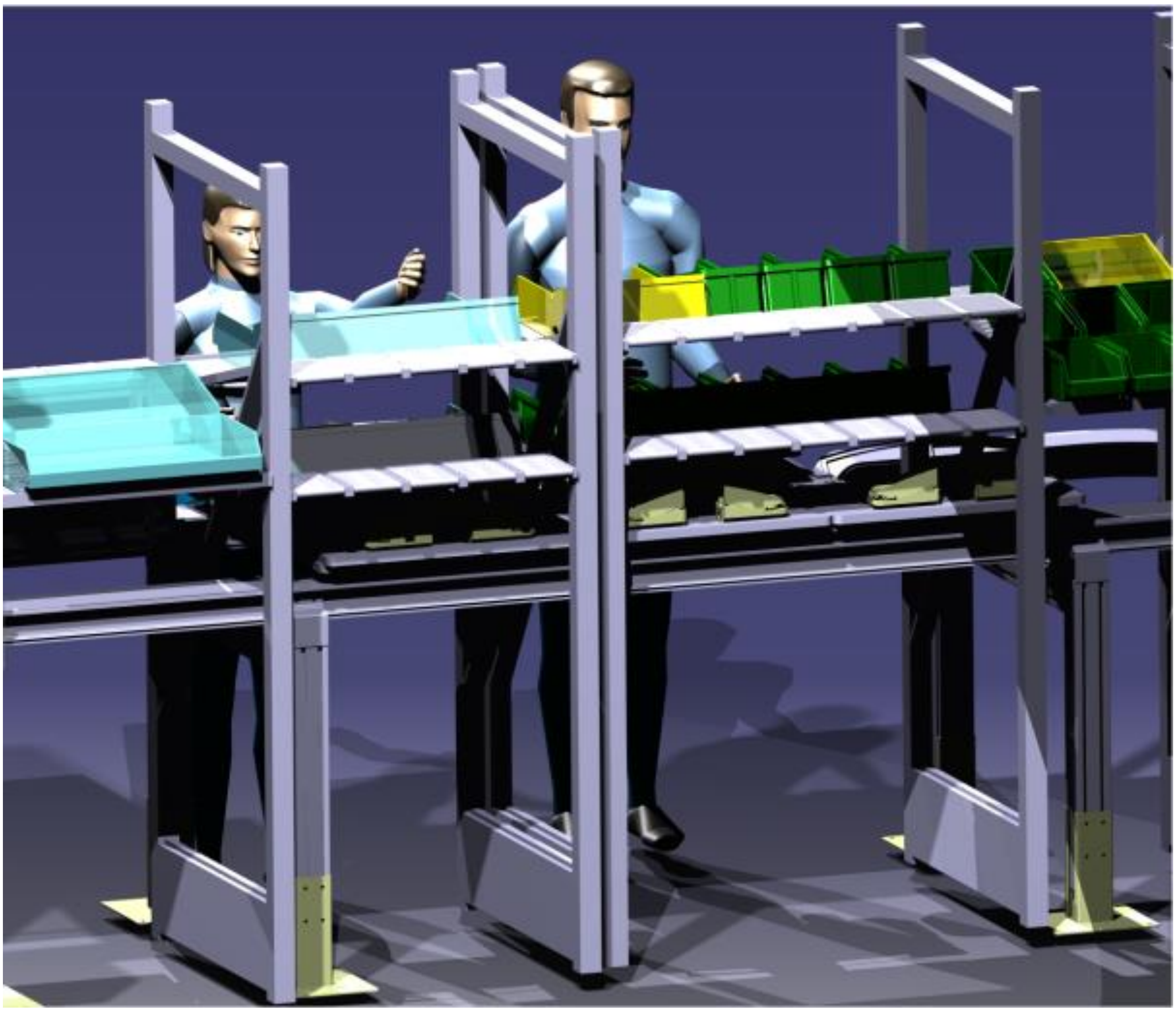


		Get					PUT							USE						RETURN PUT							SUMMARY OF FACTORS				
		Step	GS			Add. For handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke, prip etc			Apply Force	Weight > 5 kg	PD				Add. for Precision	Apply Force	Bend+Arise				
		S	80	45	10	-H	AW	S	80	45	10	-P	AF						AF	AW	S	80	45	10	-P	AF	B				
Row	Activity description	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	Code	3	2	3	5	4	2	3	3	12	F	f	Total (Factors)	Total (s)
1	Get middle part and put on table	2	1					2	1								0													22	3,93
2	Get side parts and put on table	2	1		1			2	1		1						0													26	4,64
3	Get bushing and put on side/middle part			2						2	2	2	2				0													32	5,71
4	Get cables and inset into circut boards			2							2	2	2				0													24	4,29
5	Get side part and put onto middle part			2							2	2	2				0													24	4,29
6	Get locking clip and put into product			4						4		4	4				0													56	10,00
7	Get product and put into test fixture			1						1		1	1				0													14	2,50
8	Function test																0													112	20,00
9	Get product and put into pallet rack			1					1			1	1				0													15	2,68
	Calculation:																			**Total net time (factors)**										325	58,04

Appendix VIII – Ranked position weight for middle and side parts

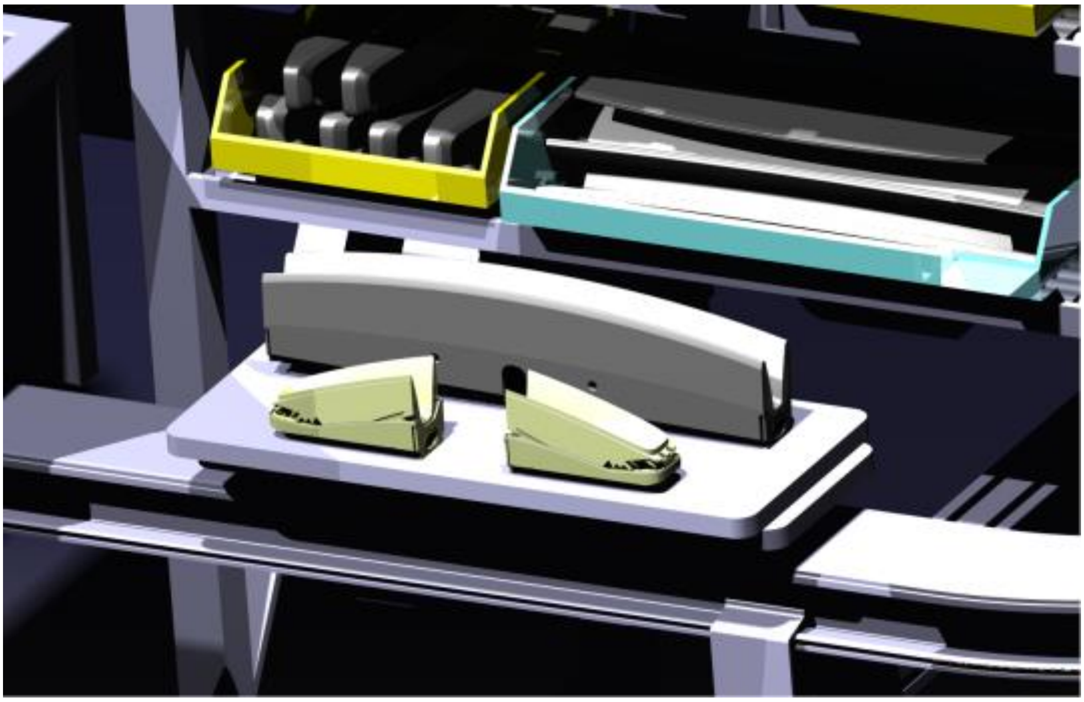
Task	Activity	Cycle time (s)	Preceeding tasks	RPW (s)
1	Get bottom and put in fixture	1,96	-	122,67
4	Get rubber washer and put around hole	2,50	3	114,46
6	Get control board and put on bottom	1,96	5	113,39
5	Get contact and put on rubber washer over hole	2,50	1	111,96
7	Get heatpad and put on bottom	1,96	6	101,06
8	Get 3 screw and put on control board and contact	9,82	5, 6	99,1
10	Get 4 led lights and put on table	2,50	-	92,76
11	Get 4 led lights from table and put on bottom	7,86	1, 10	90,26
9	Get screwdriver and tighten screws	6,87	8	89,28
2	Get tool and remove membrane from paper	3,04	1	86,69
3	Get membrane and put onto hole	1,25	2	85,44
26	Get two bottom parts and put into pallet	2,68	-	74,99
27	Get two circut boards and put in bottoms	2,68	26	72,31
12	Get 3 short cables and put on table	5,36	-	71,34
28	Get heatpad and put on bottoms	2,68	27	69,64
29	Get two section 4 and put on circut boards	2,68	28	66,96
13	Get 3 short cables and put on control board/led lights	9,64	8, 11	65,98
30	Get 4 screws and put in both section 4	12,50	29	64,28
14	Get 2 medium cables and put on table	2,13	-	64,19
15	Get 1 medium cable and put on control board/led lights	3,21	8, 11	59,55
17	Get 1 long cable and put on control board	3,21	8, 11	59,55
16	Get 1 medium cable and put on control board/led lights	2,50	8, 11	58,84
18	Get 2 light holders and put on control boards and lights	3,93	13, 15, 16	56,34
19	Get 8 screws and put on light holders	23,21	18	52,41
31	Get screwdriver and tighten screws	8,66	30	51,78
32	Get two section 3 and put on section 4	2,68	31	43,12
33	Get two section 2 and put on section 3	2,68	32	40,44
34	Get two section 1 and put on section 2	2,68	33	37,76
35	Get 4 screws and put in both section 1	12,50	34	35,09
20	Get screwdriver and tighten screws	15,80	19	29,19
36	Get screwdriver and tighten screws	8,66	35	22,59
37	Inspect glue joint	5,00	36	13,93
21	Get midcover and put on light holders	2,68	20	13,39
22	Inspect glue joint	5,00	21	10,71
38	Get top and put on bottom part 1	2,68	37	8,93
39	Get top and put on bottom part 2	2,68	38	6,25
23	Get top and put on bottom - part 1	1,96	22	5,71
24	Get top and put on bottom - part 2	0,89	23	3,75
40	Get finished product and put in buffer	3,57	39	3,57
25	Get finished product and put in buffer	2,86	24	2,86

Appendix IX - The buffer



The buffers are the pallets located under the kanban shelves.

Appendix X – The production pallet

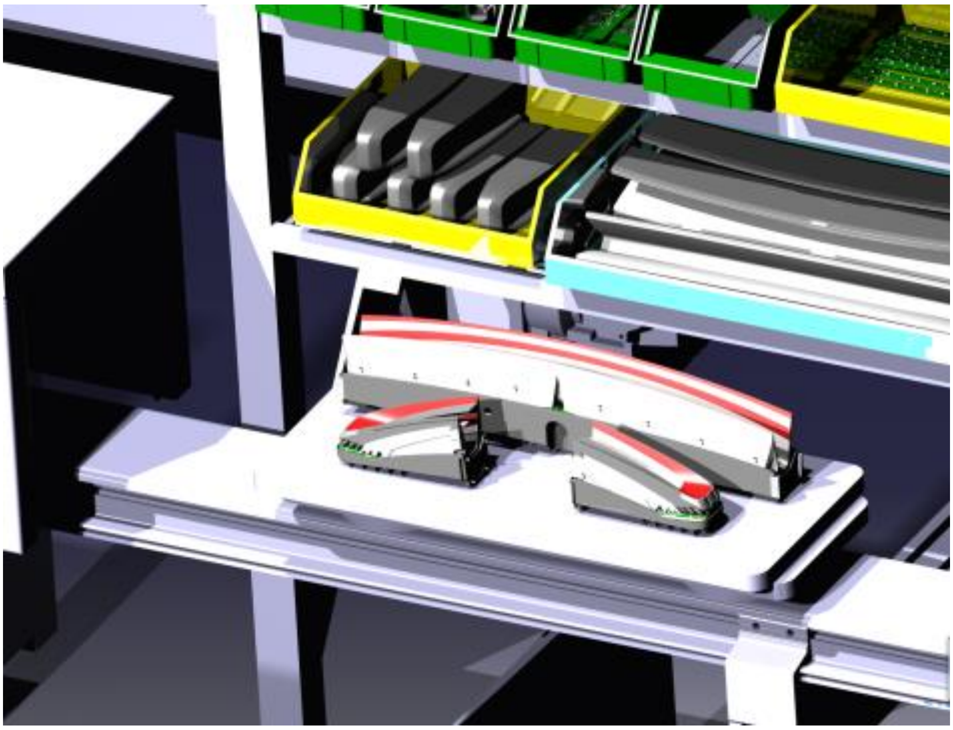


Appendix XI – Distribution of activities

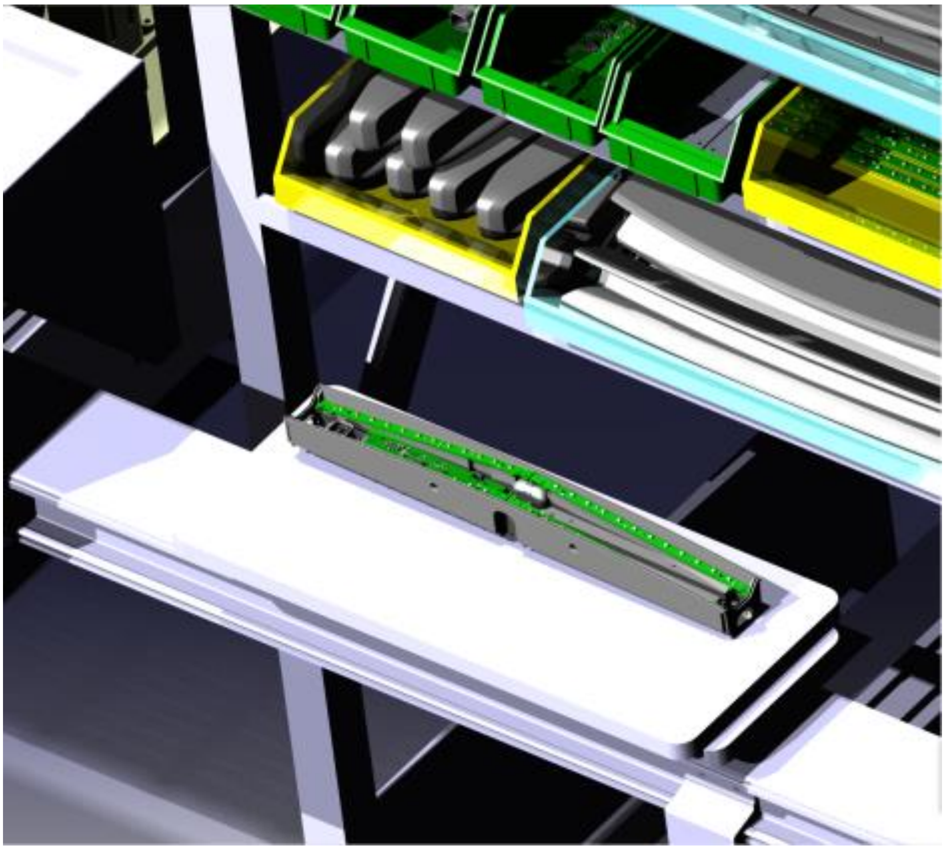
Station 1

Activity	Duration (s)
Inspect glue joint	10,00
Get top and put on bottom - part 1	1,96
Get top and put on bottom - part 2	0,89
Inspect glue joint	5,00
Get top and put on bottom part 1	2,68
Get top and put on bottom part 2	2,68
Get finished product and put in buffer	2,86
Get finished product and put in buffer	3,57
Get bottom and put in fixture	1,96
Get tool and remove membrane from paper	3,04
Get membrane and put onto hole	1,25
Get rubber washer and put around hole	2,50
Get contact and put on rubber washer over hole	2,50
Get control board and put on bottom	1,96
Get heatpad and put on bottom	1,96
Get 3 screw and put on control board and contact	9,82
Get screwdriver and tighten screws	6,87
Get 4 led lights and put on table	2,50
Get 4 led lights from table and put on bottom	7,86
Total	**71,87**

Product entering station 1



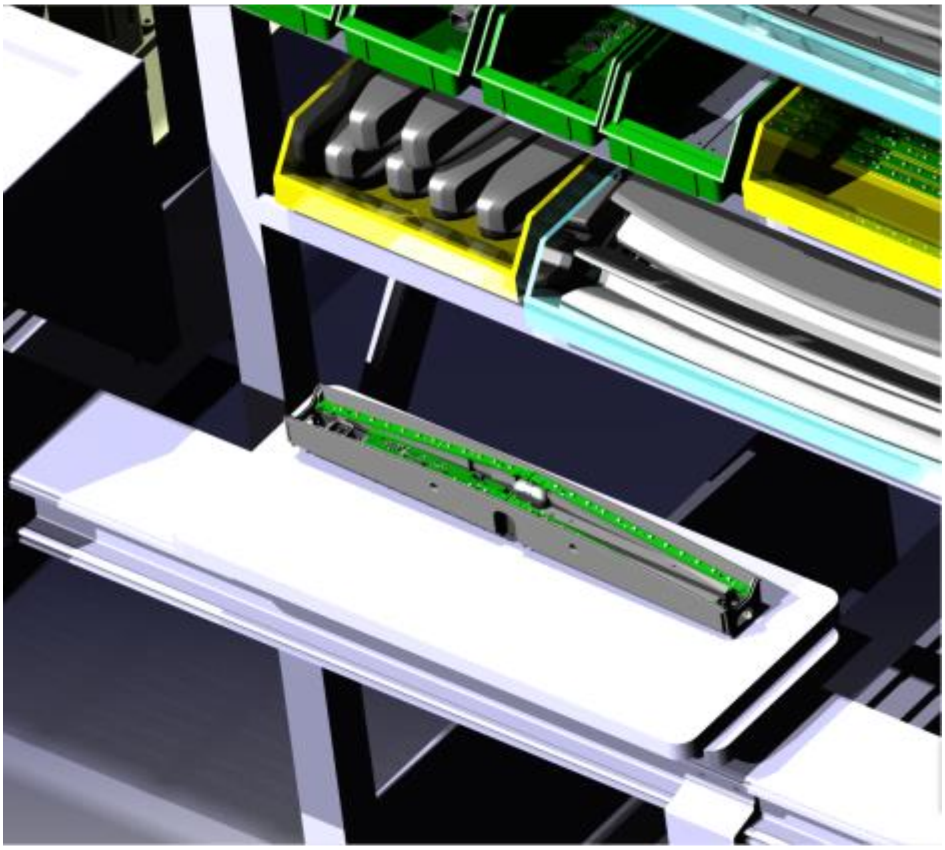
Product leaving station 1



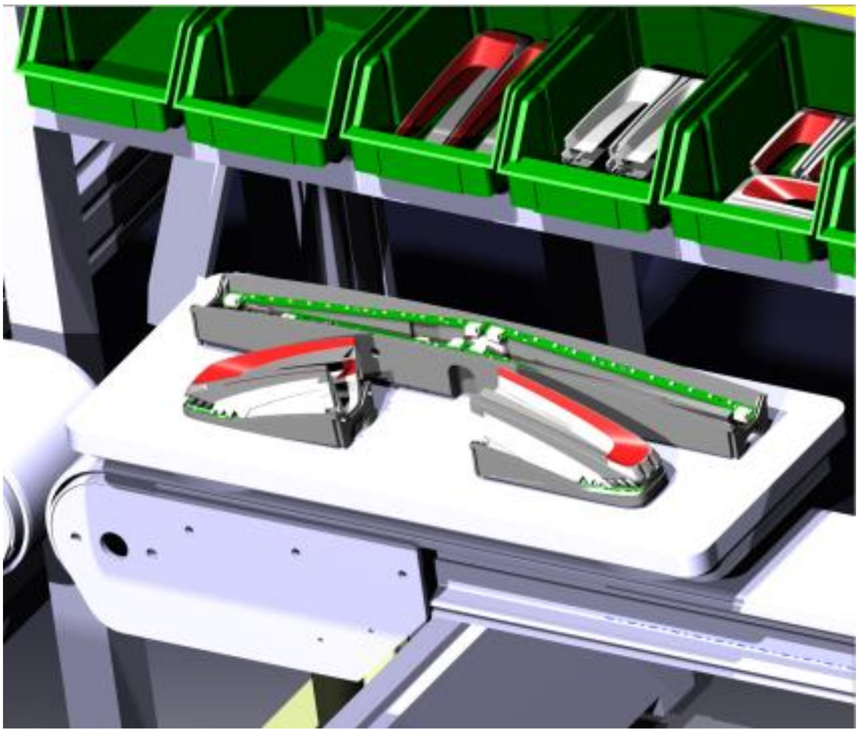
Station 2

Activity	Duration (s)
Get two bottom parts and put into pallet	2,68
Get two circut boards and put in bottoms	2,68
Get heatpad and put on bottoms	2,68
Get two section 4 and put on circut boards	2,68
Get 4 screws and put in both section 4	12,50
Get screwdriver and tighten screws	8,66
Get two section 3 and put on section 4	2,68
Get two section 2 and put on section 3	2,68
Get two section 1 and put on section 2	2,68
Get 3 short cables and put on table	5,36
Get 3 short cables and put on control board/led lights	9,64
Get 2 medium cables and put on table	2,14
Get 1 medium cable and put on control board/led lights	3,21
Get 1 medium cable and put on control board/led lights	2,50
Get 1 long cable and put on control board	3,21
Total	**65,98**

Product entering station 2



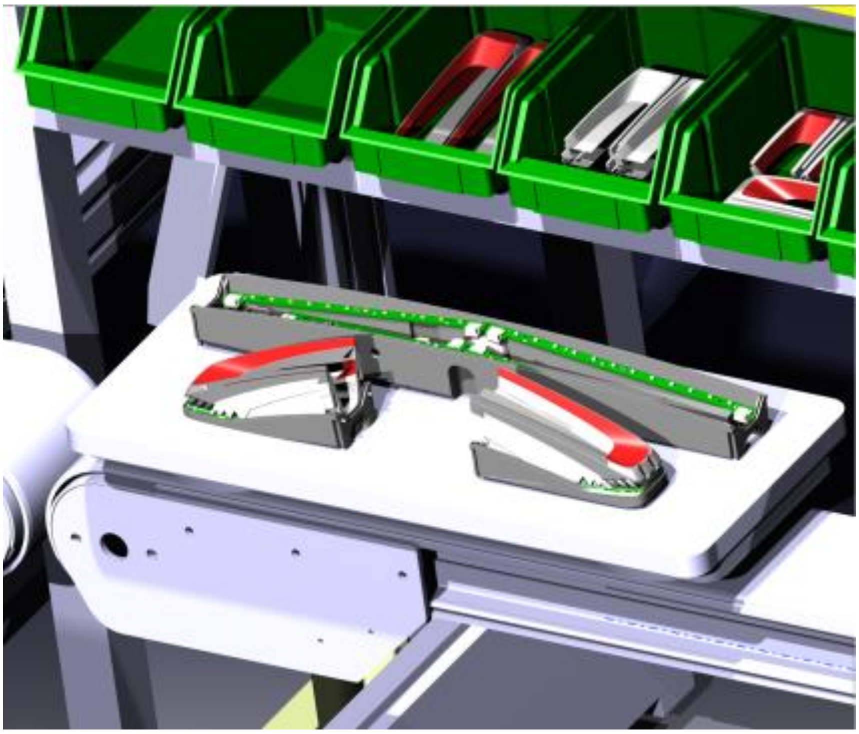
Product leaving station 2



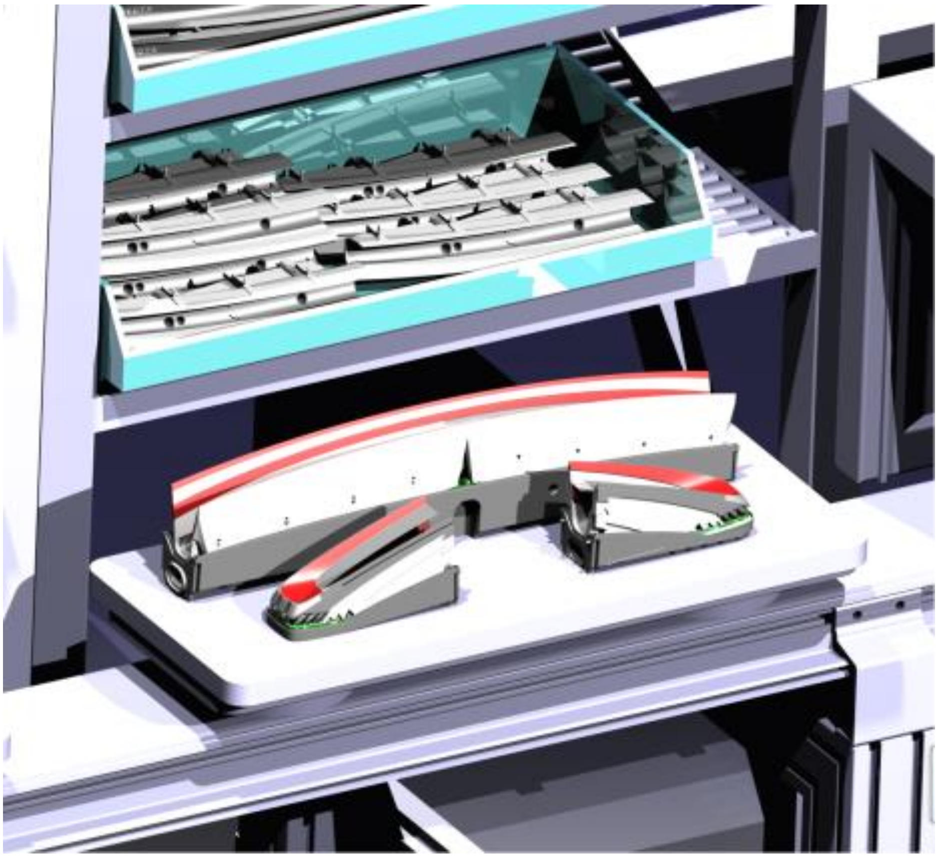
Station 3

Activity	Duration (s)
Get 2 light holders and put on control boards and lights	3,93
Get 8 screws and put on light holders	2,68
Get 4 screws and put in both section 1	12,50
Get screwdriver and tighten screws	23,21
Get screwdriver and tighten screws	15,80
Get midcover and put on light holders	2,68
Total	**60,8**

Product entering station 3



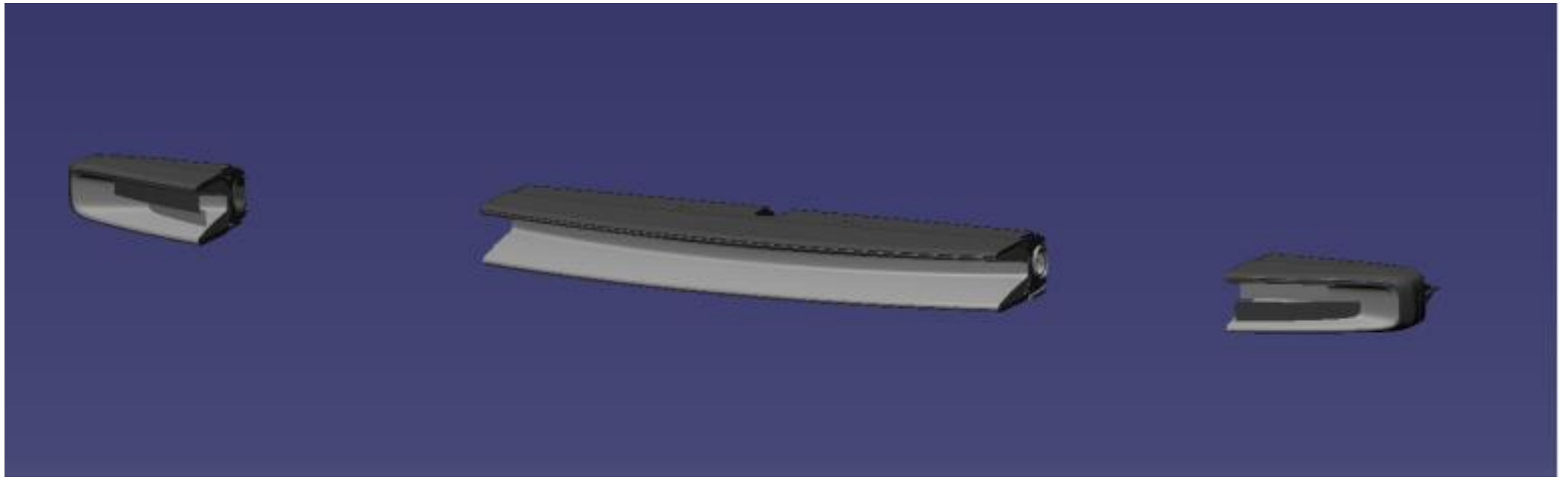
Product leaving station 3



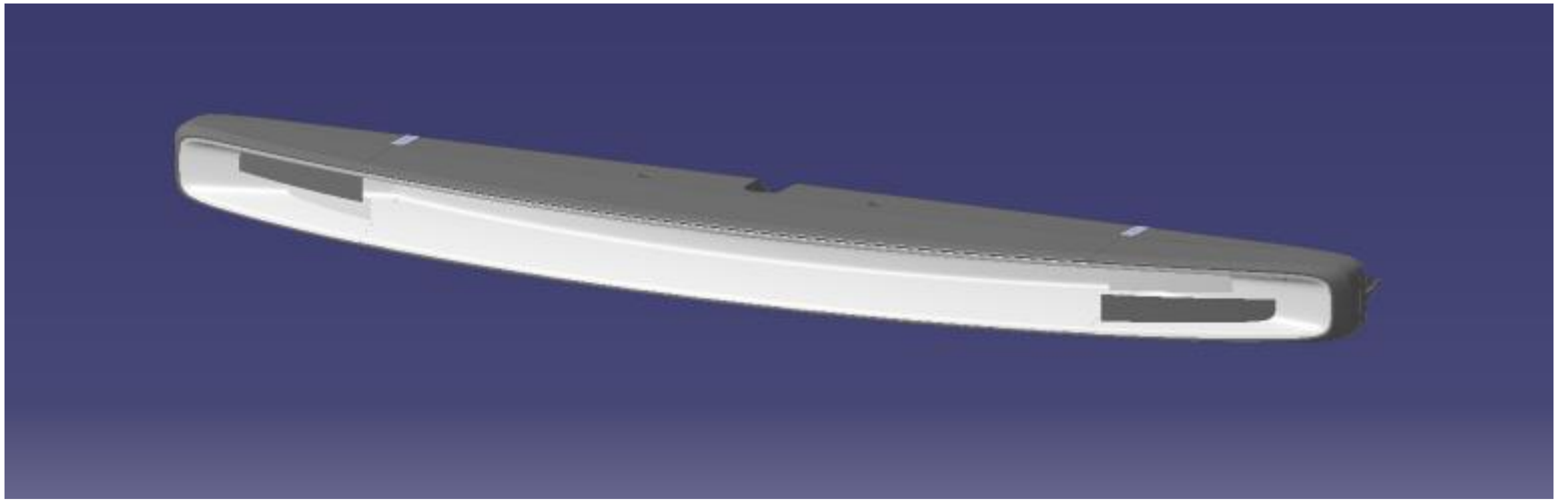
Station 5

Activity	Time (s)
Get middle part and put on table	3,93
Get side parts and put on table	4,64
Get bushing and put on side/middle part	5,71
Get cables and inset into circut boards	4,29
Get side part and put onto middle part	4,29
Get locking clip and put into product	10,00
Get product and put into test fixture	2,50
Function test	20,00
Get product and put into pallet rack	2,68
Total	**58,04**

Product entering station 5

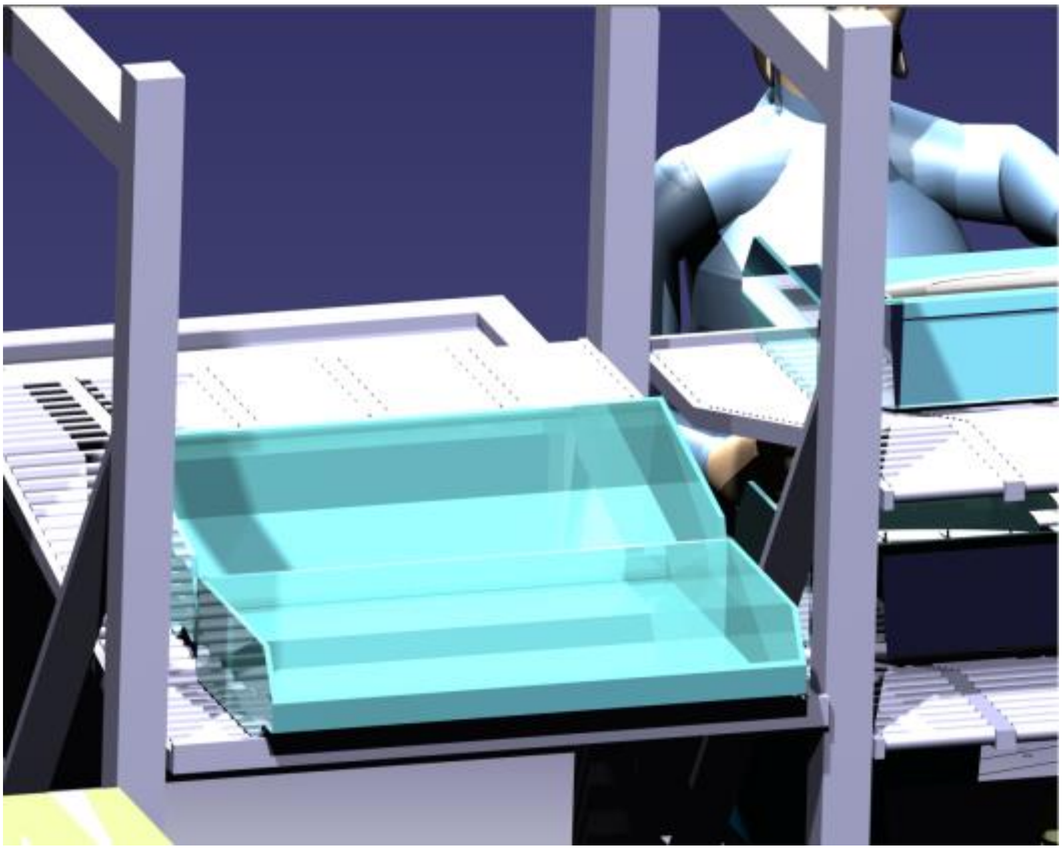


Product leaving station 5

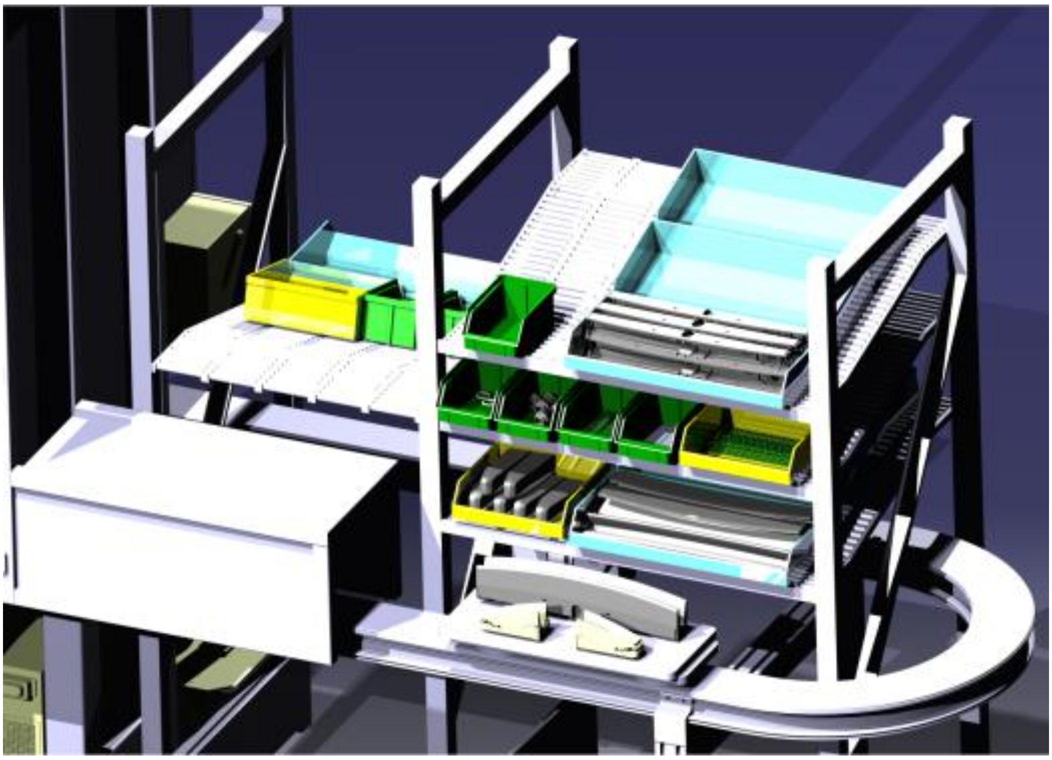


Appendix XII– Material storage system

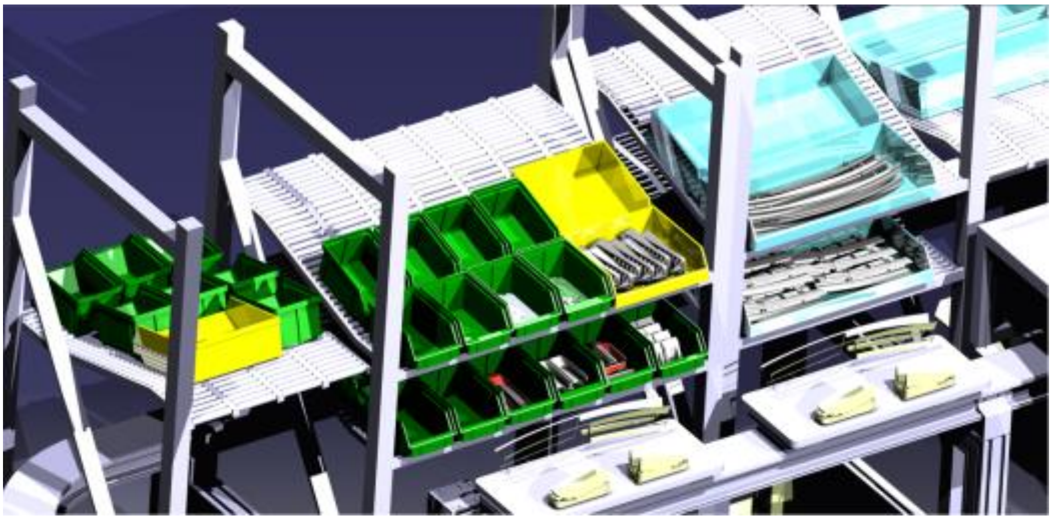
Return box in chute



Station 1



Station 2 & 3



Appendix XIII – Example of milk runs

Appendix XIV – ACD matrix with changes highlighted

		Abstraction levels				
Design perspectives		**Effect**	**Operation**	**Architecture**	**Work**	**Tools and Information**
	Problem	Assemble high quality products efficiently	How do the components flow	Assemble and glue	Support function personnel	
		Extract value from investments	How much to keep in storage	Takt vs. assembly times	What tools are needed?	
			Where to place storage	Size of hardening storage	Cables below electronics, difficult	
			50k yearly spread evenly	Material handling equipment	Even glue joint, hard to reach	
			Non damaging production design	One line pallet/fixture	Quality responsibility, who?	
			Produce different types of products	Prefer full/half paced work		
				24h hardening, storage issues		
				Utilize glue robot for multipe stations		
				Producing different products		
	Structure	Supervisor/examinator	Custom material boxes from suppliers	Pack finished products in EUR-pallets	3-8 people initially approximated	Glue on bottom parts
		Customers	Components in, products out	Number of operators		
		Suppliers	Glue robot	Number of robots		
		Tyri	Machines	Number of stations		
		Arbetsmiljöverket	People			
			Plasma treatment machine			
	Function	Deliver on time	Transport of material	60s glue operation	Control glue joint	
		High quality products	Components in, high quality product out	Pack, move, assemble, glue		
		Pleasant working environment				
		Produce more products				
	Activity	Design of product	Move components and products	Inspect glue joint	EUR-pallet shipping, sheets	
		Design of production system	Click, screw, glue components	Function test		
		Design of supporting functions	Pack products	Quality check		
		Installation of production system		Pack products in pallets		
		Installation of supporting functions		Connect electronics		
				Assemble subcomponents		
	Realization	Space restrictions	Production line (straight, U-shape)	Final storage and shipment on pallets	Grooves to place cables	
		Incorporate into existing solutions	Functional layout (functional line)	Glue robot specifications required	Screw component to prevent rise	
			Cell layout	Kanban shelves	Technical help for inspection	
			Conveyors		Operators, quality responsibility	
			Flow (one piece, parallel)		Angled glue nozzle	
	Specified system goals	Space restrictions	Defined flow of components and products	Support functions	Demand: 100 SEK/product (operator cost)	
		50 000 products in 45 weeks	Chosen production principle/layout	Balancing of stations	Wish: <50 SEK/product (operator cost)	
		High quality requirements, few defects	Decided product mix for the production unit	Layout planning		
		Produce additonal products	Production sequence (batch, priority)	Material flows		
				Work sequence		