FACULTY OF SCIENCE AND TECHNOLOGY

MASTER THESIS

Study programme / specialisation:

Industrial Asset Management

The fall semester, 2021

Open / Confidential

Alex Esquivel

(signature author)

Author:

Alex Diter Esquivel Tabares

Course coordinator:

Jan Frik

Supervisor(s):

Wolfgang Dohrn

Thesis title:

Case Study on Lean manufacturing

Credits (ECTS): 30

Keywords:

Lean Manufaturing, Lean implementation, Value stream map, Kaizens, Laerdal Medical

Pages: 87

+ appendix: 4

Stavanger, January 20, 2022
date/year

Abstract

Technological companies are struggling to keep competing in the global market. Customers have higher expectations now that an efficient and high-quality product is no longer sufficient. For example, Laerdal has to offer configurable solutions on their manikins to meet individual customer needs. All this at a reasonable lead time and cost. Lean manufacturing has proven to be a successful tool to attain a competitive advantage by streamlining the production process from raw material to the customer.

This master thesis presents a case study on Lean Manufacturing developed at Laerdal's Stavanger manufacturing plant. The objective was to map the value stream of a manufacturing process and identify "7 types of waste". This mapping found that work order process and production planning were areas of opportunity for continuous improvement, which followed two hypotheses. One of them said that the work order process method could be more efficient and help eliminate waste of time. The other says that production planning is cumbersome and can be improved by limiting trigger points and streamlining the current production process.

The results supported hypothesis one by demonstrating how lean manufacturing can help the work order method to be more efficient by eliminating non-value activities found and reducing the cycle time by 50 % on average of the work order cycle, plus "waiting time," which 53% took days, 20% took hours and 27% took minutes. Also, a non-value add activity was eliminated, which took 6 minutes per cycle.

The results support hypothesis two by demonstrating how the production planning could increase the efficiency and eliminate waste of time in production planning by introducing a pull system (Kanban) for most of the roto-molding parts, streamlining the process, and limiting trigger points by one.

The method used was action-based research, where you will find experimentation and data collection in multiple cycles. Data in the form of photos, surveys, interviews, achievement data, and documents provided by Laerdal; Then, connected with a literature study on Lean manufacturing theory and Lean manufacturing in a project setting area.

Contents

List of Tables

List of Figures

List of Acronyms

FIFO	First In First Out
JIT	Just in Time
MRP	Material Requirement Planning
SMED	Single Minute Exchange of Dies
TPS	Toyota Production System
VSM	Value Stream Map(ping)
WIP	Work in Progress
H_a	Alternative hypothesis
FMEA	Failure Mode Effects Analysis
PVC	Polyvinyl chloride
CPR	Cardiopulmonary Resuscitation

CHAPTER 1 INTRODUCTION.

This thesis applies *Lean Manufacturing* to a Laerdal manufacturing process used in one of the most profitable products the company has had in the past years; The manikin SimMan 3G (Figure 1).

Figure 1 SimMan 3G – Source: Laerdal Medical Official Website

Many companies have used *Lean manufacture* in various ways and to different extents. However, it has been more than 70 years since Lean manufacture first came to reality, making us think. Is Lean manufacture still relevant? With recent technological advances (Industry 4.0) and other smart technologies, many things have changed in the industry. Top technological companies like Laerdal face huge global competition, making Lean manufacturing more relevant today than ever. For that reason, Laerdal has been in the process of becoming a “Leaner” company and increasing its productivity.

This thesis deep dives and identify where the areas of opportunity to introduce Lean methodology during the Arm Skin Light PVC manufacturing process; while using lean tools, interviews with Laerdal employees, workshops, documenting and taking photos; Then connect this with a literature study on Lean manufacturing theory and Lean manufacturing in a project setting area.

1.1 RESEARCH MOTIVATION

In today’s global scenario, the customer is looking more into his benefits through cost-cutting. This is a challenge for Laerdal and other companies; Customers ask for high performance, innovation, and high-quality products at a competitive price.

Laerdal is an innovative company, as leader of health care education simulators; nevertheless, the company still needs to continue evolving with the market. Change is inevitable!

To overcome these changes and do not die during the trial. Lean manufacturing makes the companies more flexible and adaptable to changes and makes them survive for any change on the customer necessities in a long-term period.

I believe Laerdal understands the importance of customer and value concepts; Customers will not pay for a feature that doesn't create any value for our product. Design, development, and manufacturing should pay attention to this to keep the product manufacturing process as leaner as possible. Reducing non-value features that result in non-value manufacturing activities and must be eliminated as soon as possible. This is part of the “Toyota 3M Model” (Muda) from the Toyota Production System (TPS).

I want to mention an example of this. When I started working at Laerdal for the Technical Team as a Product Developer Inter. The team was working on developing the latest manikin, SimMan 3G Plus. This manikin has many new features from his previous model, The SimMan 3G. One of the differences was "getting fluids from the nose" (Figure 2). To manufacture this feature required some activities (work), such as person-hours from development and assembly line as they needed to make some gluing and punching holes, etc. But the question is Was this feature adding value for the customer? Based on an "A3 Analysis" made by Sondre (Product Developer) on 18.05.21. He found that the user was not using this feature, so it was easy to forget to connect the runny nose. Also, the fitting does not fit the port very well, causing the fluid to go into the airway.

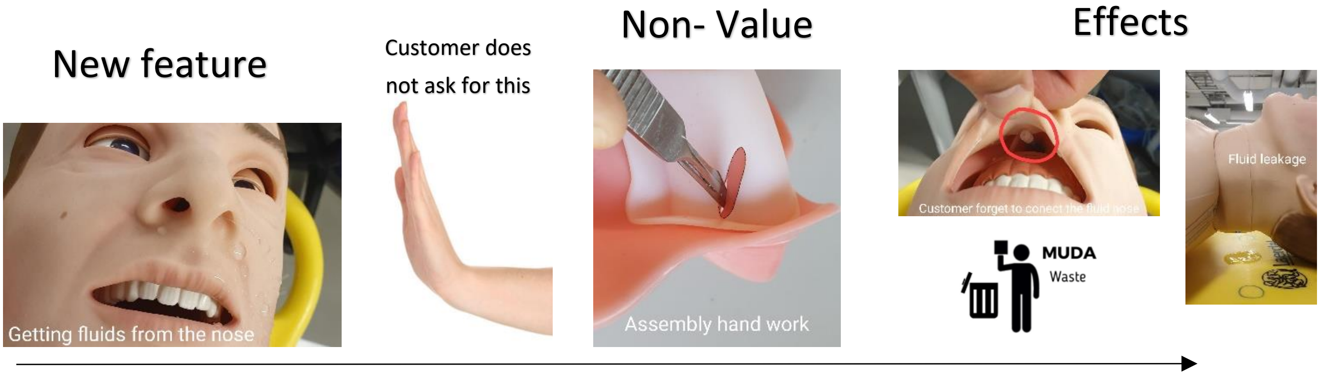


Figure 2 No value-add feature - SimMan 3G plus

After this A3 exercise, the question was, can we go Leaner? The Cost/Benefit conclusion eliminated the "waste" of time manufacturing this new feature. This let room in the nose area for introducing other new features which can add more value for the customer. Also, this change eliminated the risk of leakage of fluids.

This is just one example in Laerdal, but Lean manufacturing brings many benefits for other companies and has proven to be a successful way of working for many companies worldwide.

However, changing the way people work and think systematically can be challenging for some companies, for Laerdal Medical. For this reason, I came up with the idea of writing a thesis on lean manufacturing

CHAPTER 2 BACKGROUND.

I feel proud to work at a company known to be a leader in the medical care training sector, Laerdal Medical, family business founded 75 years ago with its headquarters located in Stavanger, Norway.

Figure 3 Laerdal Medical Logo

"*HELPING SAVE LIFES*" – Laerdal's mission.

What is the story behind Laerdal's mission? (Figure 3)

The Laerdal family has been committed to the company's long-term development since the very beginning. They have been developed since 1940, when they started with a small publishing house business printing calendars, greeting cards, and children's books, before moving the business into the manufacture of wooden toys.

Åsmund Laerdal – The founder. Brilliant guy who graduated from business school, creative and tenacious, hardworking man who has consistently achieved results throughout his career. He identified an excellent opportunity to develop wooden toys to then take them to another level. At some point of development, he started to experiment with different raw materials. Plastics. This was a success as this soft material was well suited for casting dolls and toys. So, the company became pioneering in using soft materials on toys letting them become mass producers.

Laerdal didn't stop developing, and they kept experimenting with different materials (plastics) and manufacturing various products. This is where the "Anne" doll was born and became one of his most popular toys all around Europe. Which was acclaimed "*Anne Doll," the "toy of the year," made of soft plastic, with sleeping eyes and natural hair.*

"One day, Laerdal's two-year-old son, Tore, nearly drowned. Had his father not rushed to intervene – pulling the limp boy from the water and forcing the water out of his airways – things would have turned out very differently" (Reference)

After this tragedy, as a curious man, Åsmun got motivated toward involvement in first-aid research with the medical community. In 1958, Stean Floreluis of the Norwegian Civil Defense asked him to make plastic masks for human volunteers so they could practice mouth-to-mouth breathing. After this request, him and two anesthesiologists (Dr. Bjørn Lind and Dr. Peter Safar) came back with a different product. Instead of using masks as requested, they wanted to introduce a full-sized life-like model to demonstrate a newly developed resuscitation technique that came to become what we know now as CPR.

This is how the world's first patient simulator, Resusci Anne (Rescue Anne), was developed in 1960. The manikin, a full-sized adult model, a female face, collapsible chest to practice compressions, and open lips to simulate mouth-to-mouth resuscitation. (Figure 4)

Figure 4 The first practice CPR dummy, Resusci Anne. It was showcased in September 1960 in Stavanger, Norway.

According to the American Health Association. To this day, resuscitation training manikins have trained 500 million people worldwide. This means that Laerdal has helped to save an estimated 2.5 million lives.

After the success of this product, these training manikins have been further developed and improved to keep helping train healthcare providers along the time. Today, Laerdal can offer advanced simulators with the latest technologies and top-quality products. These are divided into the following categories:

- Resuscitation training: The Unicorn product and the most popular one. CPR Training
- Emergency care & Trauma: Solution for advanced critical care training.
- Nursing Patient Care: Developing nursing competencies.
- Obstetrics & Pediatrics: To improve maternal and neonatal outcomes and reduce risk at birth.
- Manage, Assess & Debrief: To find efficiency in a unified operating platform.

These healthcare training varieties are used worldwide by voluntary organizations, hospitals, educational institutions, and the military.

"No one should die or be disabled unnecessary during birth or from a sudden illness, trauma, or medical error" – Laerdal's goal.

What a perfect match! Laerdal's mission and goal perfectly work together! The company has been dedicating its work to this matter. Pioneering healthcare simulation, allowing training everyone worldwide in a risk-free environment, and helping save lives.

"Helping Save 1 million More Lives

Every Year. By 2030". - Laerdal medical

CHAPTER 3 GOALS AND OBJECTIVES

The present work will analyze a process in the molding area from the "Lean" perspective, with the goals of first understanding lean, value stream mapping, and seven waste principles and how they can benefit Laerdal's manufacturing processes.

Then, present a practical application using value stream mapping tool, creating the complete picture of how the materials and information flow through the value stream in the current state, they would be able to identify areas of concern (7 wastes) that needs to be improved and presented as the future state.

Furthermore, analyze and discuss value stream mapping, detect, prioritize kaizen points, draw a possible solution (future state), and discuss how beneficial it would be for Laerdal.

Along the way there, a main objective can be summarized as:

- With the use of Lean manufacturing, analyze and identify the seven types of waste to identify the potential for increased operator and administrative efficiency and quality: These two manufacturing concepts work together and create a powerful combination. Efficiency is needed for profitability, and you will get efficiency by reducing waste.

CHAPTER 4 HYPOTHESIS

After defining the goal and objectives, subgoals or hypothesis comes out. And afterward, a series of testing comes up with a conclusion to their testing whether their hypothesis is proved true or false.

"That's the beauty of the famous scientific method. You observe your subject. Ask questions, and then research before establishing a hypothesis". – Claudia Burgoa

Hypothesis 1:

H_a: A more efficient work orders process method could help eliminate waste of time from production and production planning management.

Hypothesis 2:

H_a: Our current Production planning process is cumbersome, has too many trigger points, and requires frequent changes; We can improve this process by limiting trigger points and streamlining the current production planning process.

4.1 METHOD

"The clever man will tell you what he knows; he may even try to explain it to you. The wise man encourages you to discover it for yourself even though he knows it inside out" (Revans,1980)

The methodology used for this thesis work is "action-based research," also known as "Learning by doing." This was done by efforts to understand what was happening in the production floor (roto-molding area) for at least four days per week. Those efforts were led by following the cycle of a "spiral of steps" (Kurt Lewin's Model -1946). (Figure 5)

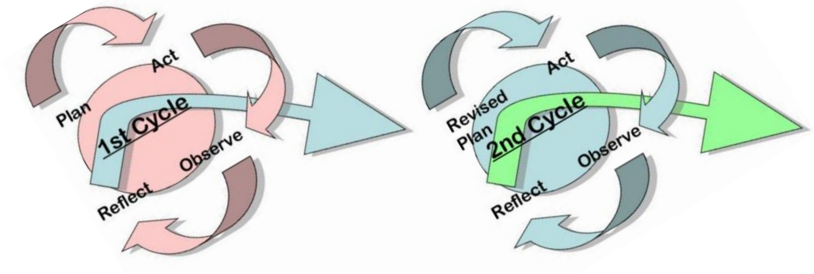


Figure 5 Spiral of steps - Lewin's Model

This cycle started with the definition of a problem (**Plan**), in this case, the two hypotheses (something that we can test or probe). Then was followed by the engagement of different literature investigations to gain a deeper understanding of the topic; this is the theory section followed by the next step in this cycle, (**Act**), where we I engaged in multiple cycles of experimentation and data collection. We got qualitative data such as process observations and interview(s) or survey(s) and quantitative data such as achievements data from Laerdal (MRP).

(**Observe**) The data was collected and organized to be analyzed and presented on tables, charts, graphs, and cluster maps (brainstorming); These two phases can be found in the analysis section.

Finally, (**Reflect**). When the research finishes, you will find the reflection of my practice in the conclusion section when the results give the answers for the stated hypothesis. As this is a cycle, this must lead to newer questions or future work for further investigation, those you can find as part of the conclusion section. The cycle will be re-started as we refine our craft. This was the methodology used in this thesis.

CHAPTER 5 THEORY

The idea behind my thesis work starts with the theory of Lean Manufacturing and useful tools used for the manufacturing industry, problem-solving and continuous improvement but before: A brief overview of the history.

5.1 HISTORIC BACKGROUND

What is the first idea coming to our minds when we hear the word "Lean"? Well. Maybe if we are familiar with manufacturing processes, we can immediately have some thoughts and relate this with Lean in manufacturing. But what if we translate this word to the human body? Yes! If we say that person is "Lean, " According to Cambridge Dictionary, Lean is an adjective that describes a person thin but looking strong and healthy. Just like most athletes, their bodies are lean, taut, athletic. Similarly, Lean processes are "healthy" as they are valuable and create an excellent value for the customer, and "thin" as they use as few resources as possible.

Having this meaning in mind, we can travel back in time for the Lean history, back in the 50s. Venetian shipbuilders were the first to standardize a process flow that could move ships through the entire production line in an hour, maximizing their efficiency, quality, and safety. However, they were the first known users of standardized process flow.

After that, the first person who took this “Lean” concept to a complete manufacturing system was Henry Ford in 1913. At that time, wealthy people could buy a car due to manufacturing them at costly prices. Henry Ford, an Ambitious and intelligent guy, Introduced the Model T with a unique production line. He uses "Flow production," which aims to reduce production and human effort through a series of innovations such as introducing interchangeable parts with standard work and moving conveyance. This led the Ford Company to its first mass-production success, as it was the longest production run of any automotive model in history. They would build around 15 million model T! What an excellent example of success using Lean principles. Henry Ford made a car that most people could buy, simple to operate and durable.

But this was just the beginning of Lean. Henry Ford faced some limitations with his system. Clients' desires were changing. They wanted variety. This was a challenge as the model T was limited to one specification. The production flow was not a problem, but they knew they needed a change to keep competing with their competitors who responded to customer needs (variety).

In 1950, Eiji Toyota and Taiichi Ohno got inspiration from "Flow of production" when they visited him in one of his plants in Detroit. They saw an area of opportunity to revisit Ford's original thinking in something new that helps to respond to the wide variety of products demand. How? One day Ohno went to the supermarket and saw what would come to become the model that later he would introduce to his factory; he noticed than when a customer takes the desired amount of goods out of the shelf, the shop needed to restore the shelf with a new product to fill up the shelf space. Similarly, the suppliers of these goods will produce only when the shop required and at the quantity it needs. These observations became the foundation of what will be known back then as the Toyota Production System (TPS), in our days known as Lean Manufacturing, transforming manufacturing worldwide.

This completely changed the focus and culture of manufacturing when lead times were shortened and kept the production line flexible. The overall quality improved, customer response, productivity, and equipment utilization, responding to dynamic customer needs.

5.2 LEAN MANUFACTURING

"The machine that changed the world"; A best seller book published in 1990, made the term Lean Manufacturing known worldwide. Nevertheless, this system helped Toyota Motor Company to be the world's largest automaker for the last years.

Although this system is relatively new, some of the tools were used back in the 20th century with the "Taylorism" – A theory of management made by Frederick Winslow Taylor that analyzed workflows to maximize labor productivity. Now, Lean combines some of these tools to create a system that can be used in any environment and manufacturing practices and administrative or engineering activities. No matter the field Lean was used; the goal was to encourage continuous improvement by systematically eliminating "waste" during the process.

5.3 THE SEVEN WASTES

What is waste? Waste adds NO value for the process and is an important term in Lean manufacturing. Toyota production system (TPS) has defined the seven wastes as Transportation, Inventory, Motion, Waiting, Overproduction, Overprocessing, and Defects. They are also known by the acronym "TIMWOOD." They can be applied in most manufacturing environments. In the following section, I will examine each of these waste with one example:

- Transportation: This is excessive movement, which can damage the product or even a person when hospitals are unnecessarily moving patients from one department to another.
- Inventory: Excessive inventory leads to a waste of space and costs associated with the stock. This can happen when a company stores unused or rarely used equipment.
- Motion: This involves the unnecessary movement of people within the work area. This leads to delays in production or heathy and safety issues for the personnel. For example, if they need to walk or look for a tool or equipment to work.
- Waiting: This waste refers to a product waiting to be processed, but the following process is not prepared to accommodate them. This usually results in a bottleneck and wastes production time for the whole value stream—for example, patients in the waiting room.
- Over-production: This is basically when you produce too much of an item, leading to excessive lead times, high cost of inventory, and difficulties in detecting defects. One example is when a bakery keeps baking cakes that are not sold.

- Over-Processing: This means doing work that does not add any value to the customer, and this usually leads to overprocessing and represents a higher cost for production. One good example could be when product developers add features that no one uses.
- Defects: Any scrap or part rework represent waste. High cost for the production facility

The elimination of “waste” is the heart of Lean Manufacturing methodology. The proposed Lean is always spending as much time possible creating value for the customer by eliminating these seven different wastes.

5.4 VALUE STREAM MAP

Value stream mapping (VSM) Is a well-known tool used in Lean manufacturing. Used to visualize the entire value-adding process and how the information and material flow from A to Z. The main purpose is to understand the process better and identify hidden wastes (non-value-added activities).

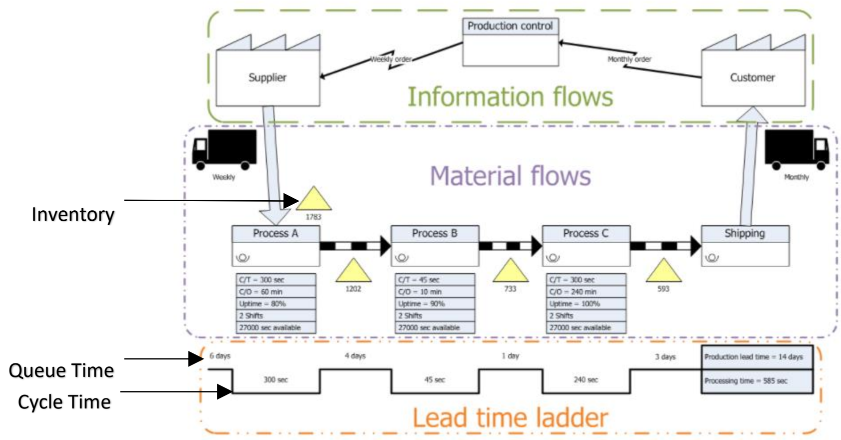


Figure 6 Value Stream map - Source: Tallfy.com

This is an example of how a value stream map can look (Figure 6). There's a lot of information here but focus on the main three sections divided. In the first section on the top, we can see information flows from the customer to our supplier. In the middle, we see the flow of materials, so after we make an order from the supplier, we will see a shipment of parts that, in this case, is weekly. And then, in the middle, you can see the manufacturing plan divided into separate processes steps involved to produce the finished product. After we get everything finished up, it will be shipped out to the customer. So, we have a flow of information on the top and a flow of materials in the middle. Finally, on the bottom is what we call the lead time ladder. This tracks the time we spend processing the materials and how much time is spent waiting in queue to be processed between process A to process B, and so on. The value stream wants to minimize the non-value activities, so one of the focuses could be to reduce the waiting time on the queue. These are defined as “Kaizen points” or points for improvement.

5.5 GEMBA WALK

“Gemba” term comes from the Japanese and means “the real place.” This is an essential part of the Lean manufacturing methodology, especially for the value stream map tool. The main objective is to allow you to observe the actual process, engage with employees, gain knowledge from the process, and use your Lean glasses to identify possible opportunities for continuous improvements.

This tool can be applied anywhere—for example, For a restaurant owner. The "Gemba" is the restaurant and the kitchen. For this master thesis, the "Gemba" was the roto-molding area production floor. And this is where the real work happens!

By developing this concept Taiichi Ohno (Considered by many the father of Lean and the developer of "Gemba walk") suggest three essential elements of this tool to be a success: Go and see, ask why and respect the people**.** Keeping this in mind will ensure you come away from each "Gemba walk" with the information you need to make the best decision about improving your processes.

5.6 5 WHY'S

After the "Gemba" value stream map and identifying wastes, you will probably need "5 Why's". This technique developed by Toyota (Sakichi Toyoda), Is used in many industries now, and it helps find causes of simple to complex problems. If this tool is applied correctly, you can reach the root causes of many types of issues. The strategy has been proved to be an effective and powerful tool, easy to use as its names stated. The process is to ask "why?" five times until you get to the root cause. Although 5 is just the number in the tool's name, the tool might ask "Why?" at different times, which could be less or more than five times. No matter that. The main objective is to identify the root cause and then get counter-measures to solve or prevent the recurring issue.

5 Why's is the basis of a scientific approach to problem-solving with other know methods in Lean manufacturing. Those can be combined and used to identify and solve problems, and one of them is the fishbone diagram. Let us talk about it.

5.7 FISHBONES DIAGRAM

They are also known as the Ishikawa diagram or cause and effect diagram. Kaoru Ishikawa created this method in the 1960s to measure quality control processes in the shipbuilding industry, but now it is usually used in manufacturing or product development. The idea is to brainstorm ideas with an experienced team, identify possible causes and sort them into different categories. The most common category is 6M's, which means Manpower (people), Methods (Processes/procedures), Materials (Supplies), Machine(equipment), Measurement, and Mother Nature (Environment). But other concepts are used like 4P's and 7P's of marketing.

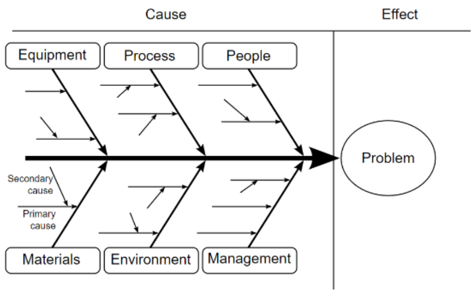


Figure 7 Fishbone diagram

The diagram resembles a fish skeleton (Figure 7) where the "ribs" show the causal factors in the different categories and go into some outcome (problem) which is the head of the skeleton. Once all inputs are established on the fishbone diagram, you can also use the 5why's tool to drill down to root causes.

The Fishbone diagram is part of the Lean toolkit and will help the team focus on the causes rather than the symptoms. A powerful tool for problem-solving.

5.8 FMEA (FAILURE MODE AND EFFECTS ANALYSIS)

FMEA or Failure mode and effect analysis is a proactive, systematic approach to understanding potential failures in processes or products and taking corrective actions before the failure occurs. It can also be used to minimize common failures during a manufacturing process. FMEA begins with a review of the process, where the experienced team brainstorms potential failures modes, answering what could fail in the process. Next, for each failure mode, they need to list the potential effects of each failure mode, which means that if a failure occurs, what problems could the failure cause? Next, write the potential causes of those failures. And finally, we assigned gradings from 1-10 to evaluate each effect's severity, occurrence, and detection. The severity will tell us how serious the effect is; Occurrence is a measure of how likely this event is to occur. The detection tells us how likely we will detect the failure when all the analysis is done. They calculate the RPN (risk priority number), the product of Severity*Occurrence*Detection. This result will prioritize which failure mode should be addressed first due to the highest RPN number and which is not that risky. The way to address those failures modes is by doing action plans, and the aim is to reduce the highest RPN number found. Usually, severity can be reduced, so the team should lower the occurrence or increase detection.

After the action plan is complete, the RPN is recalculated, and the new risk is determined. This is a continuous improvement tool, so the FMEA live document. This means that this document will constantly change, and there will always be new risks the team could work on.

5.9 MATRIX XYZ / ABC

ABC analysis is an inventory categorization method that divides items and categorizes them based on their perceived importance on sales volume and uncertainty. This method is based on a technique that originated in the 19th century; Pareto, who brought the 80/20 rule. That says that 20 % of the total offering can bring 80 % of the revenue. This rule is interesting for the supply chain when it comes to categorizing the inventory and dividing them depending on the importance of a product. (Which product/s brings the most revenue to the company). This method classified items in three: Items with high sales and usually constitute 15-20 % of the inventory are categorized as A parts, while B-parts have medium sales and constitute 30- 40 % of inventory and C-parts have low consumption (sales volume) and represent 50 %of the inventory.

The XYZ analysis is usually used as an extension of the ABC analysis to not only base the categorization on sales value and volume but also based on the consistency and predictability of the consumption. In other words. If the demand is stable or not, and how the fluctuation is. Where X-parts represent a minor fluctuation (constant level of demand), Y-parts represent unsteady demand which means that the fluctuations are usually because of the trend-moderate or seasonal reasons. Z-parts are irregular or sporadic, making it difficult to forecast their demand.

Not all items are born equal, and classifying data can generate actionable information, and some parts have stable demand or consumption (sales volume) than others. For this master thesis, this classification would help choose the suitable candidates for a Kanban system. But what is Kanban?.......

5.10 KANBAN (PULL SYSTEM)

Kanban is also called Just-in-time manufacture (JIT), and it is one of the two pillars of the Lean manufacturing house. It was first used by Toyotas motors company in the 1950s, and Taiichi Ohno developed it. The word "Kanban" comes from the Japanese and means signboard or billboard. This tool aims to visualize your work, limit work in progress (WIP), and maximize efficiency, which we can call "flow." This approach represents a "pull system." This means that the production will be based on the actual customer demand. This differs from the typical "push system" where production pushes items into the market linked with material requirement planning (MRP).

Taiichi Ohno stated that to have an effective Kanban system, one must follow six rules and monitor them all the time. Those rules are:

1. Visualize the workflow: Visualize your work on boards, cards, and colors, name the team to view the work in progress. The work is currently ongoing, and the work is coming in real-time.

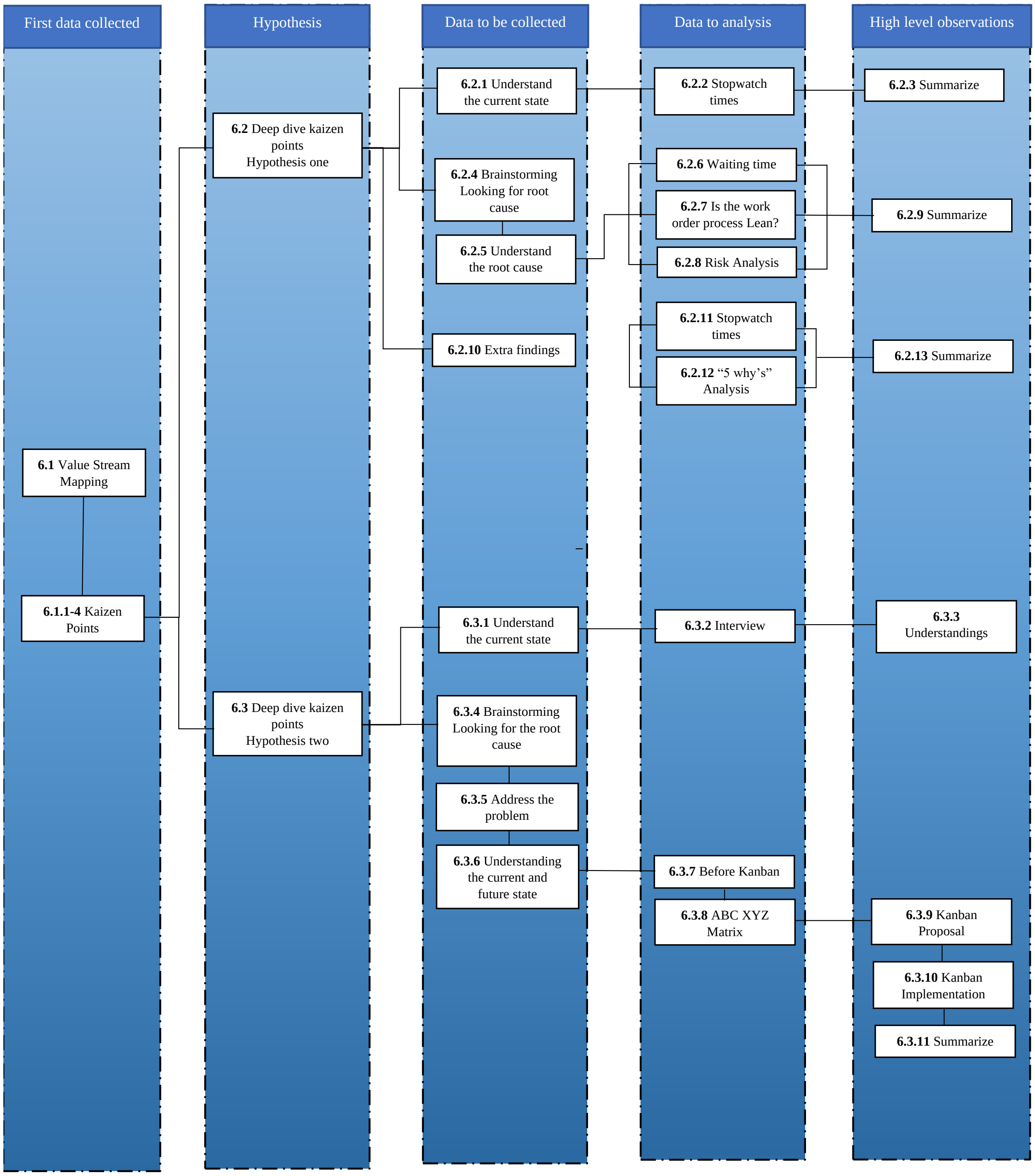
Today, the era of digitalization. Some teams are replacing the classic whiteboard with physical Kanban cards with a digital system, more intuitive, easy to use, and agile. This relay in more benefits for the company.

2. Limit work in progress (WIP): Set limits on how much work can be in your system. How many Kanban cards you might use, the Kanban size, and a given time on each cell.
3. Manage flow: Visualizing the workflow will be an opportunity to highlight potential bottlenecks that interrupt a normal flow and address them.
4. Continues improvement: During and after implementing the system, improvements will be there. Monitoring the system will be constant work to visualize the areas of opportunity.

By following these four principles, you should have enough overview to get yourself started with a Kanban system and make the most out of the main benefits. Some of the main benefits are. To increase the visibility of the flow, delivery speed, predictability, ability to manage scale and dependencies, and increase customer satisfaction.

CHAPTER 6 ANALYSIS.

This overview of information flow and logic links from hypothesis to high-level observations.



6.1 VALUE STREAM MAPPING

After visiting the production area (Molding injection area), I was impressed by how the latest Laerdal product has been implemented; SimMan 3G Plus. The newest doll, made of silicon skins; one of the differences between his previous model SimMan 3G made of PVC. What does it mean for the production area? They had to implement a new production process, Silicon injection molding.

I had the opportunity to walk and see the different processes and how they work—injection molding of thermoplastics, Roto molding, and Silicon molding.

As my working background is in the molding area, I immediately got familiar with the process. I started to think and compare methods, procedures, equipment, standards, etc., from the company I was working with. At that moment, I began to see some areas of opportunity. My quick thoughts were faster changeovers, less equipment downtime, smaller lot sizes, Kanban, or digitalized paperwork. After going back to my desk. I thought. Maybe this is an excellent opportunity to help the Laerdal production area. How?

This was when my thesis came to this story. I got accepted to write my thesis with the production area (Molding area). What a good opportunity! I was so excited to help with this.

The journey started

(Along with this analysis, you will find concepts that I addressed in the theory part of this paperwork. Would you please make sure you first read the theory part to understand this better? Thank you!)

The question that leads this topic was: How can we improve the SimMan 3G process using "Lean Manufacturing"?

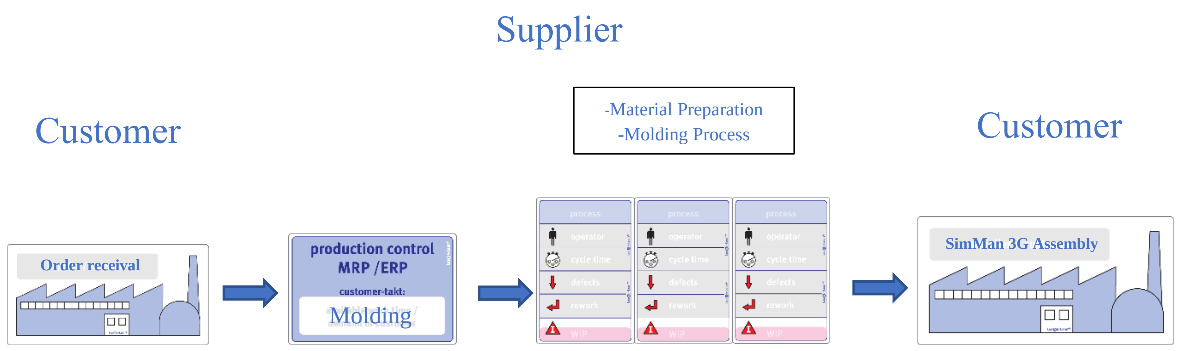


Figure 8 Diagram – SimMan 3G

The plan was to select one item from the SimMan 3G Manikin, map the current state from the order received (customer), pass through the manufacturing process (supplier), and finally, deliver the product to an internal customer (SimMan 3G Assembly Line) (Figure 8). Analyze the value stream map to detect "kaizens," reduce "waste," increase operator and administrative efficiency, reduce lead time, shortages of components, or unexpected changes in the production plan. All this looks from the "Lean" perspective.

Wolfgang; My thesis supervisor and Director of Digitalization, Tarje; Department Manager, and I started to have meetings and discussions to define the thesis's direction. After this, we called for a meeting and invited Hjarle (Plant manager) and Torbjørn Gjerdevik (Vice President of supply chain and manufacturing) to decide and choose a product to be mapped for this thesis work. The item selected was:

SimMan 3G – Light Arm Skin PVC- Rotation Molding process. (Figure 9)

Material and information flow mapping or "Value Stream Mapping" was first needed to analyze the current state of the process and visualize every necessary step involved to deliver a Light Arm Skin to our customer (Assembly line).

We needed a Cross-functional team from the different departments /areas involved in the process flow. (Table 2)

VALUE STREAM ANALYSIS TEAM

Figure 9 SimMan 3G - Arm Skin Light Right

DEPARTMENT / POSITION	NAME
Production Manager	Tarje / Cato
Production Planning	Tarje / Cato
Team Leader Molding	Odd Egil
Logistics	Nina T
Procurement / Incoming	Kathrin Øvestad
Material Preparation/molding	Kjell Lerbrekk
Manufacturing engineer	Lars Erik
Master Thesis Student	Alex Esquivel
Master Thesis Supervisor	Wolfgang Dohrn

Table 1 Value Stream Map Team

The team was formed for production staff, but we also included logistics and procurement support. We were ready to kick off the exercise!

“Go to Gemba” or “Gemba walk”

The first step was a "Go to Gemba" walk (Figure 10), which means "go and see" the actual process on the factory floor. We observed and started to learn about the work process and explore possible opportunities for continuous improvements or applying Lean Manufacturing tools.

Figure 10 "Gemba walk" Plastic Molding Area

Before drawing the map, we had to investigate some important information. The customer “takt time,” or the “drumbeat” of the process, the time allowed to produce one unit (arm skin) of product through all the value streams. This is calculated as follows:

$$T = \frac{Ta}{D}$$

Where:

T= Product assembly time required to meet customer demand.

Ta = Net time available to work. = 248 Working days per year with 2-shifts model.

D = Customer demand. = 1,800 Pieces per year.

Takt Time

= 2.1 Hours.

Figure 11 Production control MRP – Source. Learn – Lean

The formula is simple (Figure 11) Includes the availability of time (Ta) divided on the customer demand (D). we considered 248 working days per year and 15 hours each day as the molding area works with a two-shift model, one in the morning and one in the evening. The customer demand was based on MRP's historical data from July 2020 to July 2021.

The result was **2.1 Hours or 124 Minutes of "takt time,"** This is the maximum time the molding area should use to produce one piece to meet customer demand.

If we divided the availability of time (Ta) with the "takt time," as you can see below.

$$\frac{\text{15 Working Hours per day}}{\text{2.1 Hours (Takt Time)}} = \text{7.1 Pcs. Per day}$$

<u>Roto molding area needs to produce 7.1 pcs per day to meet the customer demand.</u>

The current set MRP (QAD) production batch needed was 200 pieces for the roto-molding process and 200 kg. for the material preparation process. They need around 1 kg. of PVC per each molded arm skin.

As long molding area is producing at the same "beat of production" (Takt Time):

They need 28 days or 1,4 months to make one batch (200 pcs.). (Table 2)

Production Batch size	Inventory reach of a batch	
200	28 Days	1,4 Months

Table 2 Inventory reach of a batch

We already know yearly customer demand which took us to calculate the "takt time" of the arm skin, and we also know how many pieces they need to produce per day to meet that demand. The batch size was taken from the MRP, and according to "takt time," we got the reach time (days or months) for each batch. Now, we can continue with this analysis, followed by a question.

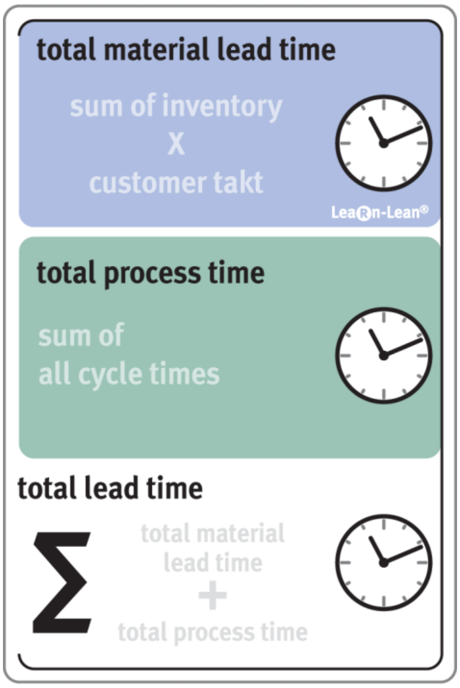
Why do we need this?

When we talk about "Lean," time is one of the most important factors we need to care of within our processes. An efficient value stream depends on lead, process, and total lead time, and the next step was to calculate those times. Going through all the value streams, we stopwatches each cycle time was watched and recorded on the value stream map presented on this analysis.

For this, we needed:

- “Takt time” or **Customer takt = 2,1 hours**.
- Sum of inventory = We found three operators working along the pipeline to produce the arm skin, and the **total inventory was 102 pieces.**
- Sum of all cycle times= We got the sum of all the cycle times involved to produce one arm skin. **36.5 Minutes.**

The formulas and the results were the following (Figure 12). (Please see figure 13 - value stream map below to visualize details for this time).



=14.1 Days — Time taken from one work unit to travel all value stream

=36.5 Minutes. — Time taken from one work unit to be processed

=14.14 Days — Sum of Total material lead time and Total process time

Figure 12 Sticker used from Learn-Lean company.

These times are important for the “value stream map” to visualize how our value stream flows in the current state time-wise. And time will be affected by:

- How is the material flowing?
- How is the information flowing?
- Seven types of waste.

All these questions can be answered using value stream mapping, where we will see a top-down overview and analyze it step by step for the current state (See figure 13 below – Value stream map).

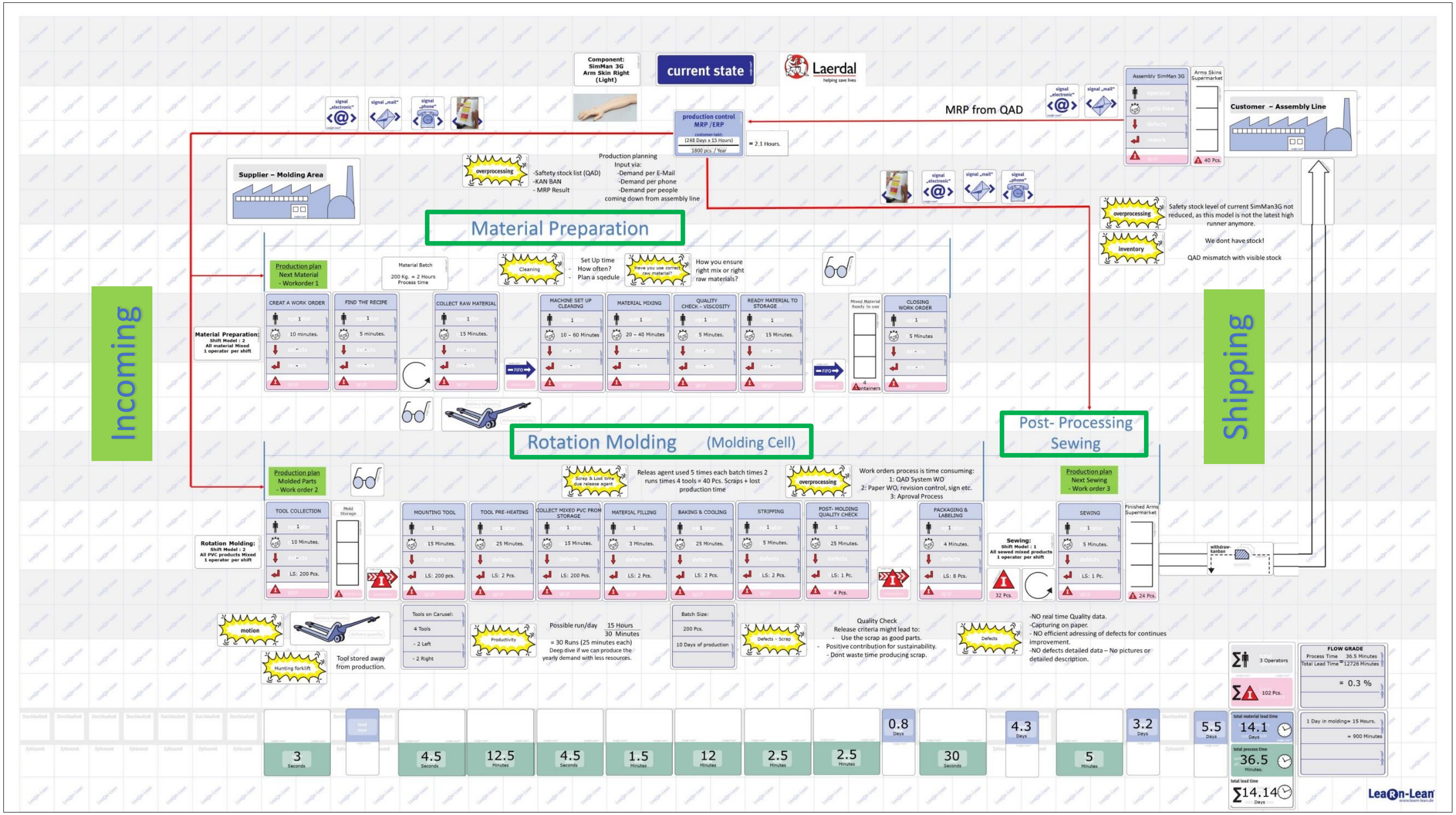


Figure 13 Value stream map (current state) - Template from Learn-Lean Company

Production control / Order receival & Production planning

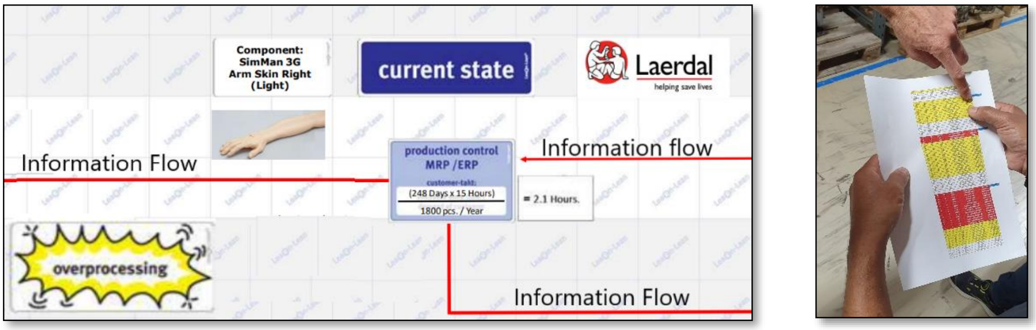


Figure 14 Production control - Value stream map template from Learn-Lean Company . And safety stock list

The flow starts with production control (See figure 14. a fragment of figure 13. Value stream map – current state) based on a safety stock list. This list collects information from the MRP system (QAD). And it is one of the trigger points sending the signal to the molding area to start production. The safety stock is based on a minimum of 40 pcs inventory. This means that if the inventory is below 40 pieces, the part will be shown with yellow on the safety stock list, and production control should plan the production for the following weeks. If the item is shown with red; This item is in stock out and must be prioritized to produce as soon as possible. This part will be addressed in detail later on in this analysis. (On the deep dive Hypothesis two)

The materials are not flowing (moving) yet at this point of the value stream. But we can say the planning signals are already sent down to production to be planned according to priorities given by the “red list.” And this is how the information flows.

6.1.1 KAIZEN POINTS - AREAS OF IMPROVEMENT ("WASTE" DETECTION):

Before going to the next part and after a Gemba walk, the team gathered in a meeting room to brainstorm detected wastes or non-value-add activities through the value stream—the main question to answer. Can we improve? We detected some “kaizens” or areas for improvement and summarized; those points are presented below. (Table 3)

The table presented shows the type of waste and the description. For this case, we found two interesting ones, both related to overprocessing. For each part of the value stream, there would be waste detections. Let us see how the rest of the value looks like.

	Production controls tend to be time consuming process. with to many trigger points.
	Can we go paper less? Production control is based on the list shown.

Table 3 Kaizen points -Production Control

Kaizens' points were defined before discussing the opportunities on each part of the value stream with the team. Those are based on the "Seven waste of Lean manufacturing" theory.

Now, the team is ready to map the next part of the value stream. This is the material preparation cell. This cell works in a two-shift model, where they produce mixed models and work with 1-2 operators per shift.

Material Preparation Process Cell

Material Preparation:
Shift Model : 2
All material Mixed
1 operator per shift

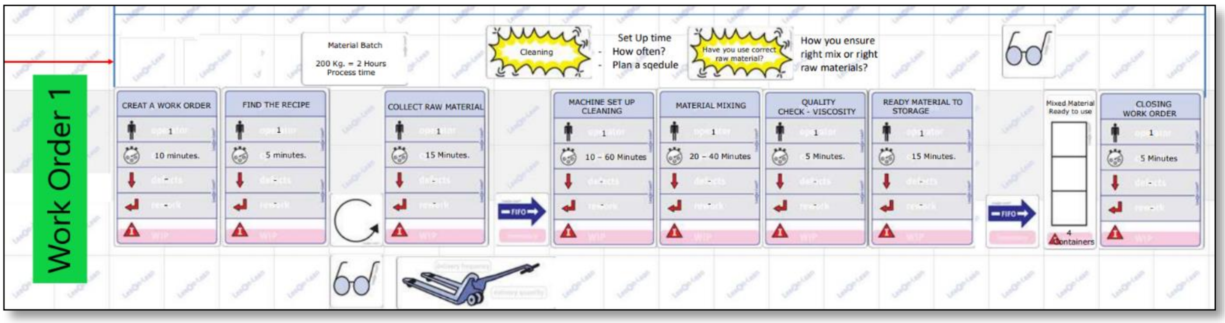
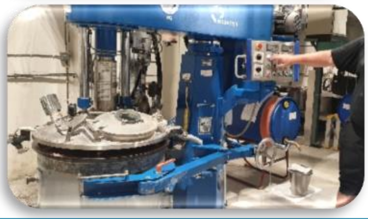


Figure 15 Material Preparation Process - Value stream map template from Learn-Lean Company.

The information flows down from production control to the production floor. The trigger point is a "work order 1". First rotation molding gets the order, and afterward, the material preparation area gets the replication of it, but both areas will work in parallel, so they both need to know the production plan to follow for the coming week. (See figure 15. a fragment of figure 13. Value stream map – current state)

The manufacturing process starts with the material preparation cell (Plastisol - PVC). And the description of each step is the following. The following table describes each step, with a description and a figure to better visualize and understand what is happening. (Table 4)

Step	Description	Figure
1	**Create a work order** Use of QAD System and paper to open work Orders when PVC material is required.	

2	**Find the recipe** Recipe safeguarded. The technician needs to open the security box and look for the recipe required.	
3	**Collect raw material** Look for the raw materials to mix in the warehouse (Batch size. 200 kg.)	
4	**Machine set up** **Cleaning** Depending on the previous material color was mixed, it will need some pre-cleaning. The machine starts to pre-heat to begin mixing.	
5	**Material mixing** The machine is ready to mix the first ingredients. Then the technician waits until the mixer reaches 29 C. This is when he can mix the rest of the materials. The cycle finishes when the machine comes to 40 C.	
6	**Quality Check- Viscosity** After mixing the materials, a sample is taken to test the viscosity of the material. The results are written on a paper list for the record and then uploaded to the computer.	
7	**Ready material to be used.** Using a crane to move the mixed material and poured into the recipients. Then labeled them manually.	

8	**Closing work order** Use of QAD system and paper to close Work Order before being revised and signed by the area supervisor (manager of the area).	

Table 4 Material Preparation Process flow

Material preparation cell usually works with two technicians. The process starts with creating a work order; then, they need to start planning to produce the material. Starting from looking at the recipe, collecting the necessary materials, setting up the mixer machine, and starting the mixing process, the plastisol could be poured into the container and moved to the following process: Roto molding area.

6.1.2 KAIZEN POINTS - AREAS OF IMPROVEMENT ("WASTE" DETECTION):

Followed by the question. Can we improve? The team found three interesting "kaizen points." two of them are related to an overprocessing type of waste, and one is related to a waste of time. On the first one, a possible excessive cleaning on the mixer machine was found. The second one was found a possible opportunity for increasing the efficiency of how the technician follows the recipe. And on the third one was found a waste of time on the work order process. (Table 5)

	Set up the time of cleaning: Can we plan or schedule it regarding the different mixes needed for the different products in the best way possible to avoid as many cleanings as possible we can? The cleaning procedure takes around 1 hour for change over material mixes from dark materials to lights.
	How can we ensure the use of the right mix of raw materials? As the recipe is safe guarded in a security box. The technician in charge of following the recipe, can sometimes miss some materials or use different amounts as they do not use or have some standard procedure that helps them to ensure to follow and check each step by all the recipe from the beginning to the end.
	Work orders is time-consuming process: 1: Open order: They need to be printed on paper from the QAD system. 2: Filled: They need to be filled with production report, configuration control and release for internal distribition. 2: Aproval control: They need to be revised and signed by the supervisoor of the are and the manager. 3: Digitalized: They need to be uploaded into the computer system and closed.

Table 5 Kaizen Points - Material Preparation

Rotation Molding Process Cell

Rotation Molding:
Shift Model : 2
All PVC products Mixed
1 operator per shift

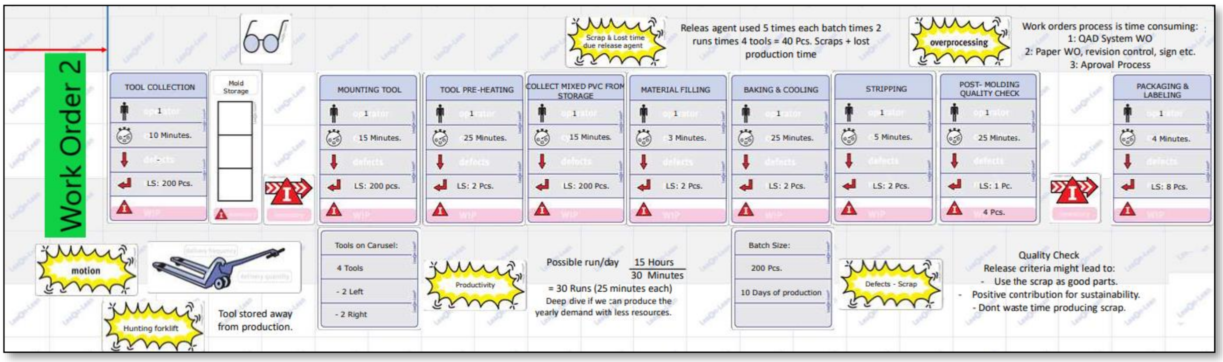
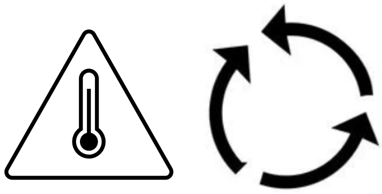
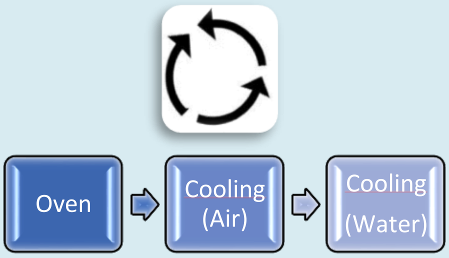


Figure 16 Rotation Molding Process - Value stream map template from Learn-Lean Company

Two hours have passed from the beginning of the materials flow in the material preparation. Now the roto-molding process will start producing. Remember, this cell had begun at the same time as the material preparation cell started. They were effectively making pre-molding activities before the process began. The process started when they received work order 2, letting them know that material preparation has finished (See figure 16. a fragment of figure 13. Value stream map – current state). The following table describes each step, with a description and a figure to better visualize and understand what is happening. (Table 6)

Step	Description	Figure
1	**Open work order** Use of QAD System and paper to open work Orders when arm skins are required	
2	**Tool collection** Walk to the tooling warehouse near the production area and look for the mold/s to be used.	

3	**Mounting tool** Clean and mount the mold/s into the rack. (Right arm skin has three tools possible to use) Change over time takes around 15-20 minutes on average	
4	**Tool pre-heating** Run one cycle (25 minutes) empty to reach the temperature needed and avoid moisture inside the mold.	
5	**Collect mixed material PVC from storage** Using a crane to move the material will be used from the material preparation cell to the molding cell. (Average batch size 200 Kg /Container)	
6	**Material filling** Upload the process program in the roto-molding machine and pour the material (PVC) into the mold/s	
7	**Baking & cooling** The machine cycle is divided into two main steps: Heating and cooling. Colling gets the parts down to room temperature using water and air and lets the polymer inside be unloading (stripped).	
8	**Stripping /Unloading** The parts are stripped out of the mold easily and without being damaged. The use of release agent is needed five times each 200 produced pieces to avoid problems while stripping	

9	**Post-molding Quality check** Parts need to cool down one more time on a table. After, a quality check is done by looking for black spots, contamination, deformation, or incomplete pieces. In the end, they cut the flash (extra material), and the part is ready.	
10	**Packing & labeling** Prepare, print, and place labels for the cardboard boxes. (8 pcs each.). The boxes are waiting to be picked for the following process (post-processing - sewing cell).	
11	**Close work order & Production report** Close the work order before being signed by the supervisor (manager of the area) and then upload it electronically into the system. After filling the production report, the reports need to be handed to the supervisor who introduces the data into the system again	

Table 6 Rotation Molding Process Flow

In this cell, we found 1-2 operators working, and they work in a 2-shift model. This is the most “complex process” for this value stream. It has eleven steps, starting from the work order process. Pre-molding activities are already done, including the collection and the preparation of the tool. This includes some cleaning and preventive maintenance. Then technicians will do the changeover of the tools. After this, they started with the pre-heating cycle for the tools to be ready for a proper molding process; While running this cycle, the technicians used a crane to collect the material they would use. The preheating cycle finished, and they started the roto-molding process with the material filling, then the machine cycle started. After 25 minutes cycle, they started stripping the parts out of the molds, cleaning, and performing a quality check. Finally, work in progress (WIP) parts were packed and stored in work in progress (WIP) area where they will wait for the following process to be processed. This process is the sewing cell.

6.1.3 KAIZEN POINT - AREAS OF IMPROVEMENT ("WASTE" DETECTION):

Before talking about the following process, I want to present our findings after Gemba walks on this cell. The brainstorming meeting was fruitful, and we detected some “kaizens.” Please see the following table where I presented these points, followed by the question. Can we improve? (Table 7)

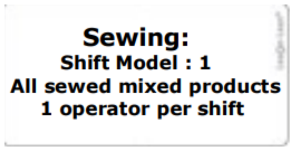
motion	Tool (forklift) stored faraway from production area . The technician(s) spends some time lookinf for it.
Scrap & Lost time due release agent	Release agent used five times each batch (200 pcs.). Each time is used. The machines needs to run two cycles , which generate 40 pcs of scrap in total. Can we reduce the frequency of this? Can we find a different solution that facilitate the tripping process too?
Productivity	• Based on the daily available working hours in the molding area we have 15 working hours per day in a two shifts program. where the machine cycle takes around 30 minutes. Possible run/day $\frac{15\ Hours}{30\ Minutes}$ = So, we have that we can run the machine 30 cycles per day. Deep dive if we can increase the productivity of the cell.
Defects	-No real time quality data -Capturing on paper. -Room for implement continues improvement for defects. -No detailed data to describe defects, no pictures or detailed description of the problem.
Defects - Scrap	Quality check Is it possible to release criteria?. They are scraping a good amount of pieces with defects that are bearly visibles and doesnt affect the main funtionality of the product. Release the quality criteria will lead to: Use the "scrap" as good parts, positive contribution for sustainability and dont waste time pruducing scrap.
overprocessing	Work orders is a time consuming process: 1: Open order: They need to be printed on paper from QAD system. 2: Filled: They need to be filled with production report, configuration control and release for internal distribition. 2: Aproval control: They need to be revised and signed by the supervisoor of the are and the manager. 3: Digitalized: They need to be uploaded into the computer system and closed.

Table 7 Kaizen Points - Roto-Molding Process

We detected six wastes. The first one we found was detected when the technician was looking for the tools. We noticed he uses quite a time to move, look for a forklift and walk to the warehouse where the molds are stored. Then we found a “defect waste” when they need to use a release agent frequently on the roto-molding process, generating scrap parts. We saw an area of opportunity to investigate the possibility of increasing the productivity of the roto-molding machine by using total machine capacity. Then we found two more “defect wastes.” One of them is to look for improvements for defect detection and the other for quality criteria re-assessments. Finally, we found the work orders process time-consuming with room for improvement.

The roto-molding process had finished, and the team was ready for the last Gemba walk to see the following process in this value stream mapping, Sewing process cell. Please join me to see how it was.

Sewing Process Cell



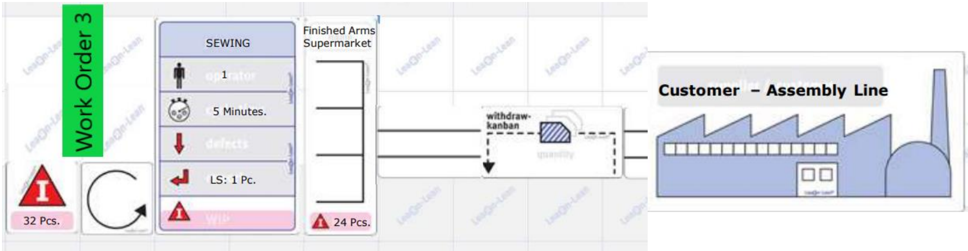


Figure 17 Sewing Process - Value stream map template from Learn-Lean Company

Molded arms skins (WIP parts) are ready for the last step, the post-processing or sewing process. According to the production planning, work order 3 will be needed in this cell which is the trigger point to start production (See figure 17. a fragment of figure 13. Value stream map – current state).

As we have learned from the previous step. We have a location where the WIP (work in progress) is waiting to be picked by the sewing operator(s) when finished parts are needed. The sewing operator takes the parts out of the box (one piece at a time), and the process starts. In this cell, we found one operator, and the cell works in one model shift which means they work only the morning shift. The following table describes each step, with a description and a figure to better visualize and understand what is happening. (Table 8)

Step	Description	Figure
1	**Open work order** Use of QAD System and paper to open work Orders when sewed arm skins are required	

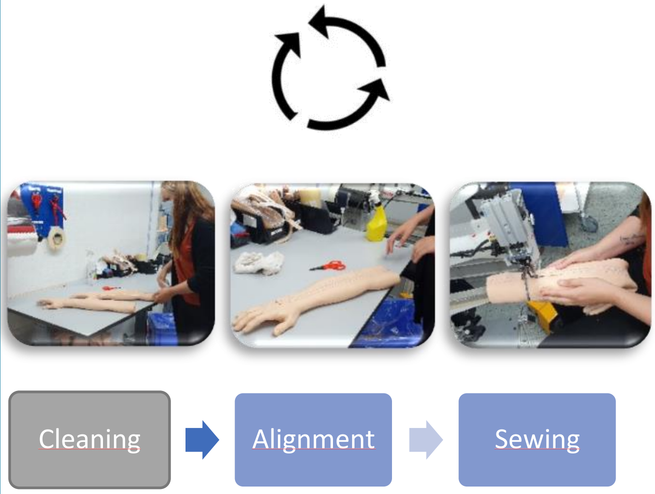
2	**Sewing** 1.- Clean the part using antibacterial 2.- Zipper needs to be aligned using a mark around the arm that indicates the correct position. 3.- Finally, the operator uses a semi-automated sewing machine to complete the sewing of the zipper.	
3	**Close work order & Production report** -Close the work order before being signed by the supervisor (manager of the area) and then upload it electronically into the system. -After filling the production report, the reports must be handed to the supervisor to digitalize the data into the system.	

Table 8 Sewing Process Flow

The sewing process involves creating work order 3, sewing process, and closing the work order. A very straightforward process that only takes 5 minutes of processing per part. This process also has a low scrap percentage as almost all defects can be reworked (fixed).

As this is the last process, after processing, the parts are moved to the supermarket of finished parts located right out of the cell where the customer can withdraw finished pieces when they need. This was done by an intuitive and visually pull system (Kanban) where they had two strollers with a capacity of seven boxes, eight pieces per box. In total, 56 parts for each stroller. This is the supermarket for arms skins (Figure 18). How is this work?

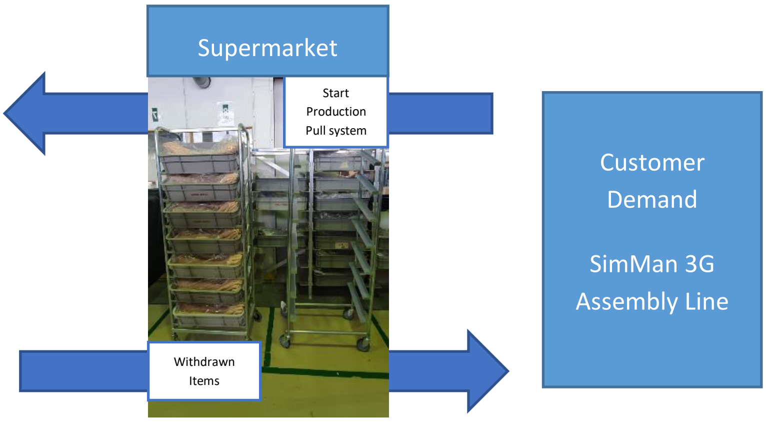


Figure 18 Pull System – Arm Skin Light SimMan 3G

The sewing cell will stop working when both strollers are full until the customer takes one and returns an empty stroller to the supermarket area, and this will be the signal (trigger point) to start production in the sewing cell. Quite lovely and visual pull system, right? Customer pulls what they want when they need pieces, and they are served and happy just as when you go to the supermarket, and you always find the fridge full of milk so you can always take what you need anytime at any quantity.

The material flow in the manufacturing process finished, and after the Gemba walk, the team detected kaizen points.

6.1.4 KAIZEN POINT - AREAS OF IMPROVEMENT ("WASTE" DETECTION):

The whole value stream involves the creation of three work orders. One for the material preparation, the second for the roto-molding process, and the third for the sewing process. All three share this work order process, using the same method. For that reason, the work order process was found to be time-consuming for the three manufacturing processes. (Table 9)

Work orders is a time consuming process:
1: Open order: They need to be printed on paper from QAD system.
2: Filled: They need to be filled with production report, configuration control and release for internal distribition.
2: Aproval control: They need to be revised and signed by the supervisoor of the are and the manager.
3: Digitalized: They need to be uploaded into the computer system and closed.

Table 9 Kaizen Points - Sewing Process

You have seen how material and information flow through the value stream and the detection of "seven types of waste." We found many kaizens we could address; however, those kaizens led to the analysis of two hypotheses.

6.2 DEEP DIVE KAIZEN POINTS ANALYSIS – HYPOTHESIS ONE

I would say that the work order process in Laerdal involves most of the areas. Logistics, production, IT, maintenance, etc. The purpose of work orders is to start a task, clarify what is to be done, probably specify completion dates or give special instructions for a job. Most of the work done in the company has to be registered somehow, and work orders help for this. For that reason, the team and I choose to analyze this kaizen point and deep dive into this. The analysis will prove the hypothesis that the process was time-consuming and how changing the method could help to reduce the time and make the process more efficient.

6.2.1 UNDERSTANDING THE CURRENT STATE

To start this analysis, I would like to map the current state of the process. I took a work order from the rotation molding process, as this one is the one that includes more steps, but I would say the method is similar for all three.

After a Gemba walk, the cycle is the following (Figure 19):

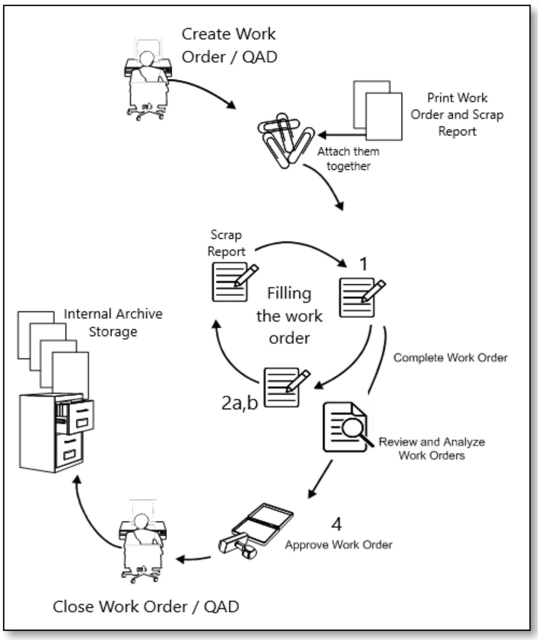


Figure 19 Work Order Cycle – Laerdal Medical (Stavanger plant)

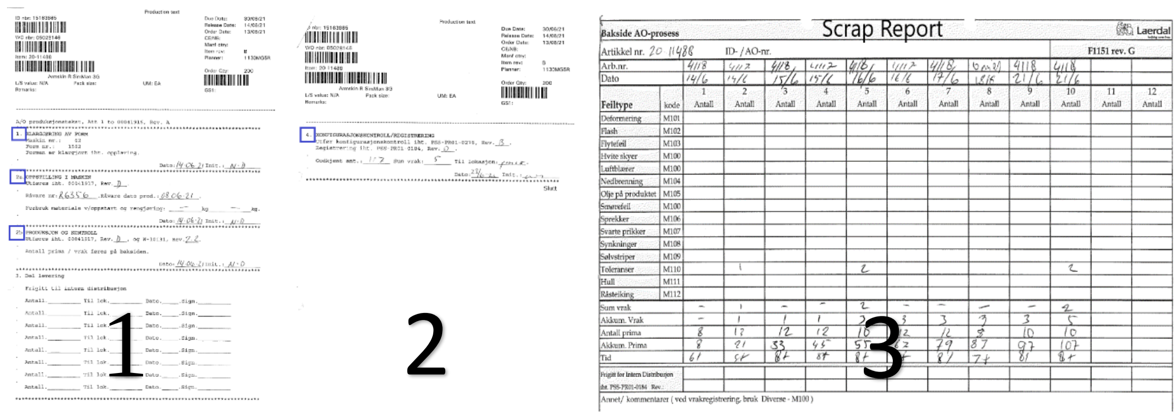


Figure 20 Documents used in the WO (work order) cycle.

The process involves the use of three different documents (paper sheets) as shown (Figure 20), the first two are part of the work order template (Att 1 to 00041916), and the third one is the scrap report (F1151 rev.G). As you saw in the work order cycle diagram (Figure 19), First, this document needs to be printed and hand-filled by the operator/s in charge of the process using a computer with an MRP (Material Requirements Planning) powered by QAD. After the documents are filed, a final inspection and release of the process needs to be done by an extra operator or Odd Egil (Team leader Molding); Why? I will explain this later in this analysis.

When this is done, the work order can be closed. The data is loaded into the system again (QAD), and the papers need to be archived for the record for ten years in a particular location in the building.

This is how the process must be done in the roto-molding area and other areas in the Stavanger plant. Some take more time than others. But how much time does this process take? Please follow me through this analysis and discover why we said that this process is time-consuming.

6.2.2 STOPWATCH TIMES.

Laerdal wants to be a competitive company, so they need to reduce production cycle times as much as possible. And this includes the work order process. How much time does this process take? Using a digital Chrono graphed, I first measured when five different trained operators performed a work order process, and I took the average time for each step and got an average total. The results were recorded and written in the following table. (Table 10)

Steps	Responsible	Average Time (Minutes)
Create Work Order	Department Manager or QAD Trained operator	2.5
Print Work Order and Scarp Report	Department Manager or QAD Trained Operator	1
Filling Work Order:		
1.- Klargjøring av form / Mold preparation	Operator	0.3
2a.- Oppstilling I Maskin / Setting up the machine	Operator	0.3
2b.- Produkjon og Kontrol / Production and control	Operator	0.3
3.- Del levering / Partial delivery	Operator	-
4.- KonfigurasjonsKontrol / Approve Work Order	Department Manager or Trained Operator	3
Fill Scrap Report	Operator	2
Close Work Order and Scrap Report - QAD	Department Manager or QAD Trained Operator	3
Internal Archive Storage	Department Manager	2
	Average Cycle Time	**14.5**

Table 10 Work Order - Cycle times

The average total cycle time was 14.5 minutes from the beginning till the end of the cycle for one process and one item.

We had three different processes: Material preparation, roto-molding, and sewing, and each one has its work order format. The table presented previously was just for the material preparation process. The steps, time, and paper sheet used varied within the work order from process to process, so I decided to measure the time for the other processes. Different operators performed five different samples for each process and average time.

The following table shows the average steps, paper sheets used, and cycle time for each process and the total average: (Table 11)

	Process	Paper Sheets used	Cycle Time (minutes)
1	Material Preparation	2	6
2	Roto-Molding	4	14
3	Sewing	3	8
	Average	3	8.6

Table 11 Chronograph cycle times for Arm Skin PVC (5 Items each process)

Now, we can say that for the whole value stream producing a Light Arm Skin PVC Right. The average time on WO (Work Order) was 8.6 minutes, and the use of three paper sheets per cycle. This took me to the next step.

Was this something Laerdal should consider as "Kaizen Point"?

It looks like it was not that time-consuming, right? But let's visualize the whole picture. Nina Tsukamoto (Shipping manager) provided me updated data from the MRP (QAD) system to visualize the number of work orders that have been made for one year (Sep 2020 - Oct 2021) in the whole plant (Stavanger plant). I found that just 95 work orders were made for Light Arm Skin PVC Right, which represents just 1.6% of the total work orders made for all the manufacturing items in the plant. This number was significantly small, and it looks like it probably was not something I should deep dive on. Still, Laerdal is creating work orders every day for hundreds of products, and perhaps if we included more products in our analysis, we would understand better the extent of this kaizen point.

Currently, Stavanger Plant has 714 manufacturing items in total. As I have mentioned, work orders change from one process to another, and the cycle time could vary. So first it was necessary to calculate a more accurate average cycle time we can use for the next calculation. This time It was taken a group of ten different processes that, according to MRP (QAD), they have generated the most work orders in the same period. The cycle times were stopwatch for three samples per process and then calculated the averages for each process, total cycle time, and total papers sheets used. (Table 12)

	Item	Process	WO (1 year)	Paper	Cycle Time (Minutes)
1	Head skin with zipper	Sewing	62	2	8
2	Suitcase Grey 20L	Injection molding	50	3	15
3	PVC universal skin 171	Material Preparation	125	2	6
4	Skin, Torso, and Head	sewing	130	2	8
5	IV Pad-Arm	Gluing Silicon Part	101	2	6
6	Torso Skin with zipper	Sewing	130	2	8
7	IV skin Left w/zipper, RA	Sewing	99	2	8
8	PVC light skin 130	Material Preparation	76	2	6
9	PVC light skin 171	Material Preparation	96	2	6
10	Ventre bein Resuci Baby	Roto molding	77	3	14

11	PVC Light skin 160	Material Preparation	24	2	6
12	Arm Skin R SimMan 3G	Roto-Molding	29	2	14
13	Arm Skin R w/zipper	Sewing	48	2	8
Total			1047		
Average				2	9

Table 12 Average Cycle Time and Paper used

The average cycle time was now calculated with a more significant sample of 1047, representing the 19% for work orders generated in one year in the Stavanger plant. The result was that the average cycle time per work order is nine minutes and the use of two paper sheets per order.

6.2.3 SUMMARAIZE

Based on these results, the following chart shows time and paper used on work orders. For the bars colored in grey it was considered just the items which form part of the arm skin right PVC value stream (3 items) and the bars colored in blue were considered all the manufacturing parts (714 items) (Figure 21):

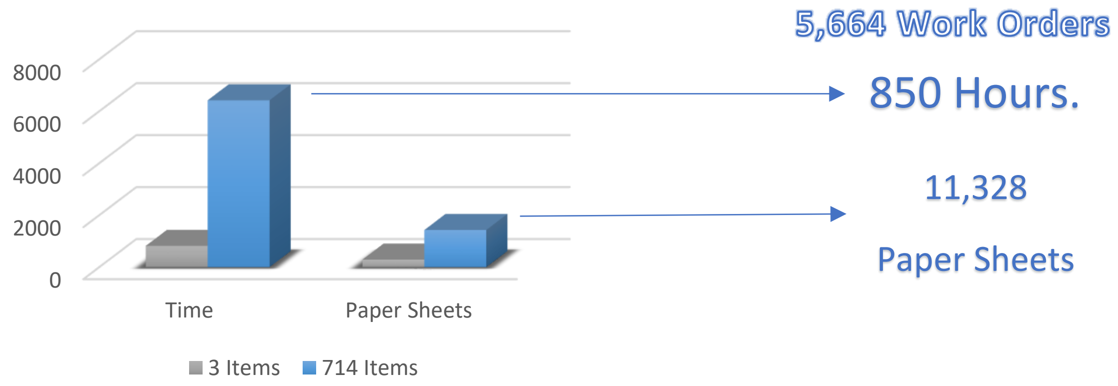


Figure 21 Data base form MRP (QAD) – Sep 2020 - Oct 2021 / Stavanger Plant

As you can see, Laerdal has an important area for improvement to reduce the time used doing work orders. Laerdal Stavanger has created 5,664 used 850 hours ((Average cycle time calculated 9 minutes *5,664 Work orders)/60) and 11,328 paper sheets (5,664 Work orders * 2 Average paper used calculated) in one year (Sep 2020 - Oct 2021). Additionally, there is an area of opportunity to reduce paper waste in the factory.

NOTE:

We can also visualize this in terms of money:

Paper sheet cost: 50 NOK / 500 Paper Sheets. (Clas Ohlson store)

The average hourly rate salary in Laerdal for 2021 is 870 NOKs /Hour.

After doing the math, we got that in one year (Sep. 2020 – Oct 2021), Laerdal Stavanger spent 1132,8 NOK's for the paper used and 739,500.00 NOKs for the man-hours (time) used doing work orders.

Imagine the result if we consider the three manufacturing plants Laerdal has. We can probably be impressed how much time, paper, and money Laerdal uses for this matter. Interesting right?

6.2.4 BRAINSTORMING - LOOKING FOR ROOT CAUSE

For now, the problem has been defined with facts, and then it is time to continue. The next step of the analysis was to investigate the root cause/s of the problem, and for that, I met with Odd Egil (Team leader). We discussed this Kaizen point and started having different ideas of the various causes of this problem. We ended up brainstorming ideas, but we still needed some structured way to do it that helped us analyze them better and find out the root cause of the problem. So, I decided to use the cause-and-effect analysis method (also known as Fishbone Diagram). This method helps us generate ideas about why the problem is occurring and the possible effects of this cause. Please, see this diagram in the following figure (Figure 22).

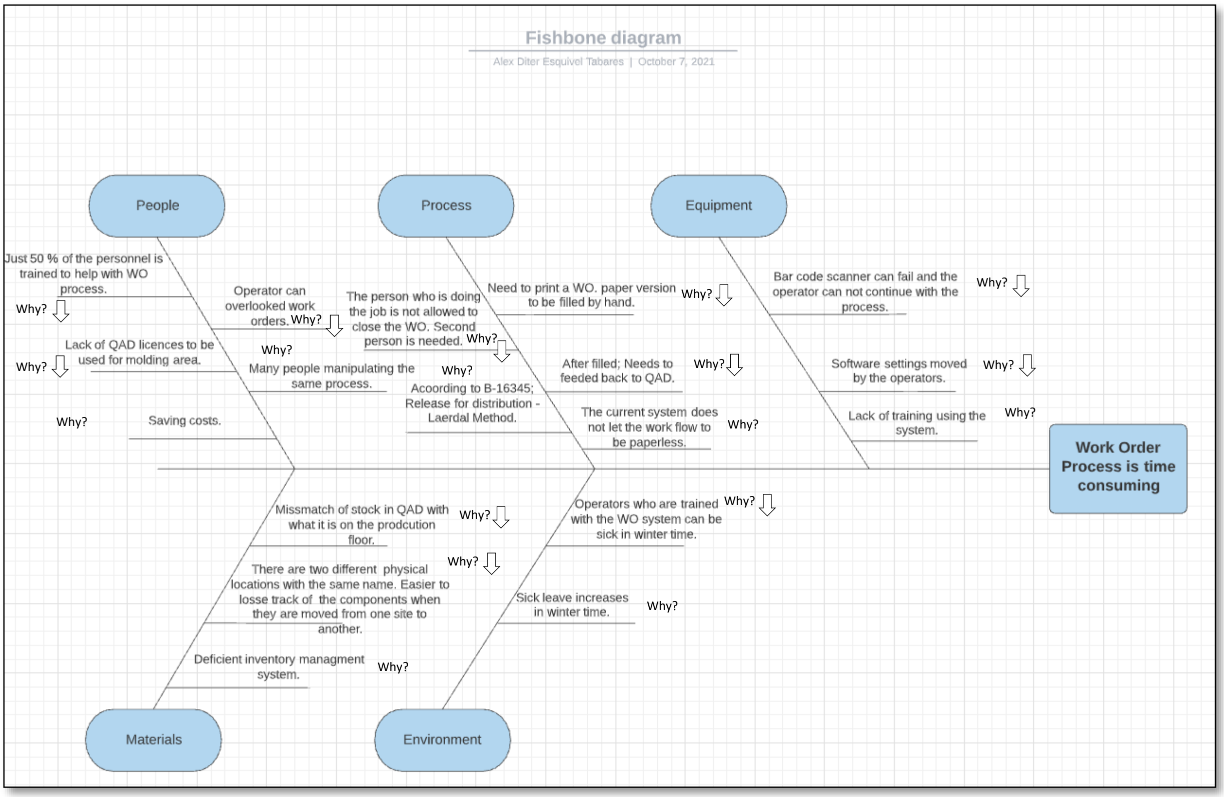


Figure 22 Fishbone diagram – Molding area (2021)

We used five different categories for this cause-and-effect diagram: People, Process, Equipment, Materials, and Environment. To drill down to each cause and find a root cause we used "5 why's". All of them were interesting ones, but not all then added time to the same degree, making the process time-consuming, for example, in the environment category, where sick leave increases in wintertime. Some trained operators can be sick, and for instance, the area or cell where this operator/s works will take more time in this process as they lack some of their trained personnel. This cause will usually affect just certain seasons of the year.

On the contrary, another cause that I considered more critical is in the equipment category. We saw that the barcode scanner they use for open and close work orders usually failed (at least once per week, as the team leader said). This caused the operator to stop the process and ask for Odd Egil's assistance, who could continue the rest of the process. Usually, he was not available right away, so the procedure lasted for hours and sometimes days until he could continue. As discussed with Gerd-Marie – System Support. She said that this could be a lack of trained people with this system. Because many operators are manipulating the same computer, they could change the settings of the equipment from operator to operator, so suddenly, the bar code scanner tended to "fail."

Those two were examples of some of the causes from the brainstorming discussion (Fish Bone Diagram). Are those relevant potential causes? We have seen that they are to some degree, and these causes could be investigated and addressed in a way that can be eliminated or reduced, helping reduce the time for the work order process. But we cannot focus on all of them even though they are causes for our main problem; they can lend us to a divergent approach if we don't prioritize relevant causes.

According to experience and available data, we decided to focus on the process category as potential causes of the effect as they were the causes that contributed the most to our problem.

Under the process category, we identify two possible causes. Below each cause, the “5 why's” methodology helps us identify the root causes, as shown below in the table. (Table 13)

Process	
Cause	***Root Cause***
Work Orders need to be released by a different person to be CLOSED.	According to B-16345 Release for distribution, Laerdal Method.
Need to print WO paper version to be filled by hand and then after fed back to QAD	The current system does not let the workflow be paperless

Table 13 Top Root Causes

After this brainstorming exercise, we can summarize and describe the problem with the root cause. The current process cannot take the entire workflow paperless, which generates waste of time and reduces the productivity of the operators and the production leader. Moreover, the method to release for distribution could be more efficient as this is generating a waste of time on the final revision done by an extra person.

After defining our problem and root cause, we could continue to understand the root cause of the problem to present a possible solution.

6.2.5 UNDERSTAND THE ROOT CAUSE

According to Tim Hicks (Conflict management professional), one of the seven steps for effective problem solving is first to identify the issues but be clear about the problem. And that is what we intended to do for the next step. The plan was to deep dive analyze the root causes first to understand better what was happening. It was decided to analyze the following cause -root cause:

Cause	***Root Cause***
Work Orders need to be released by a different person to be CLOSED.	According to B-16345 Release for distribution, Laerdal Method.

Table 14 Cause and root cause

Why does Laerdal use an extra person to approve (close) a work order? This makes the process cumbersome. An additional person needs to double-check if the work has been done correctly during manufacturing.

Laerdal based this on the International Standard of Quality Management System, **ISO 9001:2015, and the CFR (Code of Federal Regulation).** They established guidelines for introducing a method for acceptance activities, including inspections, tests, or other verification activities.

This method form part of the Laerdal's quality link (Internal quality website); How to manufacture (W-10118). This is divided into two parts, one in charge of production personnel and the other to designated personnel, as you can see in the figure below (Figure 23)

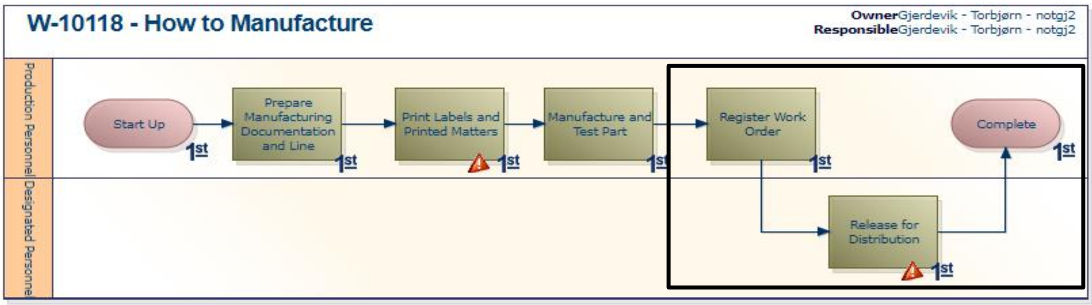


Figure 23 W-10118 - How to Manufacture

Please focus on the last part of the diagram. Before the manufacture has *completed*, the production personnel need to *register a work order*; afterward, a *Release of distribution* is required where designated personnel have to do this step. This means that "*The person performing the release must be independent, i.e., other than the person who has manufactured.*" (This is described in a Laerdal method, B-16345) Odd Egil (Team Leader) needs to do the last inspection. He needs to verify if all steps have been done correctly. Some trained operators can do this inspection and signature, just if they haven't been participating in the manufacturing process's previous steps.

But what does **ISO 9001:2015** and the **CFR (Code of Federal Regulation)** says about the release of products and services? This question was important if we wanted to understand from where Laerdal based the release of distribution method.

- In clause 8, Operations. Section 08.06 Release of products and services. **ISO 9001:2015** Says:

  "The organization shall implement planned arrangements, at appropriate stages, to verify that the product and service requirements have been met.

  The organization shall retain document information on the release of products and services. The document shall include:

  a) Evidence of conformity with acceptance criteria.
  b) Traceability to the person(s) authorizing the release."

- In Title 21 Food and drugs, Chapter 1 Food and drug administration, department of health and human services, Subchapter H - MEDICAL DEVICES. Volume 8, Revised as of April 1, 2020, CITE 21CFR820. **CFR (Code of Federal Regulation)** says:

> *"Final acceptance activities. Each manufacturer shall establish procedures for finished device acceptance to ensure that each production run, lot, or batch of finished devices meets acceptance criteria.*
> *(3)* ***the release is authorized by the signature of a designated individual(s)****; and*
> *(4)* ***the authorization is dated".***

Both clauses give Laerdal the free will to implement their arrangements to verify that the product met the requirements. Laerdal has implemented their own method for internal distribution, these clauses also asked to retain evidence of this. This evidence must have a signature or proof of conformity of a person who can be responsible and traceable. Laerdal has stored signed printed work orders in the internal archive room for at least ten years. So, Laerdal meets this requirement well! But there is no text where the clause asks for an extra person who must be the person authorizing the release. The question is: Is this requirement giving us value for the process?

Also, FDA (Food and Drug Administration) is responsible for protecting public health, ensuring the safety, efficacy, and security of human and veterinary drugs, biological products, and medical services. Laerdal medical in Stavanger manufacture training products. Can we consider these products as medical devices? Open question to investigate later. Probably this

The objective is not to change quality procedures during a work order release. The objective is just questioning, investigating, and analyzing the possibility of eliminating an extra person for this release. However, Laerdal has been doing a great job as the quality system, aligned with word-wide recognized quality regulations (ISO and CFR) and implemented its arrangements consistently to verify the manufacturing products meet the established requirements.

6.2.6 "WAITING TIME" DUE TO THE EXTRA PERSON.

But why do I think it is important to see the possibility of eliminating an extra person? Coming back to the hypothesis, our objective is to reach a more efficient work orders process to eliminate "waste" of time from production and production management.

I would say efficiency is the ability to avoid wasting time. And I believe that the requirement of a second person to do a double check is taking time from production personnel and the team leader. I decided to do a Gemba walk and watch closer this part of the process, stopped watch cycle times, talked with the people who performed this process, etc.

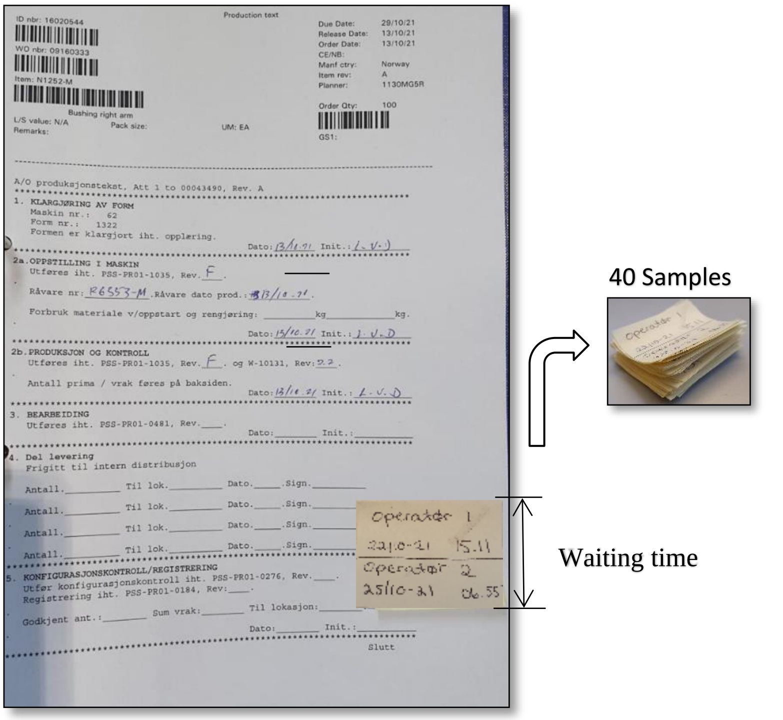
Steps	Responsible	Time (Minutes)
Create Work Order	Department Manager or QAD Trained operator	2.5
Print Work Order and Scarp Report	Department Manager or QAD Trained Operator	1
Filling Work Order:		
1.- Klargjøring av form / Mold preparation	Operator	0.3
2a.- Oppstilling I Maskin / Setting up the machine	Operator	0.3
2b.- Produkjon og Kontrol / Production and control	Operator	0.3
3.- Del levering / Partial delivery	Operator	-
4.- KonfigurasjonsKontrol / Approve Work Order	Department Manager or Trained Operator	3
Fill Scrap Report	Operator	2
Close Work Order and Scrap Report - QAD	Department Manager or QAD Trained Operator	3
Internal Archive Storage	Department Manager	2
	Cycle Time	**14.5**

8 Minutes

55 %

Figure 24 Work Order Cycle Time

The process was generally straightforward to take for the operators. It was found that 55% of the time was used in the last three parts of the work order (Figure 24). Why? One reason was that the operator needed to find this second person to make the final distribution (Final release). In an ideal world, the person will be available to do this job right after the first person finished, and this would take between 3-4 minutes, but this was not happening. For some cases, the waiting time took minutes, hours, or even days. Let us see an exercise was done for measuring this time that I named the "waiting time."



10 Different areas / processes

1	Material Preparation
2	Roto Molding
3	Sewing
4	Silicon Molding
5	Decoration
6	Assy Line Nursing anne
7	Assy Line Resuci baby
8	Assy Line Sim Man 3G
9	Assy Line LSU Suction Unit
10	Assy Line Spare Parts

Figure 25 "Waiting time"

Production operators from different areas (processes) helped me register when the operator 1 finished the first part of the work order before the intervention for the second operator needed to start the final revision. Operator 2 reported when they started with the work order released (Figure 25). The time in between was the "waiting time" required for the second person to come and continue with the process. This was the result based on 40 different samples. The waiting time was divided into three ranges: Minutes, hours, and days. (Figure 26)

40 Samples	**Minutes**	30	4	1	1	1	10	15	5	4	1	1										
	Hours	1	2	3	2,5	2,5	2,5	3	3													
	Days	1	2	1	1	1	2	3	3	4	4	1	3	1	1	1	1	1	1	4	4	2

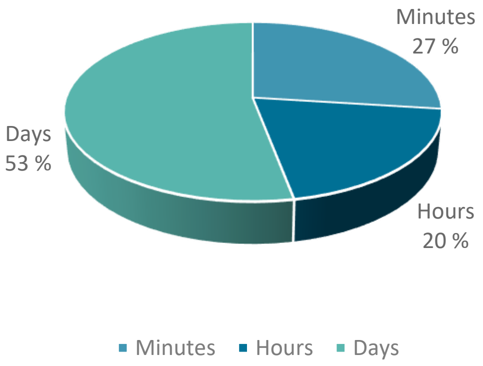


Figure 26 Pie Chart - "waiting time"

It was found that 53% of the "waiting time" were days of wait until the second person was available to do the double-check, 27 % were minutes, and 20 % were hours. According to an interview with the operators and team leaders involved, I found the common reason for each period.

1.- Why is the main reason you need to wait **days** for the release?

Operator – "Just the manager or few operators can do this job, sometimes these persons are not available, or they are on sick leave."

2.- Why is the main reason you need to wait **hours** for the release?

Team leader – "We are few operators working in the cell, and we need to wait for others to come."

3.- Why is the main reason you need to wait **minutes** for the release?

Operator – "Busy times sometimes, and we need to stop colleges working on other activities."

This time depends on the availability of the second person needed and, as we saw, most of the time takes "days," the workload was accumulated. The person in charge of it ended up with a bunch of paper which are work orders waiting to be double-checked and released by Odd Egil (Team Leader molding). (Figure 27)

Around 30 Work Orders were found on queue to be released on 1 week

Figure 27 Work orders workload

After this exercise, we have seen that required a second person for this "release of distribution" takes:

- On average 55 % of the Work Order Process time was concentrated in the last three steps, including the work order approval.
- Plus, the "waiting time," which 53% of this time takes "Days" to be re-checked and released.

6.2.7 IS THE WORK ORDER PROCESS LEAN?

The work order process is time-consuming process, and the "release of distribution" takes a big part of this problem. Laerdal wants to be as efficient as possible and reduce the time of this process as much they can. But what does this imply? Just remember this master thesis is about "Lean Manufacture," and to achieve a Lean environment, what is needed is to follow the six steps to become "Lean" (Figure 28)

Figure 28 Six steps to becoming Lean

Probably you have heard about some of these steps before. If yes, you should know that following them helps to eliminate waste and boost productivity. But please focus on the 5th step; Empowering people, which means sharing information, rewards, and power with employees. I'm sure Laerdal wants to become Leaner and demonstrate trust in his employees, delegating them more than just "work" so they can take the initiative and make decisions or solve problems.

As doing this, the results on the work order process could be:

- Laerdal trusts his people. When they produce, they can release their products by themselves to take responsibility for their work.

- Laerdal can trust that the product will be according to specifications when a single person has produced a batch of items and released /checked by themselves.

We have seen that to reach a lean environment, we need trust in our people. The result will be shown with the elimination of “waste" of time during the work order process by eliminating the second person involved for the double-check. And take this process by just one person. But, to get there still one more question to answer. Is there any risk involved in doing the final release by one person? Please follow me with the next exercise where we will find the answer.

6.2.8 RISK ANALYSIS – ELIMINATE THE SECOND PERSON?

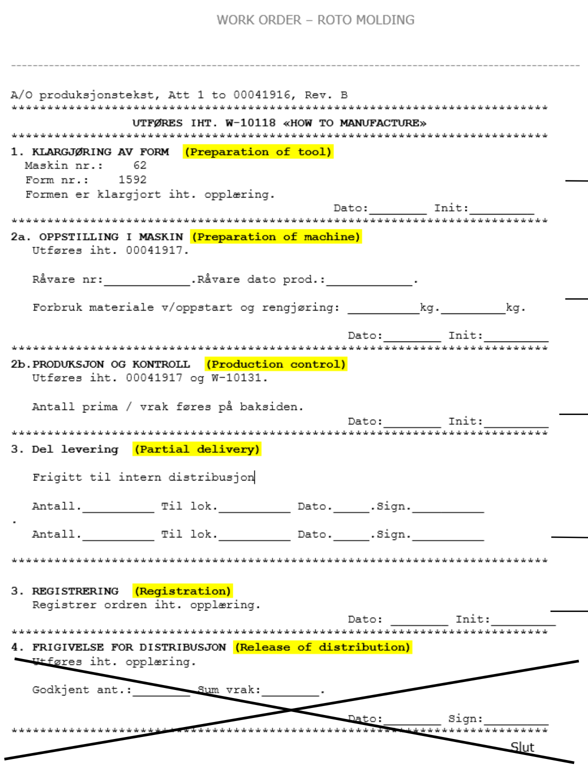
Can we consider the time spent on the final release as waste?

I would call it "waste" if it were not adding value to the process. As you may remember, the primary purpose of the "release of distribution" Is "*Verify that the product and service quality requirements have been met by implementing planned arrangements or checks*" from here. I would ask; Is this extra person needed to reach this goal? Because it seems like for now, there are more pros than cons on eliminating the release of the distribution by an extra person, right? To answer this question a simple FMEA (Failure Mode and Effects Analysis) was done where we could first understand what the second person check and then identify possible failures and mitigate the most significant risk of taking this process by one operator.

Please, see this analysis for the Arm Skin Light PVC made with the participation of Odd Egil (Molding Leader).

For now, I would like you to imagine that just one operator performs the work order process. This operator would fill the work order and release it by himself by following the activities that usually the second person needs to do for each step before signing a “release of the distribution.” Those activities are the following (You can see the work order image 29 below to follow each step)

1. The first step is the **“preparation of the tool.”** The operator needs to verify if a signature and initials are there. It supposes to be the technician in charge of change over the tool.
2. The second step is **“preparation of the machine.”** The operator must verify if a signature and initials are there and if the part number matches the raw material used.
3. The third step is **“production control.”** The operator needs to verify if a signature and initials are there.
4. The four-step is “partial delivery” The operator needs to verify if a signature and initials are there.
5. The fifth step is **“registration”** The operator needs to verify if a signature and initials are there. Also, review if the scrap report and production numbers make sense and match the MRP system with what is on paper. (Sometimes, there are math errors).
6. ~~The final step is the “final release.” Where the operator checked that everything was done correctly~~. **FOR THIS EXERCISE, THIS STEP IS DONE BY THE SAME OPERATOR**



WORK ORDER – ROTO MOLDING

A/O produksjonstekst, Att 1 to 00041916, Rev. B

UTFØRES IHT. W-10118 «HOW TO MANUFACTURE»

1. KLARGJØRING AV FORM (Preparation of tool)
Maskin nr.: 62
Form nr.: 1592
Formen er klargjort iht. opplæring.
Dato:________ Init:_________

2a. OPPSTILLING I MASKIN (Preparation of machine)
Utføres iht. 00041917.
Råvare nr:____________.Råvare dato prod.:____________.
Forbruk materiale v/oppstart og rengjøring: __________kg._________kg.
Dato:________ Init:_________

2b.PRODUKSJON OG KONTROLL (Production control)
Utføres iht. 00041917 og W-10131.
Antall prima / vrak føres på baksiden.
Dato:________ Init:_________

3. Del levering (Partial delivery)
Frigitt til intern distribusjon
Antall.__________ Til lok.__________ Dato._____.Sign.__________
Antall.__________ Til lok.__________ Dato._____.Sign.__________

3. REGISTRERING (Registration)
Registrer ordren iht. opplæring.
Dato: ________ Init:_________

4. FRIGIVELSE FOR DISTRIBUSJON (Release of distribution)
Utføres iht. opplæring.
Godkjent ant.:________ Sum vrak:________.
Dato:________ Sign:_________

Slut

Figure 29 FMEA (Failure Mode and Effect Analysis)

High-level FMEA (not detailed)		
Probability of failure	Failures	Remarks
Low	Wrong or miss date and initials	This could affect if we want to trace the people who performed the work
Low	Wrong or miss date and initials	This could affect if we want to trace the people who performed the work
Low	Wrong or miss date and initials	This could affect if we want to trace the people who performed the work
Low	Wrong or miss date and initials	This could affect if we want to trace the people who performed the work
Medium	-Miss match on the inventory when the paper mismatch with what the MRP says. -Wrong or miss date and initials	-Miss matches in the MRP inventory could lead to overproducing or the risk of getting stockout if they produce less. -This could affect if we want to trace the people who performed the work.

As figure 29 shows, the risk is significantly "low" if we take this process by just one operator. The table presented the FMEA (not detailed)

The first four steps are not giving a significant value to the process. The operator who is doing the final release is just checking that dates and initials are there, and this is not adding any specific value to meet the specified requirement of the product. Then there is a step that presents a medium risk because the double-check helps to verify if the sum of production and scrap parts report matches with what MRP says. This failure represents a mismatch in the inventory, and this could affect the production planning. By Odd Egil's experience, the failure occurrence is relatively low with high chances of detection on the MRP system (red list) also, this failure could be shown even if there is a double check by a second person. (Tables with scales are presented in the Appendix - FMEA Scales)

6.2.9 SUMMARIZE

Extra-person required for release of distribution requires time and this has been demonstrated with facts. however, this time could be considered as waste for the following reasons:

- Is not clear from where or why Laerdal introduced the extra person for the release of the distribution.

-This method could not be considered as Lean due to the lack of trust in their employees while releasing their own work. important to construct a Lean environment.

-Extra-person releasing a work order is not giving any value to the process. The risk of taking this process by one operator is significantly low.

After this analysis, can Laerdal take the work order process with one person? Important question Laerdal should be considered.

6.2.10 EXTRA FINDINGS

During the analysis, it was found two important points that contribute to supporting the hypothesis and this deep diving, for that reason it was decided to include them in this thesis. Those points are presented now.

1.-New work order version

Laerdal has been looking for a Leaner work order process since 2017. Helle Hvid (QA Manager) updated the work orders used by manufacturing Stavanger. These changes include changing the reference from non- product-related (technical documentation) to W-10118 "How to Manufacture" and reviewing the revised work orders to simplify the setup to adapt to the current use of electronic documentation. (Figure 30 to see new format)

These changes will reduce the time by 1-2 minutes on the work orders process, as they don’t need to check that the process has been done with the latest revisions of each procedure.

Today (03.01.22), this change has been implemented in some items, but still, many areas are left. This will come gradually over time.

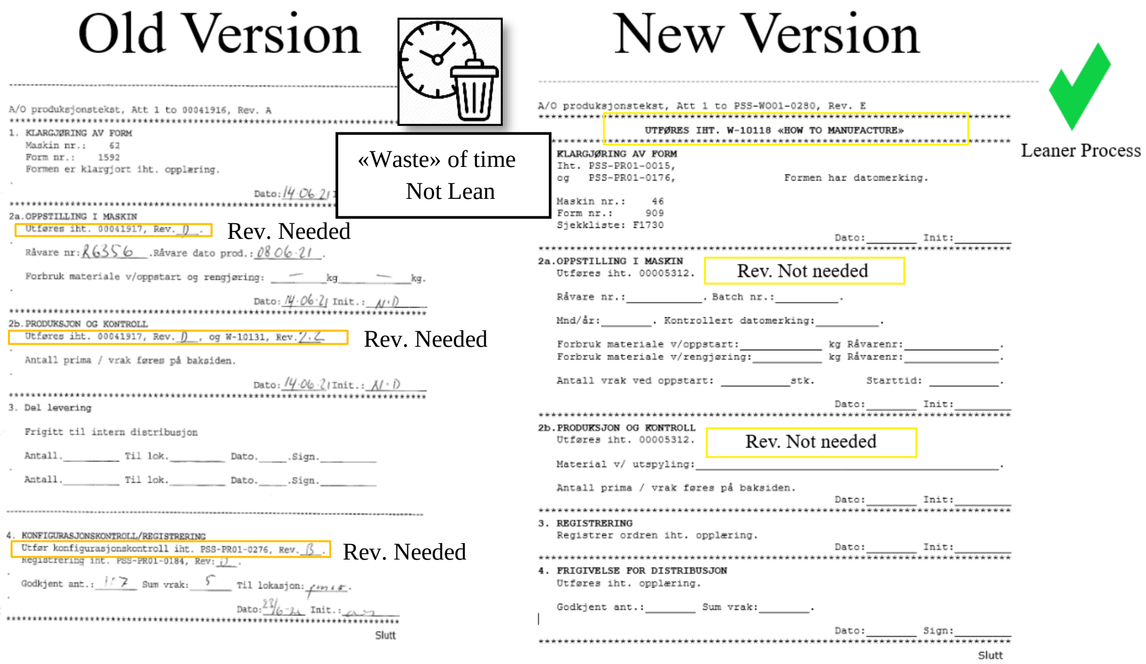


Figure 30 New Work Order Format

2.- Viscosity Test

One of the seven wastes of Lean Manufacturing is *extra processing*; This is, having to do anything more than is needed. Along with mapping the work order process, it was found an excellent example of this in the material preparation process.

They have been doing a "quality control" test to measure the viscosity of the PVC. This test needs to be done after producing a batch of PVC, and this must be done with a digital rotary viscometer (Figure 28) also, the results must be recorded in the work order.

Figure 31 Viscometer

6.2.11 STOPWATCH TIMES

This activity required the operator about 6 minutes in total for each batch produced. I present table with details of where the time was gotten. (Table 15). (I will come back to this table later after this analysis)

List of activities		Time
Turn on the Viscometer.		30 sec.
Take a sample from the batch.		60 sec.
Walk over to the machine.		60 sec.
Start the machine and do the test.		20 sec.
Wait for the result.		20 sec.
Turn off the machine and release the test pin.		20 sec.
Clean the test pin.		45 sec.
Clean the cup.		60 sec.
Take note of the result.		20 sec.
Putting the results in the WO and checked.		30 sec.
Total	**365 Sec. =**	**6 Minutes**

Table 15 Viscosity Test - Work Flow

My first impression of this process was: "This just a simple quality control test where Laerdal cares about meeting the quality requirements since raw material preparation to manufacture its products."

But there was something that made me think that probably this activity was a "waste" of overproduction. It was found that the results of this test were not limited. This means that no matter the test result, the material passed as an OK product. (Figure 32) Why?

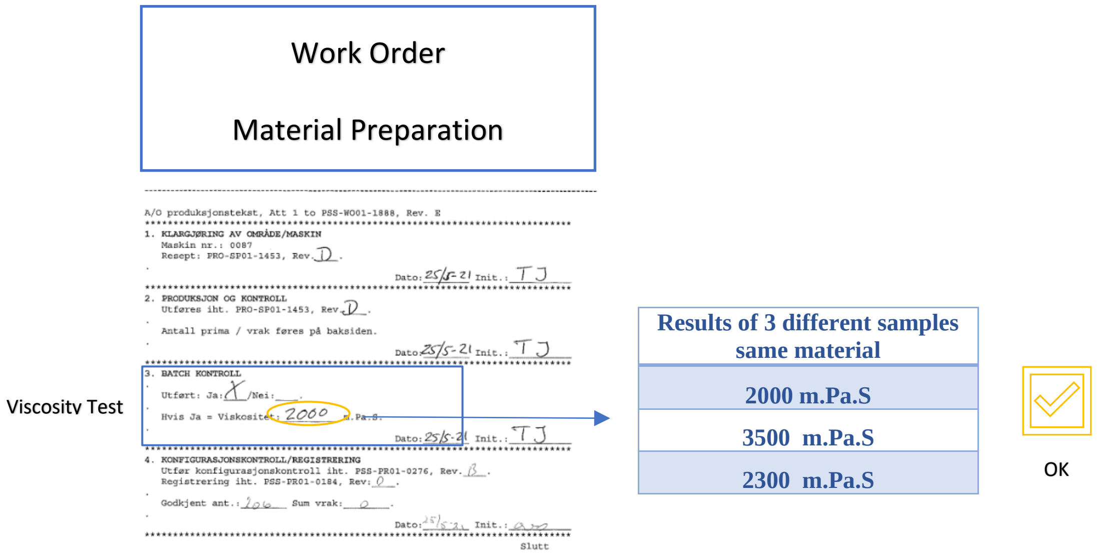


Figure 32 Viscosity test results

6.2.12 "5 WHYS" ANALYSIS

It was decided to make a "5 Whys" exercise to find out the reason (Root cause) for this test. If the results of this test have not been used for quality assurance. Why production area has been doing viscosity test for the plastisol (PVC)? The technicians in charge of this process and Odd Egil (Team Leader) answered the questions. Please see what the results were below (Figure 30).

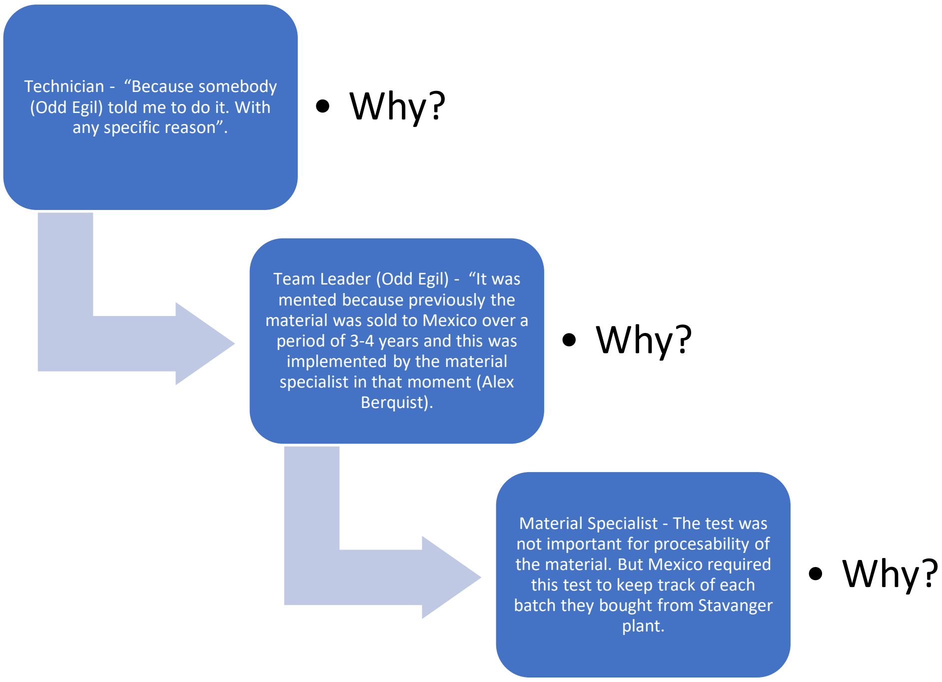


Figure 33 "5 Why's"

6.2.13 SUMMARIZE

According to the answers on this exercise. It can be summarized as:

The test was introduced ten years ago (2013) by the material specialist of that moment. It was meant just for documentation for customers (Laerdal Mexico Manufacture Plant) buying plastisol to Stavanger Plant. Today, it has no value for processability.

After this period, the plastisol was sold for over 3-4 years to produce the Arm Skin Light PVC. The tools were sent to the Stavanger plant for manufacturing, and the plastisol Stavanger – Mexico shipments stopped, but the viscosity test remained with no reason for the next ten years.

Stavanger plant was making this viscosity measurement for six recipes: R6334-R6353-R6354-R6355-R6356 of current recipes, the 6th was R6340 but is no longer in use in Stavanger.

This activity was not adding value to the process, so this results in a waste of overprocessing. For this reason, it was necessary to eliminate this test as soon as possible.

To support this and make this happened, A risk analysis (FMEA) was created with the material specialist (Giovanni Mondin) and Odd Egil (Team Leader) support. The objective was to present the possible risks production could get with eliminating this test. The result was the following (Figure 34)

Failure Mode and Effect Analysis

Item Name: Plastisol - Roto Molding **5 Items : R6334-R6353-R6354-R6355-R6356**	**FMEA Team:** **ALEX ESQUIVEL (Moderator)** **Giovanni Mondin (Material Specialist)**	**Prepared by: Alex Esquivel** **FMEA Date (Orig): 04.11.21**

Process Step or Variable or Key Input	Potential Failure Mode	Potential Effect on Customer Because of Defect	S E V	Potential Causes	O C C	Current Process Controls	D E T	R P N	
What is the process step? Or Variable ? Or Input ?	In what ways can the Process Step, Variable, or Key Input go wrong? (chance of not meeting requirements)	What is the impact on the Key Output Variables (customer requirements) or internal requirements?	How Severe is effect to the	What causes the Key Input to go wrong? (How could the failure mode occur?)	How frequent is cause likely to	What are the existing controls that either prevent the failure mode from occurring or detect it should it occur?	How probable is Detection of cause?	Risk Priority # to rank order concerns	Viscosity Test
Eliminate Viscosity Test from Work Order Process	No failure registred.There is no record that they have thrown away ever a batch of plastisol for having higher or lower number of viscosity.	Unknow and lose of record of pastisol viscosity. Could be high or low m.Pa.S	1	Viscosity Test was implemented 8 years ago for documentation for customers buying plastisol but this has no extra value for the material prep. process	1	No control needed The process is standarized with a mixing manual, reciepe and the use of the same machine always. -Viscosity is not relevant for quality checking. -There is no system in place with tolearce to measure.	1	1	

Figure 34 FMEA - Viscosity Test (Failure Mode and Effect Analysis)

After brainstorming, we mitigated the possible risks and determine that the severity of the potential effect by eliminating this test was low. Also, based on the experience and records. There were no cases registered where they haven't thrown away a batch of plastisol for having higher or lower viscosity numbers. So, there were no possible failures due to the viscosity test results. (Tables with scales are presented in the Appendix A- FMEA Scales)

The extra findings were interesting as they will contribute positively to support hypothesis one:

1.- New work order format is something in the implementation phase. Laerdal did a really good job as this will save time by 1-2 minutes on the work order cycle.

2.- With the elimination of the viscosity test. Production will save 6 minutes for each batch produced.

6.3 DEEP DIVE KAIZEN POINTS ANALYSIS – HYPOTHESIS TWO

Production planning and control is not a simple job and requires specific skills. Such as systematic planning and coordinating. This can be challenging when hundreds of items produce the final product. You need to direct all manufacturing activities and influence them to deliver final products on time and of high quality and not to forget that this is a business! So, this must be done at a reasonable cost.

6.3.1 UNDERSTAND THE CURRENT STATE

To start a deep dive on this topic, we should first understand how the status of the production control is. As we have seen in the value stream mapping, Laerdal has his way of controlling the production in the molding area, using the safety stock list based on the MRP (QAD) as the primary trigger point for start production and to control maximum and minimum of inventory. (Figure 35)

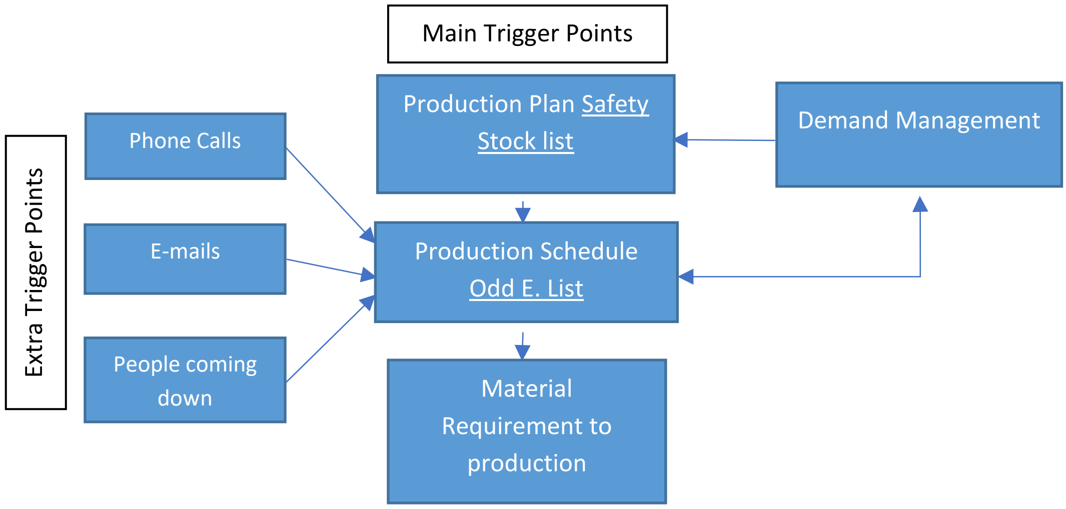


Figure 35 Information flow diagram – Production Planning

As you may see in this chart (see figure 32). The information flow starts from the customer **"demand management,"** this demand feeds the MRP (QAD) system with the forecast for the following weeks. This information feeds the trigger points, creating the "**safety stock list**." As its name says, this list is based on a safety stock number with a minimum and maximum inventory. This list is also named the "red list" because it marks the stock-outs with red, making them priority number one to start production. Then every Monday morning, Odd Egil (Team leader), in a daily molding production meeting he gets the last update from the list, which he will use to make the weekly plan for production in the material preparation, rotation molding, and sewing process. Before making the weekly plan, he needs to update a second excel list **("Production Schedule")** also based on the "safety stock list" data. Then, he can start with the **"material requirement production";** This is made every Monday morning when the roto-molding technicians receive a post-it note, text messages, or a phone call with the plan for the week.

6.3.2 INTERVIEW

The process gets cumbersome when Odd Egil deals with different trigger points. For a better understanding of this, I interviewed Odd Egil about it.

My first question was:

- How much time do you use for planning the production?

Odd Egil- The weeks production plan takes around 2 hours

- How much time do you use for replanning for urgent parts?

Odd Egil- It depends on several factors, do we have free capacity on the machine, do we have the required material, and do we have the right operators to do it, but it is normally not taking long time to find out, maybe 30 minutes.

- How many trigger points do you have?

Odd Egil – "I have the main trigger point, the "red list," I have one list that I created for personal use that also helps me plan the production. I usually get extra trigger points for urgent items that make me change the following week's plan.

- Which are the extra trigger points?

Odd Egil – "I usually get "**Phone calls**, **e-mails** and **people from assembly"** line coming down asking for urgent parts."

- How frequently do you receive phone calls?

Odd Egil- "I get 1 or 2 phone calls per week."

- How frequently do you receive e-mails?

Odd Egil- "I get 1 or 2 e-mails per week."

- How frequently do you receive people coming down from the assembly line?

Odd Egil- "They rarely come down asking for urgent pieces. They usually use e-mail or phone calls."

Short interview – Odd Egil (Molding Team Leader)

6.3.3 UNDERSTANDINGS

After the interview, I understood the different extra trigger points for production planning and how this makes the processing cumbersome and time-consuming. He gets additional trigger signals every week in different frequencies, and for that reason, the planning for production can be challenging week after week. But It was necessary to evaluate if more potential factors were causing this problem.

6.3.4 BRAINSTORMING - LOOKING FOR ROOT CAUSE

It can often be challenging to identify the real reason of why things are going wrong. We could usually spend too much time worrying about symptoms rather than the root cause, which could take us going around in circles without a solution in sight.

A fishbone diagram was a simple way to address the problem from the root cause, and to identify the different causes and the effects.

With Odd Egil’s support the diagram was constructed with five categories—from the 6m's of manufacturing and 7p's of marketing. The result was the following. (Figure 34)

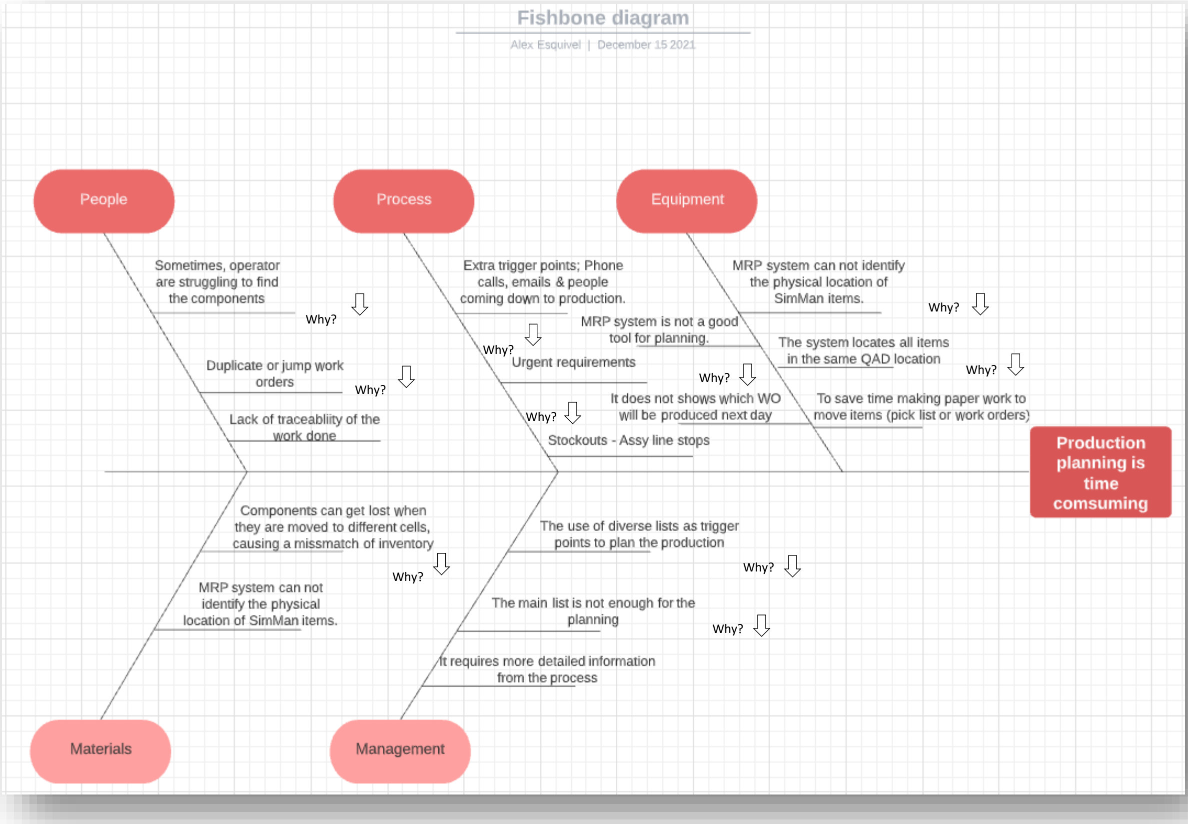


Figure 36 Fish Bone Diagram for Production planning

This fishbone diagram presented six different causes of the problem, to drill down to each cause and find a root cause we used "5 why's" on each one. All cause contributes to different degrees, causing a cumbersome process. I want to summarize them in the following figure showing the top three: (Figure 37)

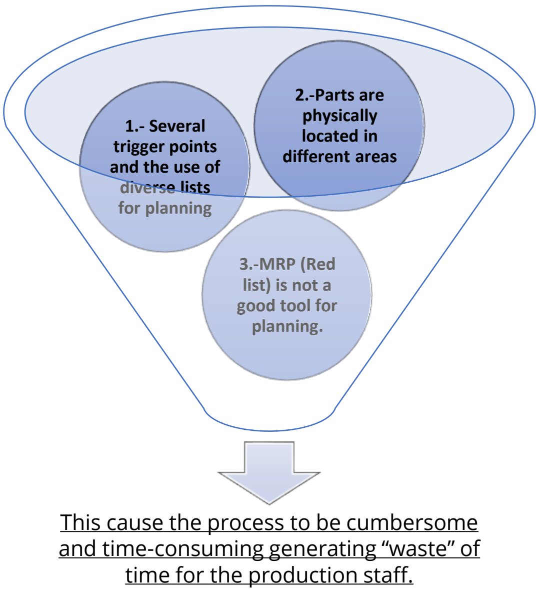


Figure 37 Top 3 causes.

Possible solution?

The first shows the multiple trigger points involved in the planning. the use of an extra list apart from e-mails, phone calls, and people coming down from the assembly line. The second cause is the different locations where molding stores pieces: molding area and two warehouses. No matter where the parts are moved, in the MRP (QAD) the parts will be shown located in AS1 (location for SimMan products). This could cause a system mismatch in inventory when they physically move pieces from one area to another as the MRP could detect where physically the parts are, causing the planning process problems (Figure 38)

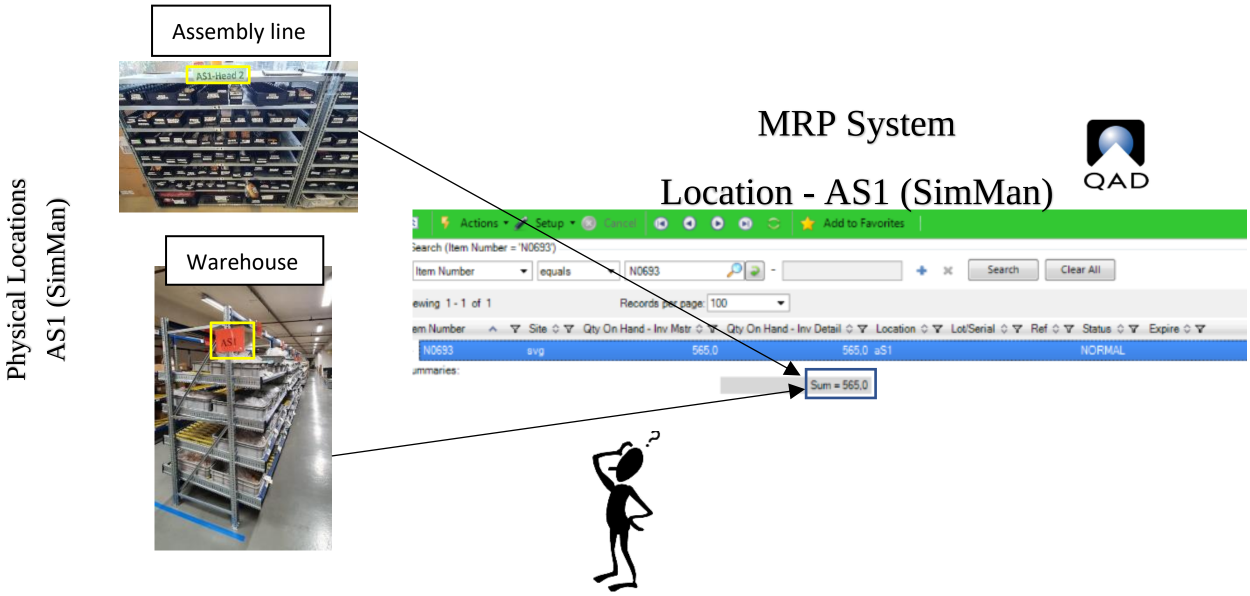


Figure 38 Parts are located in different areas physically

The third cause is related to the MRP system. As I have mentioned, the “red list” is based on safety stock data with a set of minimum and maximum levels and is used as the main trigger point to plan the production. We know that demand tends to change over time, so the list needs to be updated frequently according to current demand, and this list hasn’t been updated in the last five years (according to MRP). However, even the list could be updated with the current demand could be a good tool for daily planning and determining priorities (which item is burning and prioritizing them), <u>but not for future planning.</u> QAD system cannot show which WO (work orders) will be produced in the following days. This causes the planning process to spend time updating the red list every day, subsequently update the second list used for planning, and probably spend more time planning if there is suddenly an urgent part that appears on the red list.

After getting these top three causes, we could now address the problems as appropriate.

6.3.5 ADDRESS THE PROBLEM

A Lean Manufacturing method named “Kanban” was used to address this problem. (The theory behind this method was explained before in the theory part) Why? Production areas can experience many benefits from this powerful tool for their inventory systems; Some of the benefits are lower inventory cost, more space, better oversight, lower risk of obsolesce, and <u>increased productivity on production planning</u>. We want to focus on the last one, which could help solve the problem and make Odd Egil’s (Team leader molding) planning process more efficient and productive. And that is why Kanban was chosen as the possible solution for this problem. The action plan was traced and presented in the following figure. (Figure 39)

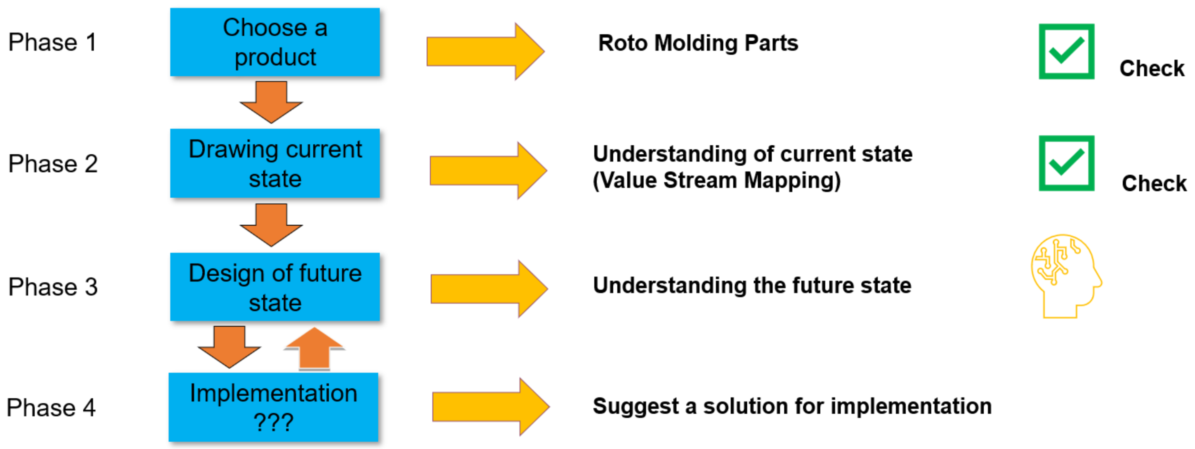


Figure 39 Approach to integrating Kanban System in the roto-molding area

This plan was compounded of four phases where the first part and the second were already done as we already determined which product/s will be included in the analysis. We knew that we were analyzing a single roto-molding part (SimMan 3G Arm skin light right), but we needed more pieces to introduce a Kanban inventory system. So, this analysis will include all roto-molding parts in the Stavanger production plant. Also, we already understood the current state of the value stream map we drew at the beginning of the analysis.

The plan is compounded of four phases and started with choosing the product. This thesis was analyzing a single roto-molding part (SimMan 3G Arm skin light right), but we needed more pieces to introduce a Kanban system, so this analysis included all roto-molding parts. In total 68 items. After defining the product(s) the second and third phase includes the understanding of the current and future state. Please follow me through this analysis to see how the following phases were developed.

6.3.6 UNDERSTANDING CURRENT AND FUTURE STATE

It was wise to first visualize the current state to understand a future state. So please look at the following drawing (Figure 40) to visualize and understand better.

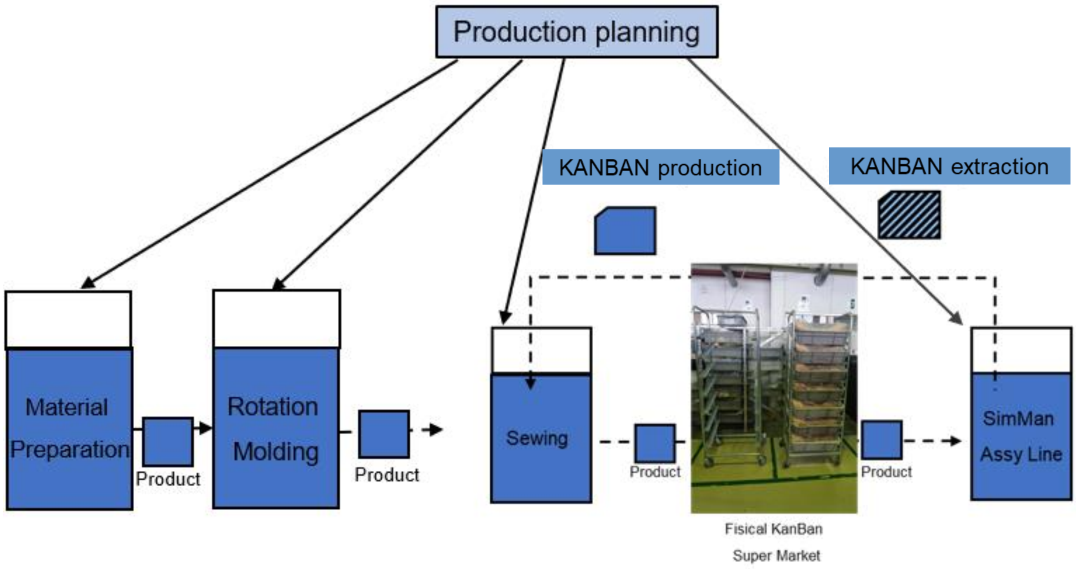


Figure 40 CURRENT STATE – Controlling production with several trigger point

In this drawing, you can see how production planning works currently. The four black arrows point to the different areas where the planning must be done week by week from the material preparation process till the end of the value stream: The SimMan Assembly Line. Also, as we saw in the value stream map at the beginning of this analysis, roto-molding were already familiar with Kanban as they were using this system between sewing and the assembly line where we can find visual extraction signals and visual production signals that currently works perfectly, that help and reduce the planning at the final part of the value stream in the link between the sewing area to the assembly line. But what happens with the rest of the value stream? Well, the principles of "Kanban" allow production to flow in a simple, easier, and more manageable way, moving from classic production planning to an automated production planning system with a few or sometimes no intervention of the manager planning the daily production. Our goal is to reach this level of "automatization" for production planning.

Please see the diagram of how the production planning would look if we used the "Kanban" system for the whole value stream. (Figure 41)

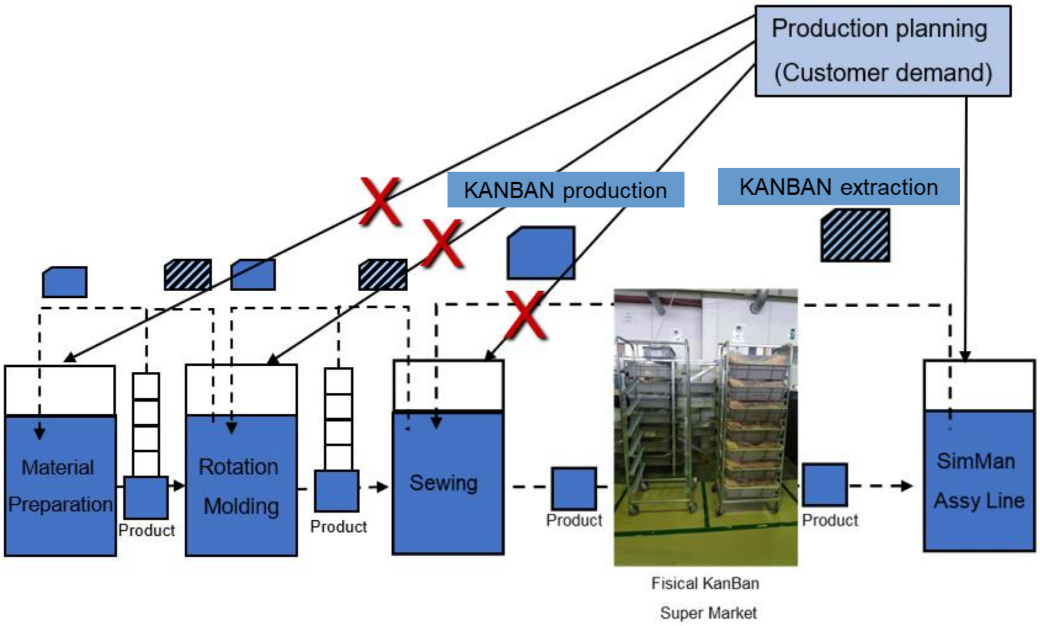


Figure 41.FUTURE STATE – Using Kanban Automated system for controlling production planning.

As you can see now, production planning is only at one point in the value stream. We can see the planning arrow at the SimMan Assembly line, where the trigger point will be the customer (SimMan Assembly Line). Then the signal will be transferred backward to sewing with a Kanban signal to start production until the signal goes to the beginning of the value stream: Material preparation cell. We appreciate how nice the automated Kanban system sends Kanban production and extraction signals when the customer (assembly line) demands it.

We have understood the current and future state of the production planning and how beneficial it would be to introduce the Kanban system in the roto-molding area. However, we still needed to figure out other aspects before introducing the system.

6.3.7 BEFORE KANBAN

Too many control points lead to disruption in the value stream, increased lead times, higher inventories, and production planning to be cumbersome and time-consuming. Undoubtedly, the future state could bring many benefits, but as I have mentioned, there was more to deep dive before applying a Kanban system.

When Toyota rolled out the Kanban inventory system in its factory, they introduced six guidelines for successful implementation; Don't stockpile, don't overproduce, don't pass on defects, stabilize processes, maintain a level of production, and optimize operations. All of them are equally important, but to accomplish these guidelines, we should first understand that Kanban as a "pull system" will support a continuous flow – "make one, move one." This means that resources will be pulled out of the system when needed or requested by the customer. So, when customer demand is unstable and unrepeatable, the Kanban system will tend to fail.

So, before thinking of Kanban, it was essential to know if the demand was stable or not.

6.3.8 ABC XYZ MATRIX

As I have mentioned, Kanban will work best when we have constant or repetitively used material, which means predictable demand and the forecast tends to remain relatively stable. However, cost, and annual quantity also play a role in determining if Kanban is the right tool for a given item. ABC XYZ Matrix is an effective tool that will help us with this analysis.

This method is many used by the supply chain, and its main objective is to optimize and prioritize inventory management. But it is also a valuable tool to determine which items are high volume and which ones are uncertain on demand and which ones are not. (Please, remember to read the theory part before understanding how this matrix works). And this is why It was chosen to use this matrix. Come along with me with this analysis, and let's find out our candidates for the Kanban system!

First, I made a list of all the items to analyze in the roto-molding area with their part number and description.

Roto Molding Items

	#	Part number	Description		#	Part number	Description
High Runners	1	20-11488	Arm Skin R SimMan 3G	High Runners	35	N1234-D	Bushing left arm
	2	20-11488-D	Armskin R SimMan 3G		36	N1234-M	Bushing left arm
	3	20-11488-M	Armskin R SimMan 3G		37	N1252	Bushing right arm
	4	20-11489	Armskin L SimMan 3G		38	N1252-D	Bushing right arm
	5	20-11489-D	Armskin L SimMan 3G		39	N1252-M	Bushing right arm
	6	20-11489-M	Armskin L SimMan 3G		40	V64	ALS Baby Lår
	7	N1013	Leg skin right		41	V65	ALS baby Legg
	8	N1013-D	Leg skin right		45	H61	Høyre Arm Resusci Baby
	9	N1013-M	Leg skin right		46	H63	Høyre Bein Resusci Baby
	10	N1015	Leg Skin left		47	V61	Venstre Arm Resusci Baby
	11	N1015-D	Leg Skin left		48	V63	Venstre bein ResusciBaby
	12	N1015-M	Leg Skin left		49	117	Bulb PVC
	13	20-11664	Leg, left lower		42	H60	Høyre Arm ALS Baby
	14	20-11668	Leg, right lower		43	H62	Høyre Bein ALS Baby
	15	20-14587	Leg lower right IO		44	V60	Venstre arm ALS Baby
	16	20-14591	Leg lower left IO		50	N2107	Cont. fluid flex. 0.25 L
	17	N0631	Hand Right		51	N2108	Cont. fluid flex. 0.1 L
	18	N0636	Hand Left	Just by demand from Mexico	52	30-00086	Plastic wound no.19 (502)
	19	N0708	Foot Right Core		53	30-00087	Plastic wound no.20 (503)
	20	N0708-D	Foot Right Core	Low Runners Spare Parts	54	8009	BP arm skin for SimBaby
	21	N0708-M	Foot Right Core		55	8018	IV arm skin for SimBaby
	22	N0953	Foot left core		56	5464	Leg skin Right for
	23	N0953-D	Foot left core		57	5468	Leg skin Left for
	24	N0953-M	Foot left core		58	5462	Leg mandrel upper right
	25	N0618	Torso skin		59	5466	Leg mandrel upper Left
	26	N0618-D	Torso skin		60	5463	Leg mandrel lower Right
	27	N0618-M	Torso skin		61	5467	Leg mandrel lower Left
	28	N1053	Foot Skin Right		62	5483	IV arm mandrel upper for
	29	N1053-D	Foot Skin Right		63	8006	BP arm mandrel for
	30	N1053-M	Foot Skin Right		64	8011	IV arm mandrel lower for
	31	N1054	Foot Skin Left	Very Low Runners	65	V62	Venstre Ben ALS Baby
	32	N1054-D	Foot Skin Left		66	996	Cast Upper Arm
	33	N1054-M	Foot Skin Left		67	994	Cast Lower Arm
	34	N1234	Bushing left arm		68	N1081	Pelvis

Figure 42 List of all Roto-molding items

We got 68 items in total, divided into four categories. High, low, very slow runners and items produced just by demand from the Gatesville-Monterrey plant. (Figure 42)

After this, "XYZ" analysis was done to classify them accordingly to the variability of their demand. An effective way to quantify it was to determine the mean and the standard deviation of weekly demand of all the parts under consideration, then calculate the "coefficient of variability" or CoV (CoV = Standard deviation / Mean).

If we plot this in bars graph, we could easily see how the demands move from one day, week, or month to another, and we could find three different scenarios:

Scenario “X” means a regular variation, steady, and easy to forecast.

Scenario “Y” means unsteady demand, but the variability could still be predicted to an extent. Usually, these fluctuations in demand are caused for known factors.

And Scenario “Z” means sporadic demand, difficult to forecast, and can fluctuate sporadically.

Knowing this, I started calculating and plotting all items. This analysis presents an example of one item to understand how it was done. Please, see the following graphic of Arm Skin Right Light PVC (Figure 43). (To see the results for all the items, see table 16 below)

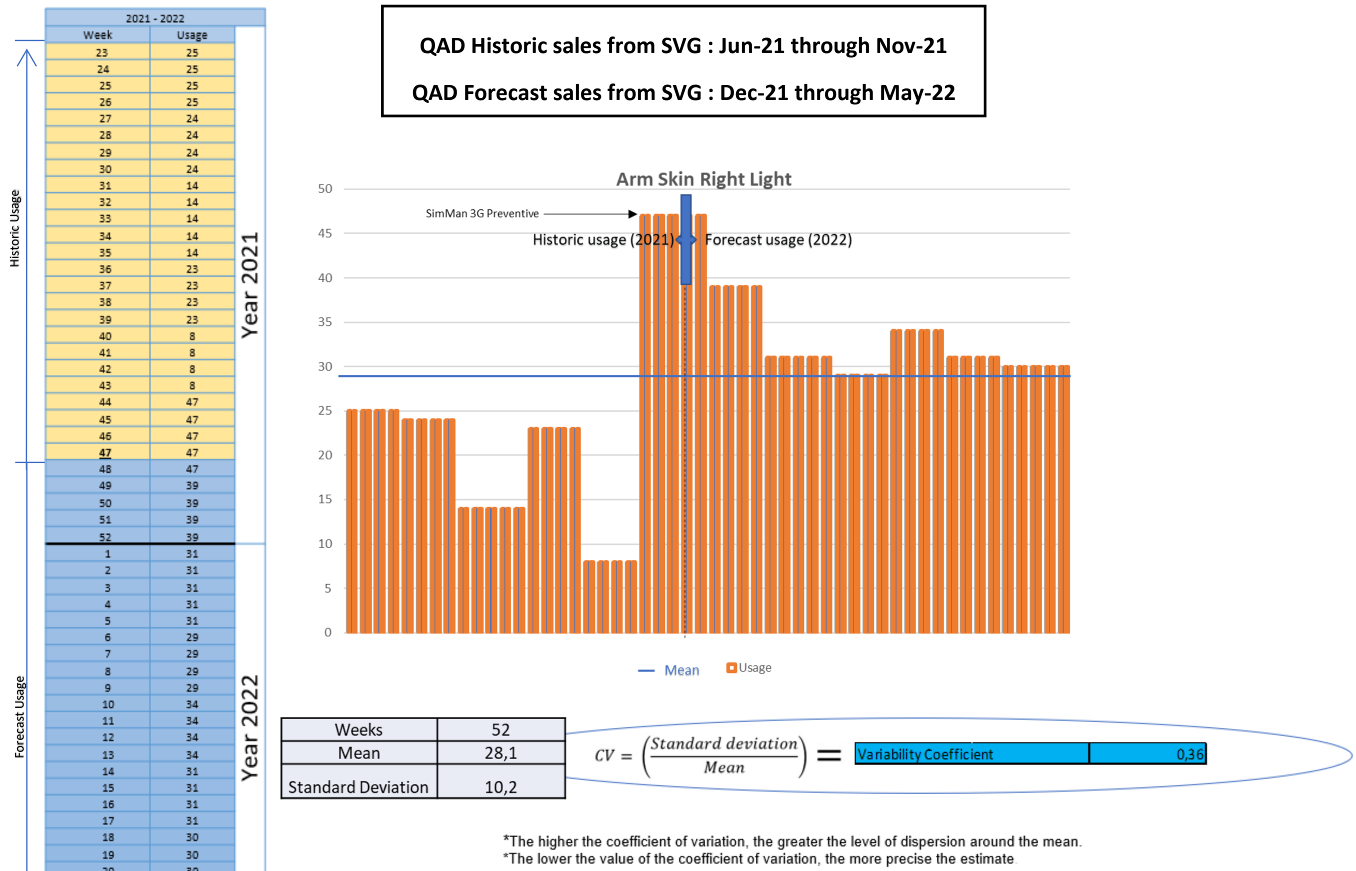


Figure 43 Variability coefficient analysis

This is how “XYZ” analysis was done for 68 roto-molding items. One year of archive MRP (QAD) data was used: A combination of historic and forecast sales. From there, I got the weekly demand (usage) for 52 weeks that compound one year. Then, calculate the “mean” of 28,1 and the standard deviation of 10,2. So I could be able to calculate the variability coefficient:

$$CV\ (variability\ coefficient\ ) = \frac{10{,}2\ (Standard\ deviation)}{28{,}1\ (mean)} = \ 0{,}36$$

For this example, the result was 0,36. What does it mean? Parts with lower Coefficients of variation have more stable demand patterns than those with higher. The criteria used to classify a “High” or “Low” VoC (Variability of coefficient) came from Siemens AG inventory management “XYZ ABC” matrix made by a corporate technology consulting in 2015. (Figure 44)

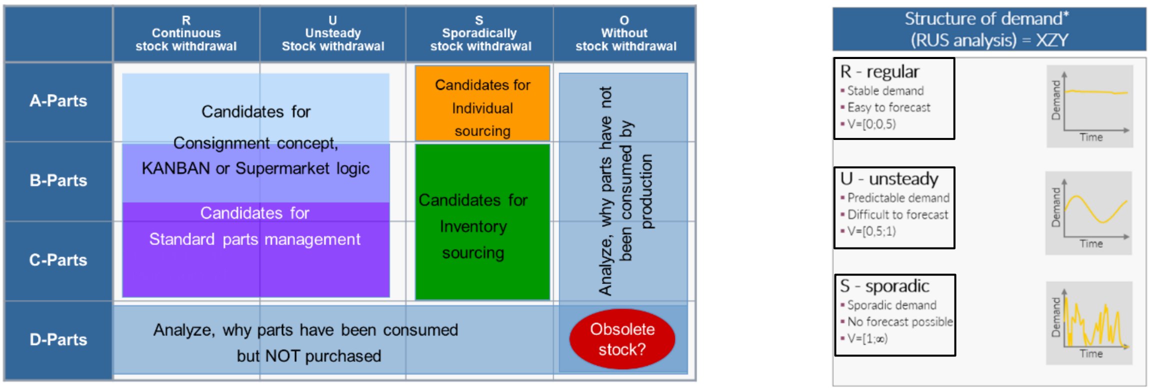


Figure 44 Source: Corporate Technology Consulting 2015 – Siemens AG

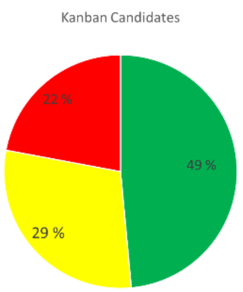
As you see in the left figure, this is the matrix that supply chain management uses to classify their items into different categories. In the first row, we can find the structure of demand or the classification X, Y, and Z, but Siemens uses the letter; R, U, S, and O instead. And in the first column, we find the classification A, B, C, and D; Both classifications need to be considered to identify candidates for the Kanban system, individual sourcing, inventory sourcing, and identify obsolete stock. Then we have the figure in the right where we find the criteria used to classify the structure of demand:

X Regular variation = VoC (Variability of coefficient) = 0 to 0,5

Y Unsteady demand = VoC (Variability of coefficient) = 0,5 to 1

Z Sporadic demand = VoC (Variability of coefficient) = 1 to ∞

After getting all the VoC (Variability of coefficient) for all the parts and evaluating them according to this matrix and criteria shown, I was impressed with the first results I got from classification “XYZ.” The results were that 53 out of 68 parts were possible candidates for Kanban. This was 78 % of the total roto-molding items. More than I thought! This means that most items have regular or unsteady demand, and just 22 % were parts with sporadic demands (Figure).



Demand	Roto Modling Items
Regular	33
Unsteady	20
Sporadic	15
Total	68

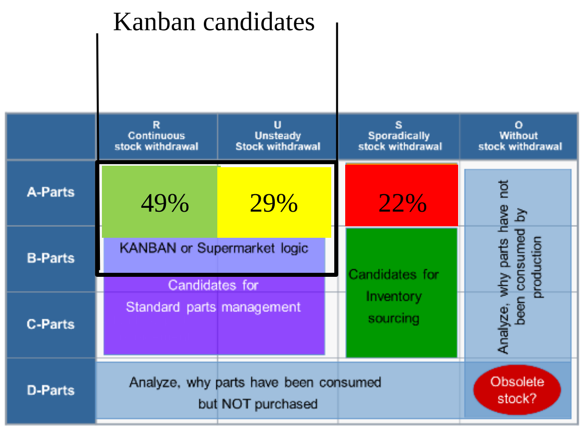


Figure 45 "XYZ" Matrix results

If you see the Siemens matrix on your left, we can see that most of our items are localized in the marked area between R (Continues or Regular demand) and U (Unsteady demand). The 22 % were not candidates for Kanban, these parts were removed from this analysis and continue with the rest of the parts. This let us with 53 out of 68 parts left defined as possible candidates for Kanban. (Figure 45)

Now it was time to evaluate these parts with the “ABC” analysis. The supply chain mainly used this to prioritize inventory management according to sales volume. For us this will help us focus our time and energy on the products that represent the most significant sales for Laerdal and the most inventory cost for the company. The following table shows the results from “XYZ” evaluation category that I already mentioned and the “ABC” category that I will explain now. (Table 17)

POSSIBLE CANDIDATES FOR KANBAN SYSTEM

		«XYZ» Classification				«ABC» Classification						
Item Number	Description	Average	Standard Deviation	Variability Coeficient	Structure of Demand	QTY Manufactured L12M	Annual Volume (%)	Extended Cost (NOK)	Annual Cost (%)	Clasification	Range	
											Annual Cost	Number of Items
N0618	Torso skin	49,10	16,91	0,34	Regular	2941	5 %	1 052 869	19 %	A	61 %	55 %
V61	Venstre Arm Resusci Baby	26,69	14,42	0,54	Unsteady	6541	12 %	346 735	6 %	A		
V63	Venstre bein ResusciBaby	26,54	14,43	0,54	Unsteady	4705	9 %	247 600	4 %	A		
H61	Høyre Arm Resusci Baby	26,62	14,38	0,54	Unsteady	4938	9 %	247 212	4 %	A		
20-11488	Armskin R SimMan 3G	28,12	10,21	0,36	Regular	1651	3 %	241 211	4 %	A		
N1013	Leg skin right	16,21	6,47	0,40	Regular	1017	2 %	201 393	4 %	A		
H63	Høyre Bein Resusci Baby	26,54	14,43	0,54	Unsteady	3791	7 %	199 501	4 %	A		
N0631	Hand Right	36,02	14,25	0,40	Regular	1920	4 %	176 843	3 %	A		
N1015	Leg Skin left	14,50	5,13	0,35	Regular	889	2 %	176 045	3 %	A		
N0618-M	Torso skin	9,60	5,31	0,55	Unsteady	491	1 %	175 104	3 %	A		
20-11489	Armskin L SimMan 3G	12,71	3,62	0,28	Regular	920	2 %	157 089	3 %	A		
N0618-D	Torso skin	6,52	3,75	0,58	Unsteady	380	1 %	136 397	2 %	A		
N0636	Hand Left	17,75	5,16	0,29	Regular	1223	2 %	112 645	2 %	B	22 %	27 %
N1054	Foot skin left	13,46	4,83	0,36	Regular	999	2 %	109 549	2 %	B		
N1053	Foot Skin Right	13,77	5,74	0,42	Regular	995	2 %	109 111	2 %	B		
20-14587	Leg lower right IO	16,12	4,89	0,30	Regular	1119	2 %	102 075	2 %	B		
20-14591	Leg lower left IO	16,12	4,89	0,30	Regular	1099	2 %	100 250	2 %	B		
V64	ALS Baby Lår	14,58	7,38	0,51	Unsteady	1151	2 %	89 366	2 %	B		
V65	ALS baby Legg	14,58	7,38	0,51	Unsteady	1170	2 %	85 811	2 %	B		
N1252	Bushing right arm	11,75	4,91	0,42	Regular	867	2 %	84 103	2 %	B		
20-11488-M	Armskin R SimMan 3G	6,56	4,74	0,72	Unsteady	535	1 %	80 662	1 %	B		
N1013-M	Leg skin right	7,25	3,50	0,48	Regular	393	1 %	74 759	1 %	B		
N1015-M	Leg Skin left	7,10	3,44	0,49	Regular	389	1 %	73 998	1 %	B		
20-11489-M	Armskin L SimMan 3G	4,25	2,12	0,50	Regular	397	1 %	69 013	1 %	B		
N1234	Bushing left arm	11,75	4,91	0,42	Regular	711	1 %	68 970	1 %	B		
117	Bulb PVC	37,44	15,88	0,42	Regular	3549	7 %	60 874	1 %	B		
V60	Venstre arm ALS Baby	6,04	2,30	0,38	Regular	674	1 %	57 980	1 %	C	17 %	18 %
20-11664	Leg, left lower	13,10	2,48	0,19	Regular	557	1 %	55 618	1 %	C		
20-11668	Leg, right lower	13,10	2,48	0,19	Regular	552	1 %	55 119	1 %	C		
H60	Høyre Arm ALS Baby	6,12	2,21	0,36	Regular	576	1 %	48 960	1 %	C		
N1015-D	Leg Skin left	5,17	2,99	0,58	Regular	237	0 %	45 776	1 %	C		
N1013-D	Leg skin right	5,62	3,43	0,61	Unsteady	234	0 %	45 196	1 %	C		
N0953	Foot left core	12,08	4,55	0,38	Regular	348	1 %	43 314	1 %	C		
N0708	Foot Right Core	12,50	5,38	0,43	Regular	348	1 %	43 078	1 %	C		
N0953-M	Foot left core	7,02	3,29	0,47	Regular	333	1 %	42 537	1 %	C		
N1234-D	Bushing left arm	5,08	2,98	0,59	Unsteady	413	1 %	41 193	1 %	C		
N1054-M	Foot skin left	7,02	3,29	0,47	Regular	346	1 %	39 214	1 %	C		
N2107	Cont. fluid flex. 0.25 L	18,38	8,81	0,48	Regular	1115	2 %	39 019	1 %	C		
N1234-M	Bushing left arm	7,02	3,29	0,47	Regular	383	1 %	38 150	1 %	C		
N1252-M	Bushing right arm	7,02	3,29	0,47	Regular	377	1 %	37 553	1 %	C		
N1053-M	Foot Skin Right	7,25	3,50	0,48	Regular	329	1 %	37 287	1 %	C		
N2108	Cont. fluid flex. 0.1 L	18,38	8,81	0,48	Regular	1095	2 %	37 260	1 %	C		
N0708-M	Foot Right Core	7,25	3,50	0,48	Regular	290	1 %	37 045	1 %	C		
N0953-D	Foot left core	5,17	2,99	0,58	Unsteady	261	0 %	33 495	1 %	C		
N0708-D	Foot Right Core	5,23	3,18	0,61	Unsteady	261	0 %	33 495	1 %	C		
N1252-D	Bushing right arm	5,08	2,98	0,59	Unsteady	314	1 %	31 318	1 %	C		
20-11488-D	Armskin R SimMan 3G	3,11	2,46	0,79	Unsteady	160	0,3 %	24 207	0,4 %	C		
H62	Høyre Bein ALS Baby	6,04	2,30	0,38	Regular	205	0,4 %	20 879	0,4 %	C		
20-11489-D	Armskin L SimMan 3G	2,00	1,60	0,80	Unsteady	112	0,2 %	19 528	0,4 %	C		
N1054-D	Foot skin left	5,17	2,99	0,58	Unsteady	63	0,1 %	7 151	0,1 %	C		
N1053-D	Foot Skin Right	5,23	3,18	0,61	Unsteady	58	0,1 %	6 584	0,1 %	C		

Table 16 XYZ & ABC Analysis for all the Kanban candidates

The table presented is divided into two; the first part is the evaluation "XYZ," and you may see the average or mean values, standard deviation, and the variability coefficient. Also, you can see the structure of demand of each one but remember that the parts with sporadic demand have been eliminated by now, so you could see just parts with regular and unsteady demand.

Then we have the second part; Evaluation "ABC." For this part, Stian Wiig (Controller) provided data with the quantity produced for the last 12 months from 25.11.20 to 25.11.21 and the standard cost associated to this production. From this data, the table presents the **quantity of sold items manufactured** for that period, then presented with percentage as the **annual volume sold** for each part. After, the sale value is presented, which is the **extended cost**, and the **annual cost percentage**. With those values, The items were sorted from the frequency of sales at the highest value from highest to lowest, so the items which Laerdal have sold most at the highest value are located on the top and categorized as parts "A," and the items that have sold less are located right down next to parts "A" and classified as parts "B" and the items that have sold least are right on the bottom of the list and they were categorized as parts "C."

The results were that "A" parts represented the 55% of the annual volume, which means a value of 61 % of the total sales for the last 12 months in the roto-molding area. Then we got that "B" parts represented the 27% of the annual volume, representing a value of 22 %, and "C" parts represented the 18% of the annual volume, representing 17 %.

We knew that we were looking for candidates for Kanban, and now we got some! Also, we already know which parts are suitable for a Kanban system regarding demand structure and we can prioritize our efforts of which parts would be the ones needing special attention regarding volume sold, sale value, and frequency of sales. Now we are ready to present a Kanban proposal!

6.3.9 KANBAN PROPOSAL

Kanban as a system that controls the flow of resources will help to re-structure the material control and production planning on the roto-molding area and due to the high mix of products and the different volumes, this system will work perfectly and will increase the efficiency of the material planning process, which is what we were looking!

From the 53 possible candidates for Kanban, It was decided to "Slice the elephant" and just work with the parts in the classification "A," which are 12 parts. Parts that Laerdal has sold the most at the highest value cost. Those are also part of the company's most profitable products: SimMan 3G, SimMan 3G plus, and ResuciBaby. (Figure 18)

"A" Parts

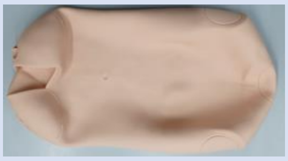
#	Part Number	Description	Image
1	20-11488	Arm Skin R SimMan 3G	
2	20-11489	Armskin L SimMan 3G	
3	N1013	Leg skin right	
4	N1015	Leg Skin left	
5	N0618-D	Torso skin Dark	
6	N0618-M	Torso skin Medium	
7	N0618	Torso skin Light	
8	H61	Right Arm Resusci Baby	
9	H63	Right Leg ResusciBaby	
10	V61	Left Arm Resusci Baby	
11	V63	Left Leg ResusciBaby	
12	N0631	Hand Right	

Table 17 "A" Parts - Candidates for Kanban proposal

6.3.10 IMPLEMENTATION

When Toyota began implementing Kanban, they identified essential principles to utilize this methodology adequately. These principles were followed along with the proposal.

Visualize workflow

The workflow needs to be clear for all the team involved. For that reason, a diagram is presented where we will understand first how the Kanban system will be visualized and put into work in production floor. Let me show you how I picture the Kanban system in the roto-molding area. (Figure 46)

The whole flow will work based on the demand and consumption of the internal customer, which is the Assembly line SimMan3G. This means that the roto-molding area will produce only what the assembly line is consuming. So, the first trigger point that puts to work the whole system is when the assembly line or the client takes (buy) one of the containers or strollers out of the supermarket. The supermarket store finished products ready to be consumed by the client. So, when one of the containers is consumed, they need to signal back to the supplier that they need to replace the product (s) that the clients have just withdrawn. The supplier needs to start planning the production for the consumed parts. They are four different suppliers: Material preparation, Roto molding, sewing, and finishing. All of them need to be informed when the supermarkets need parts. So, all of them received a Kanban production signal but at different times. First, Kanban signals go to the material preparation cell and the roto-molding area where they will start working in parallel. When the material preparation finishes, the raw material is ready to be used, and the molds and machine will be ready to work as well. The parts will be molded and put in a FIFO (First in First Out) area. The following supplier will get the Kanban signal to start production with the parts located in the FIFO (First in First Out) area. Some parts are taken by the sewing cell; others are taken by the finishing cell. When these suppliers are finish, the parts will be moved to the supermarket of finished parts. The goods are replaced again, and the supermarket is ready to serve the client again.

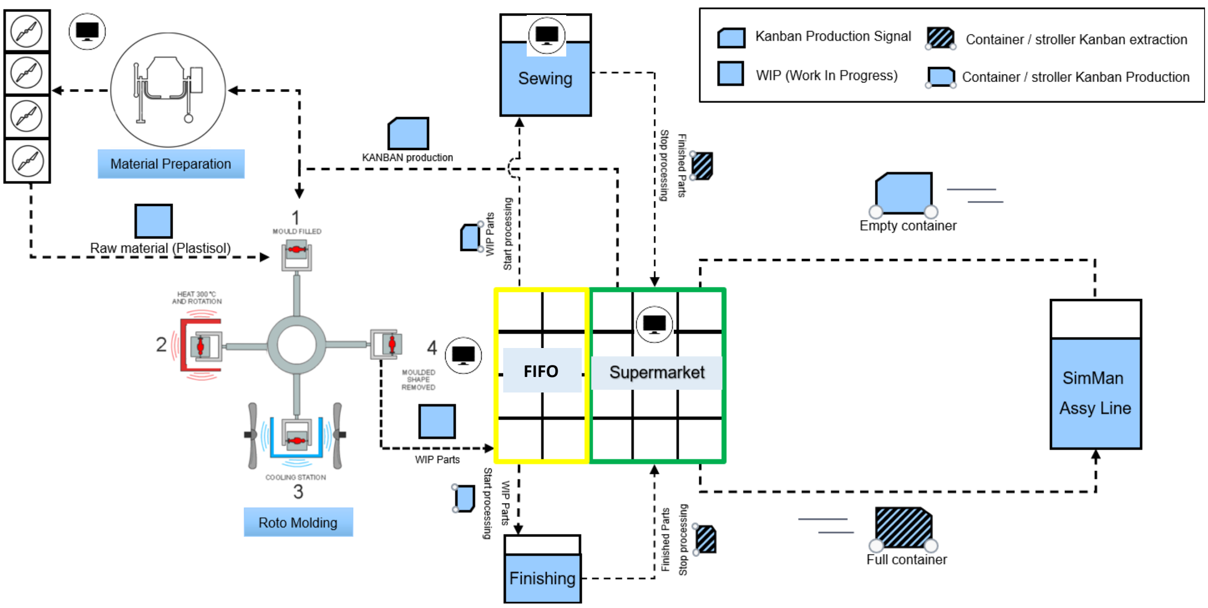


Figure 46 Kanban Proposal Diagram

The system will have digital Kanban cards visualized on the Kanban boards (screens) and physical Kanban "cards" moving from supermarket to FIFO area and backwards. These will be the containers, boxes, strollers, or any package used to move the parts from supermarket to the customer and this will be used as a visual signalization where all the personnel in the area could easily notice when parts are needed or when they need to stop producing.

You have seen how the materials will flow on the Kanban system. Still, we need to see how the personnel will visualize the information flow and understand how the part will be processed through the system.

The flow of information will not be through the classic physical Kanban board. The plan is to digitalize the system. Imagine this with four digital boards (screens) located in strategic points. Please see figure 46, where I marked with this symbol the location of each board (screen). Then follow me with the description of how this digitals boards will work on each location.

The first Kanban board (screen) will be located in the supermarket of finished parts (Figure 47)

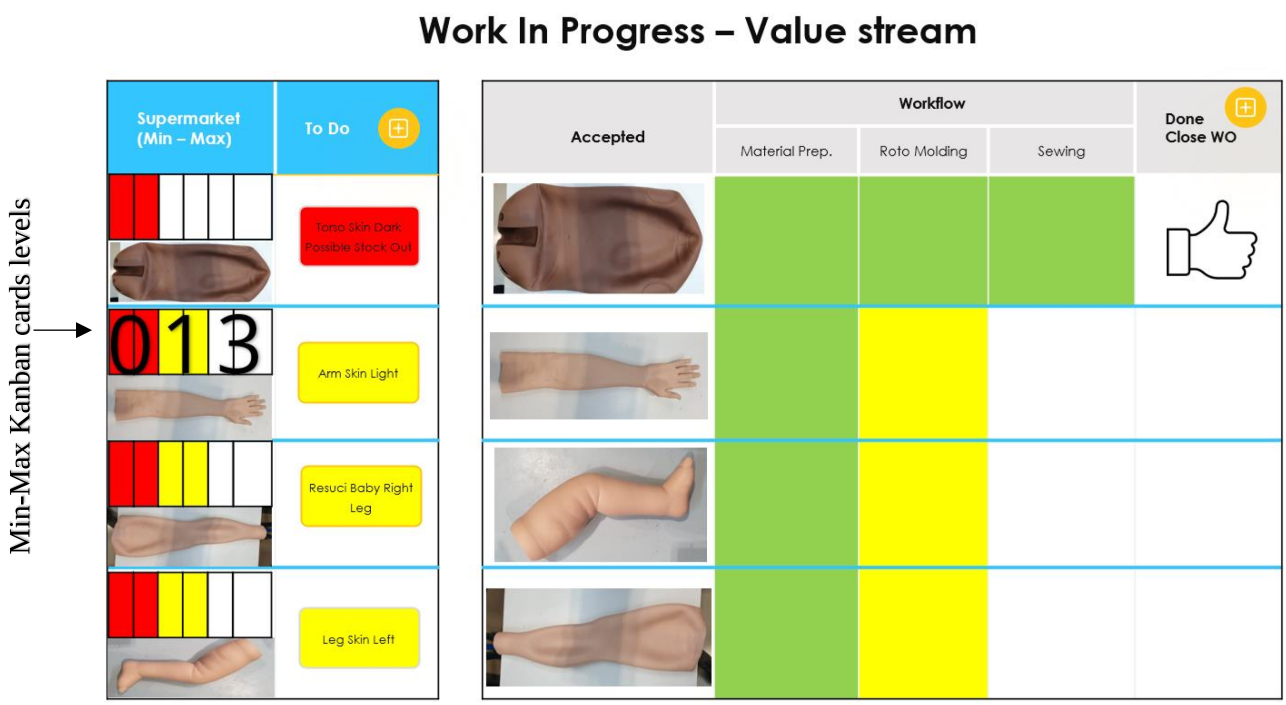


Figure 47 Kanban Board - Value Stream

Work in progress value stream board will be accessible for all the personnel involved in the value stream; Technicians, operators, team leaders, managers could visualize the work in progress for all the different cells.

If we read the board from left to right, we can see the supermarket columns colored in blue. These columns show the image and level of inventory of each manufacturing item in real-time. When the internal customer takes parts out of the supermarket the inventory level will show this using the same logic of a battery level on electronic devices. When the bars are colored in red indicates when the customer just took the last box/Container/ stroller and the roto-molding area need to start planning the production of these parts as soon as possible; then, we have the yellow indicator when the inventory level is at the minimum. Hence, they need to start planning for the production of this item, and finally, we have the green indicator when the inventory is at the maximum level. Hence, production needs to stop producing to avoid overproduction. The min-max levels help to limit the production, and this will be explained later in this analysis. Then, we have the second part of the board, and this is when the job/work is accepted from the supermarket columns. The first supplier, the material preparation cell will get the first digital Kanban card to start production. This part of the board will indicate in real-time how the workflow goes through the different cells until the job is finished, and they could visualize with colors when the job in each cell is done with green and when the job is on-progress with yellow.

The second Kanban board (screen) is located in the material preparation cell (Figure 48)

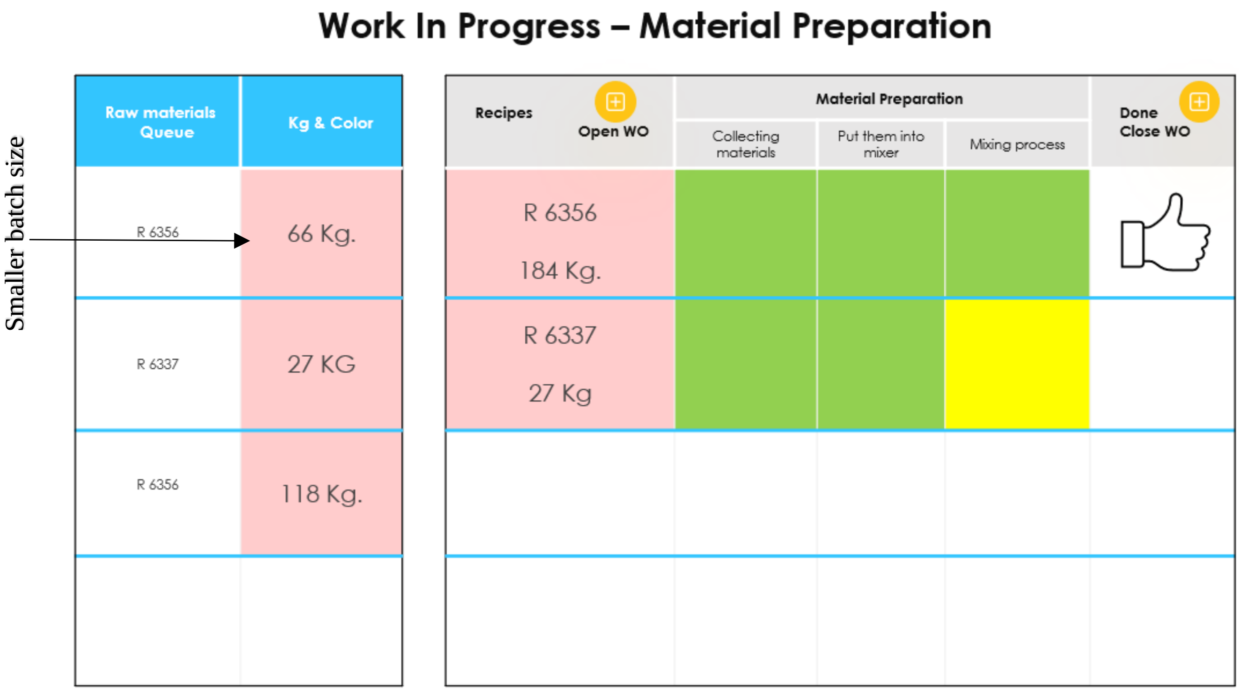


Figure 48 Kanban Board - Material Preparation

The material preparation will receive a digital Kanban card from the supermarket, and they will visualize it on the board: In the first two columns, they can see the list of the orders coming; the material number, the quantity previously calculated in Kg. (I will talk about this later), and the material color. Then, in the second part they accept the job by pressing the “open WO” (Work order) button indicating that the job has started, and they consequently will visualize how the progress of the job is passing through the main steps of the process until finish the job. At the end of the job the work order will be closed by pressing the “Done, Close WO”.

As you may notice in this example, there are three jobs in the list of orders coming, and then they have two on progress. This is because the system will detect when two orders are the same material and color. The system merges the jobs to produce both in the same batch. So, they save machine-time and person-hours. For this case, we have two orders from the R6356 material—one of 74Kg. And the other of 118Kg. The system merges them into one job of 192 Kg.

The job is finished in this cell, and the Kanban signal will pass to the next process cell, The roto-molding area. If you remember before, I mentioned that roto-molding cell and material preparation received the Kanban production signal simultaneously so both areas could start working in parallel. While roto-molding begins with preparing the tools and the changeovers, the material preparation cell would be fixing the raw materials.

Roto molding will receive the signal from material preparations of which materials are ready to use, and they will visualize them on a third board (Figure 49). The third Kanban board (screen) is located in the roto-molding cell

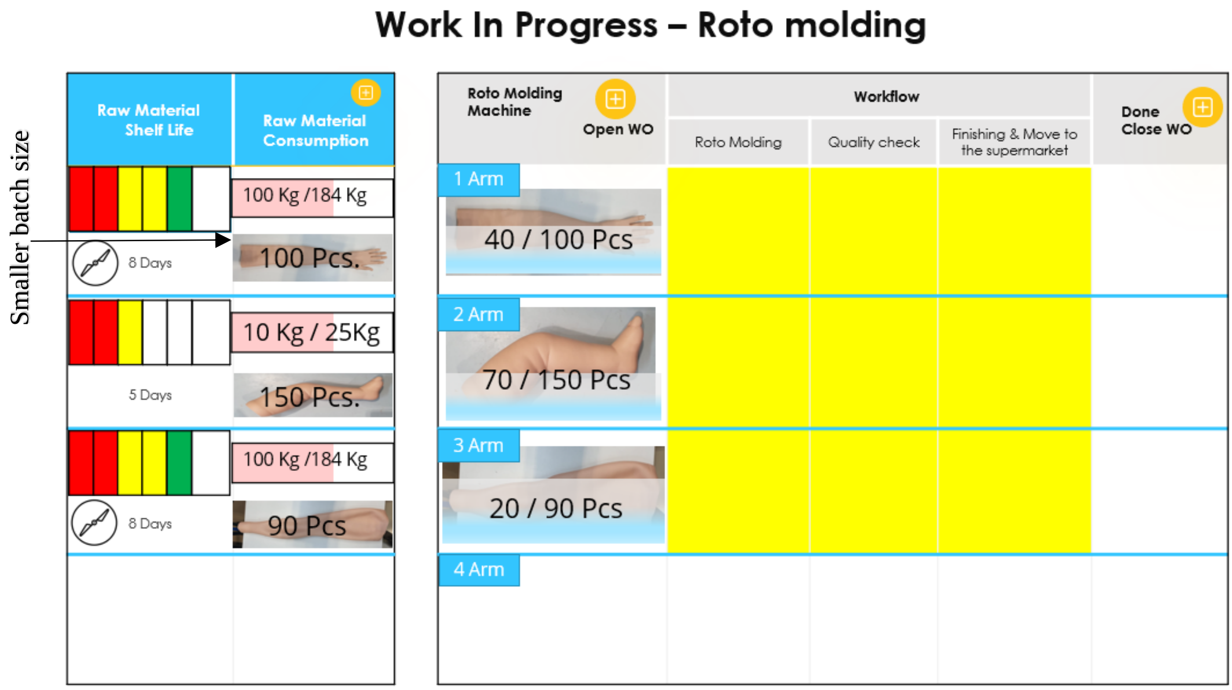


Figure 49 Kanban board - Roto-Molding

In the first blue column, the technicians will visualize the raw materials coming and ready to use. Also, they will see the shelf life of each material and if they are using moving blades to increase the shelf life by 1-2 days; This is a critical aspect for the roto-molding process to always be sure of using fresh material and to avoid throw away material out of date. The second blue column will visualize a real-time bar to see how consumed the material batch is. Also, they could see the image of the part required and the quantity required. The operators will choose how many products will be set in the machine and the desired combination of products from this list. This could depend on two aspects:

- **The machine capacity** for the shift. For example. The machine has four arms in total, and they usually work with three because the operators are not sufficient to use total machine capacity.
- **Technical aspects** are involved. Most of the products can run at the same cycle machine due to the similar processability (Heating and cooling parameters). But some could not run together with some parts. This must be considered when choosing which product to produce in each machine's arm.

In the second part of the board, the products have been selected for each arm; in this case, we use three arms of the machine, which is the typical scenario. As they select each product, they automatically open a work order. They will visualize the image of each product running in each arm, with the work progress of molded parts. Also, will see how the parts pass-through the molding process, quality checks and the finishing (cleaning and punching holes). After they finish, they can mark the job as done and close the work order.

Some molded parts will be moved to the supermarket area as finished parts, some others need to pass through a third process cell: The Sewing process. So, the parts will be placed on a FIFO (First In First Out) area. When roto-molding closes the work order, the sewing cell will visualize it on their board.

The third Kanban board (screen) is located in the sewing cell (Figure 50)

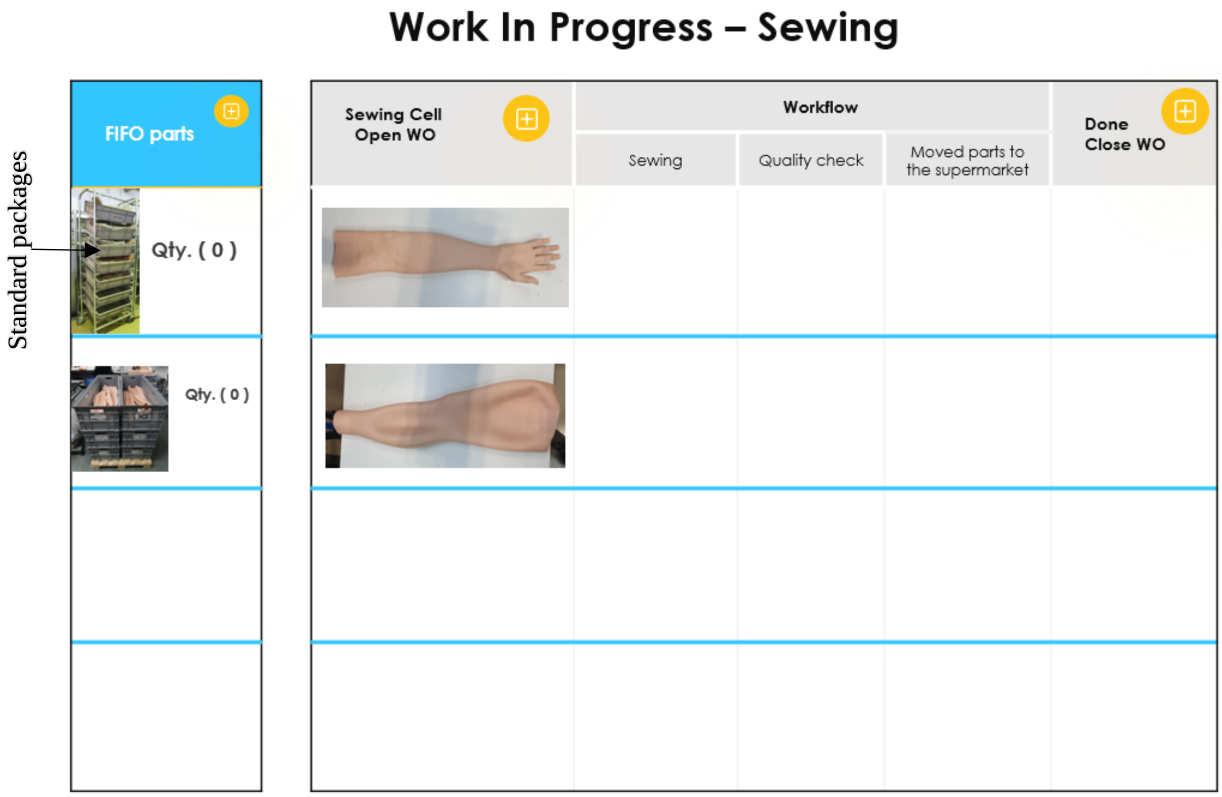


Figure 50 Kanban board - Sewing Process

Kanban production signal will pass to the sewing cell board. This will first show when FIFO (Firs In First Out) parts are ready to be sewed and the quantity of each piece with an image of the Kanban stroller, box or container used. When the parts are moved to the cell, they start a work order. The work in progress will be visualized through three different steps: sewing, quality check, and when the parts are moved to the supermarket of finished parts. After that, the work order is closed, and the job is done.

How nice, intuitive Kanban boards can be. Useful tools to visualize the whole panorama on a process, helping to improve our visibility in the operations and making it easier to detect areas of improvement as for example, bottlenecks.

But let us continue with other principle of Kanban, which will help finish the proposal of implementing a Kanban system.

This is to limit work in progress (WIP)

As you may noticed, the Kanban boards presented already had limits on work in progress. Why do we need those “limits”? A simple phrase explains the primary idea of “limits”; Stop starting, start finishing**.** This means we should finish the job already in progress before starting a new one. How? As limiting WIP (work in progress) and forcing the team to focus on smaller jobs which makes it easier to take the work to the finish line.

Let us take an example from the Kanban boards I showed you, and I would like to explain how the limits were set. Please, focus your attention on the **Arm Skin Right – Sim Man3G** located in the Kanban boards figures 43 – 46 so you can follow the explanation

A Kanban card is a signal that moves from one cell to another and indicates when to build more of a component for production. This usually comes with a bin, box, or the container you use to store the parts. So, when this container is empty, this needs to travel with a Kanban card to the suppliers that will refill the container with new parts. You probably had read this before in the theory part when I talked about the Kanban system.

Kanban cards will help us to limit the work in progress. Setting minimum and maximum on Kanban cards will limit our production, so we will just produce what the customer needs. So, first, we need to know how many parts we need in the first place—the current demand we have for the part.

The demand has changed for most of the products in the roto-molding area due to the introduction of the newest products. Please see the following table. (Table 19)

Part Number	Description	Picture		Yearly Demand (Pieces)	Takt Time (Hours)	Average Demand (Pcs. Per Day)	Lot Size (Pieces)
20-11488	Arm Skin R SimMan 3G		Demand (June-21)	1800	2	7,1	200
			Demand (Nov-21)	1320	2,8	5,3	100

Table 18 Demand (June-21) (Nov-21)

All the data was based on MRP (QAD): Historical data from Stavanger Plant: Jun-21 through Nov-21

Forecast data from Stavanger Plant: Dec-21 thought May-22

The table shows how the demand has changed by the time (Period of 6 months – Jun 21 to Nov 21) and consequently the customer takt time and lot size too. The white row shows a yearly demand of 1800 pieces, which give us a takt time of 2 hours, average demand per day of 7,1 and a lot size of 200 pieces. Those values were out of date, and we noticed it when it was decided to update these values according to the current demand and the values gotten were different. Current demand values are shown in the green row. The updated demand came from MRP provided data the updated yearly demand was of 1320/year, then customer's takt time was calculated. ((248 available working days * 15 available working hours per day) / 1320 Yearly demand) The result was 2.8 hours for this item, or average demand per day of 5,3 pieces (Available working hours per day 15 / 2.8 Takt time). As comparing the results there were significant difference between values (Table 19), so it was important to recalculate the different variables involved before introducing a Kanban system. The yearly demand decreases, and subsequently, takt time was reduced as well, and this also relies on changes in the lot size for production. It was proposed a new lot size based on MRP (QAD) data. This part is currently working with a lot size of 200 pieces. A deep dive into the historical of the MRP data for the rotation molding products shows the work orders have been done since the launch of the newest SimMan (from Jun-21 to Nov-21), and it was found that they have never produced a 200-lot size due to the decrease on the demand. They have produced an average of 100 pieces lot size —50% less of what they set some years ago. **For this reason, it was decided to use 100 pieces for a lot size**.

As you can see, it was already set some limits based on the current customer demand. For example, smaller lot size. Perfect for a pull system (Kanban) for being customizable. Now, before setting the limits for the system. we need to know the Kanban size.

Kanban size is simply, the number of items in each Kanban card. This card will be replenished only when it is empty. For this case our Kanban are the containers or strollers where the parts will be store and move though the system. Normally, a manufacturing plant produce in lots so, the number of items should be a multiple of the lot size.

Roto-molding currently use two different packages. They use boxes for WIP (work in progress) parts (8 pcs) and strollers for sewed and finished parts (56 pcs). The idea is to standardize the package by using just strollers for all the value stream of 50 pieces, where manufacturing can deliver batches of 100 pieces divided into two Kanban (strollers). (Figure 51)

Our Kanban size was set now: 50 pieces per Kanban (stroller).

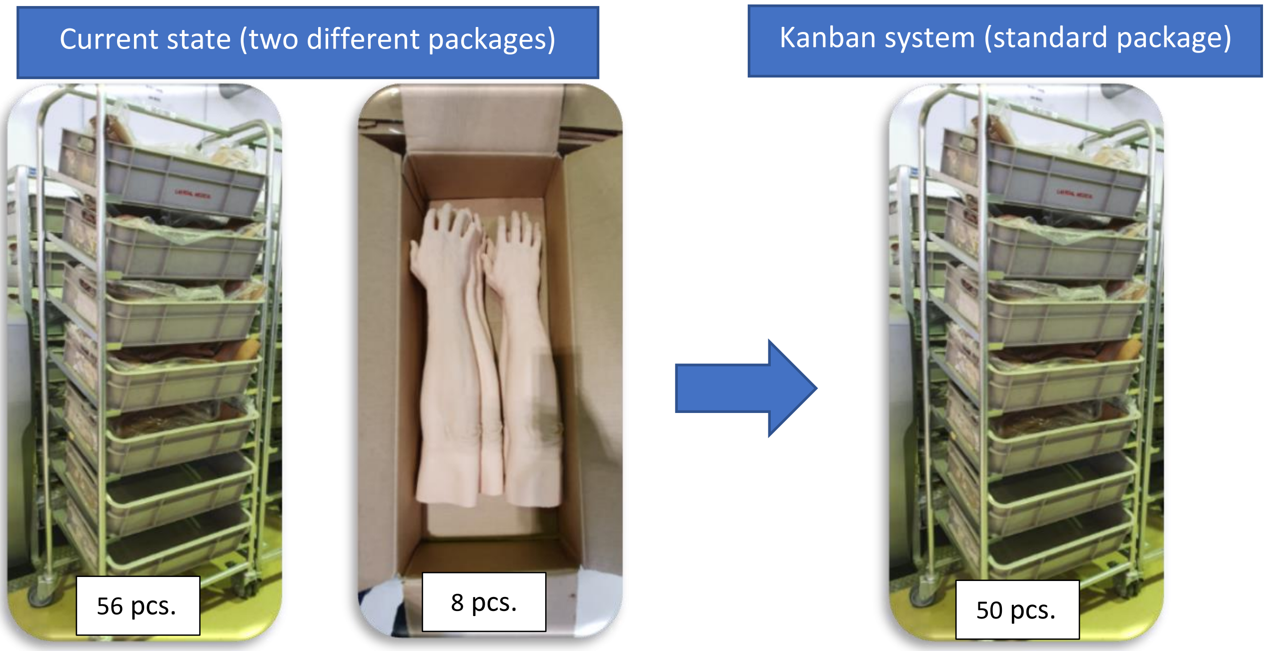


Figure 51 Packages and quantities

The quantity of parts per Kanban was already set and now the limits or constraints to implement on the Kanban boards can be set. This means to determine how many Kanban cards are needed to put into work the system and fulfill the customer demand. This was calculated with the following formula to determine minimum amount of Kanban cards:

$$N = (D * LT + SS)/Q$$

Where:

N= Is the number of Kanban cards

D= Demand in time unit chosen

LT= Lead time

SS= Safety stock in quantity

Q= Is the quantity of parts per Kanban (Kanban size)

Demand is: 5,3 pieces per day. (Available working hours per day 15 / 2.8 Takt time), Lead time: According to MRP(QAD) historical data, the time in between a work order is placed, released, and closed is **10 days of Lead time**. **Safety stock: is 55 pieces** (10 safety days needed * 5,3 Average demand pcs per day) and **Kanban size: 50 pieces** (previously explained).

$$N = (5.3 * 10 + 55)/50$$

$$N = 2.1\ Kanban\ cards$$

Our Kanban board will distribute the Kanban signals thought the different boards though the system and the first signal to be distributed is the one triggers to start the production. There is not a mandatory way to implement WIP limits, although a general rule is that they should be slightly constraining. For this proposal WIP (work in progress limits) are presented on the work in progress Kanban board located in the supermarket area (Figure 47) when the lower limit in red indicates when the customer withdraws the last Kanban (stroller). The yellow color indicates the minimum Kanban level based on the safety stock which 50 pieces 1 Kanban and indicates that production has ten days (lead time) of buffer to deliver parts and avoid stock out. Production will be triggered to start planning the production for the next batch (100 pcs). When the parts are finished and the parts in the supermarket are not consumed yet, the maximum level will be reached. In this case 3 strollers (3 Kanban cards). (Max-Kanban cards = Min-Kanban 1 + 2 Kanban cards needed to store a batch). And this indicates that they need to stop producing that part. (Figure 52).

Figure 52 Min-Max Kanban

And this is how limits are presented and visualized on the Kanban boards presented before. The Kanban signal start-stop production will be limited by the minimum and maximum numbers. All the processes involved needs to follow these limits when start producing. For example, when the Kanban level is at minimum the system will start production with a 100 pieces batch, subsequently material preparation cell needs to adjust a mix of raw material (PVC) specifically for this 100-piece batch.

It was calculated how much raw material would need to produce for this batch with the product of weight of the piece with the number of parts per batch plus 10% of scrap. The result was 66 kg raw material for 100 pieces batch (0,6 Kg. per one piece * 100 batch size +10 % of possible scrap). (Figure 48). This could be a big cost reduction for the company as now the batch size for this part is around 200 kg (67% more of what they need).

For the following processes they will limit their production with 100 pieces batch. Roto-molding will produce 100 parts divided in 2 Kanban (strollers) and send them to a FIFO (first In First Out) line where sewing and finishing (punching holes and flashing) can work with the parts in an organized way. They will visualize the queue for the items coming and process what comes first.

You have seen how the WIP limits were set for the Kanban system for one part. And the analysis was for all the "A" parts, so you can find the table with the results of all parts analyzed. The methodology explained and logic used was the same for all parts (The table is presented in the Appendix B).

6.3.11 SUMMARIZE

The system has been defined, visualized, and limited on work in progress (WIP). “Managing” and “Improving” (essential principles for Kanban) will come by the time. Kanban boards will highlight the various stages on the workflow and the status of each cell. A smooth flow could be detected or the other way around. A potential bottle necks which holding up the flow. Since the system will be new the initial levels may not accurate represent what exactly your system needs so, managing and improving helps to follow closely the WIP levels to make these little adjustments and derive what limit works best for the system and improve the flow. As follow these principles and practices, Kanban will successfully be implemented.

CHAPTER 7 VALIDATION

Do not feel absolutely certain of anything.- Bertrand Russel

This thesis uses the methodology of “action-based research,” which involves the mental model process of “triangulation”; This process looks to increase the validity of the information by gathering information from two or more sources.

I was on the site (Laerdal Stavanger Plant) during my thesis work (August 21 -January 22). During this period, I used quantitative and qualitative methods to gather data from different sources with the help of Laerdal employees from other areas depending on my necessities. You could find them along the analysis section where I started getting observation reports. This was a continuous process performed by the team or me directly on the production floor several times. The observations reports were in the form of Photos, tables descriptions, or brainstorming exercises and were an adequate description of the reality. Surveys and interviews were developed and performed by experienced people in their areas were analyzed. The reports were supported by the expertise of the interviewers and presented as it or used to construct Lean manufacturing exercises (Fishbone diagram, 5 Why’s, FMEA). Finally, data were collected from different sources provided by authorized Laerdal employees capable and experienced in their field. The data collected was Laerdal’s Internal documentation (Quality link, Docu share, and Agile), achievement data from MRP (Material Requirements Planning) (QAD), and experienced assessors from different departments willing to help and provide data when was needed.

I would say Laerdal can rely on this master thesis work as all the data collection was validated and supported by the company while the analysis was ongoing. However, there is something Laerdal need to validate for further work. And this is explained here:

For this master thesis, I took as a “fact” That the material batch can be reduced. (Page 75)

With the mixer machine that Laerdal has now is not possible to mix smaller batches, and there is no historical evidence that they have been producing smaller batches in the past. For the moment, the mixer machine can make batches from 144 to 204 kg. This is currently a limitation for the Kanban system to work properly as we want to reduce batch sizes. However, this was not technically proved, so this topic is under investigation with the material specialist's team to determine and come with a solution to somehow reduce the material batch size.

CHAPTER 8 CONCLUSIONS

"If you always do what you always did, you will always get what you have always got." -Henry Ford

Why did Laerdal agreed to have me to work on this subject as my master thesis? One big reason is because they noticed that there was an opportunity for process improvement. They probably realized that if they keep repeating the same procedures in the roto-molding area, they will not get any better results than what they have had. The term "Lean Manufacturing" has been around for many years and today it is still one of the most significant buzz words in the manufacturing industry. Companies around the world are becoming more productive, reducing their waste, and improving their efficiency at an accelerated pace.

The main subject of this thesis is "Lean manufacturing. A practical use in Molding area" and I can confidently say the results obtained are satisfactory! With the use of "Lean Manufacturing" glasses, the process in the roto-molding area was analyzed then aided by value stream mapping in order to first to understand how the information and material flow and then to be able to identify areas of improvement (Kaizen points or seven wastes).

Based on a value stream mapping workshop with several "Gemba walks," pictures, interviews to production personnel, and stop watching times, we got to know how exactly the roto-molding process was being executed daily, every detail from A to Z. With this understanding, we were able to identify Kaizen points. There were many of them to be addressed, so we (The value stream team) took on the task to filter and identify the most attractive ones to the company, the ones with the most potential to increase efficiency and optimize resources in the area. These data were synthetized into 2 hypotheses, which were validated through the analysis and the scientific method.

Hypothesis number one:

H_a: A more efficient work orders process method could help eliminate waste of time from production and production planning management.

It was validated against experimental data (times stopwatch directly from the production floor), interviews, MRP updated data provided by Laerdal, and practical work (tests, analysis, and pictures) on the production floor. The results were:

- After doing Gemba walks and deep dive into this process. It was proven that the process was time consuming for production and production management with facts, and the operators and team leaders supported it with their statements on interviews. More than ten different areas and ten processes were tested with other operators doing the same process, and Just 19 % of the total work orders made by the Stavanger plant in one year were considered; this validates how Laerdal has a significant area of improvement (waste of time) with massive impact if we could consider the 100 %.

- A root cause was found using lean manufacturing tools exercises, brainstormed ideas alongside some experienced people in the area (Team leader, operation personnel). It was validated that the leading cause of waste of time in the work orders process came from a lack of efficiency in the method. A total of seven different reasons were brainstormed and assessed from five different categories.

Conclusion: Finally, we got the answer to the hypothesis clear. After my analysis of the compiled data, two main vulnerabilities were found.

The first one is questioning, why Laerdal's methodology introduces the work order release by an extra person? It was found that there is no written requirement where the clauses ask for an extra person who must authorize release of distribution. Moreover, this method is proven time-consuming, does not follow a lean environment, and does not add value to the process (according to an FMEA exercise). This proposition was validated with facts (tests) using 40 samples from 10 different areas in the building; concluding that most of the time wasted was those days waiting for an extra person to release a work order, plus the time used to make the final release stopwatches from different samples. Which was proved to be on average 50 % of the total work order cycle time

The second vulnerability found through analysis was found at the material preparation process. Here, I was able to identify and prove that the viscosity test that was performed as part of this process was a waste of time for the process of 6 minutes per order. After discussions and deep dive, it was demonstrated with experimental data, interviews with the material preparation expert team, and lean tool exercises as a non-value activity for the process. It was concluded that there is no need to keep track of the viscosity of the material, so management decided to stop recording this data and to update all relevant documents (work orders) and processes accordingly.

It can be concluded that the work order method could be more efficient if they would eliminate these non-value activities found, first the need for an extra person for a final release and secondly the viscosity test performed for material preparation. By introducing these changes, we concluded that for 5,664 work orders made (which are 19 % of all manufacturing work orders made by Stavanger plan in one year), Laerdal could increase the efficiency from production and production planning management with the following parameters:

- Reducing waste of time of 425 hours per year, which is the time used on doing the final release for the evaluated parts mentioned.
- From 5,664, work orders placed. On 3,001 (53%), there could be save days of "waiting time". On 1,529 (27%) there could be save minutes of "waiting time," and on 1,134 (20 %), there could be save hours of "waiting time" (Time used to wait for the second person needed to do the work order release).
- According to MRP data (Sep 2020 to Aug 2021), 413 work orders were made for material preparation in one year. Laerdal could eliminate waste of time by 2,478 minutes with the elimination of viscosity test.

As I mentioned, this analysis was made using data from just 19% of work orders placed, and just for the Stavanger plant. We can just extrapolate these data to picture how significant the impact could be if we were to consider 100% of work orders made for Laerdal worldwide.

Moving on to the second hypothesis:

H_a: Our current Production planning process is cumbersome, has too many trigger points, and requires frequent changes; We can improve this process by limiting trigger points and streamlining the current production planning process.

It was validated against interviews, MRP updated data provided by Laerdal, researched literature, articles, and practical work (tests, analysis, and pictures) on the production floor. The results were:

- Based on interviews and brainstorming exercises with the department manager, we detected the pains during the production planning. It was proved that the process tends to be cumbersome and time-consuming, using a minimum 2 hours per week. It was seen the use of too many trigger points for the planning. At least five different lines. He gets urgent changes on the production at least once per week that generate a replanning process (30 minutes each change). Also, it was seen that the production floor communication could be improved to provide better internal communication. The Communication line between department managers to the production floor is done by informal channels such as post-its, text messages, or calls. With no chance to keep record on what has been planned or to keep real-time communication 2-way effective communication.
- A Root cause was validated with a brainstorming exercise and a fishbone diagram using the "5 whys" methodology. It was found six possible causes between four categories, and based on experience, research, and data analyzed, three of them were labeled as the top causes:
  - Too many trigger points were involved.
  - Parts are physically located in different areas, causing the inventory MRP system mismatch, and slowing down the planning process.
  - Red List limits (min and max) based on the MRP system have not been updated in the last five years, and the MRP system could does not have the capacity to see into the future. So, it needs to be updated every day. This causes the planning to be time-consuming; when it's time to update the red list, a second list needs to be updated as well. Also, if the red list suddenly shows an urgent part, it will probably need a replanning on production.

  These reasons prove to make the planning process cumbersome, time-consuming and contribute to different degrees to the problem.

Conclusion: Based on literature, articles, and research, the Kanban system can reduce or eliminate the workload on production planning, and it was defined as the potential solution to increase the efficiency of the process. The following diagram shows it. (Figure 53)

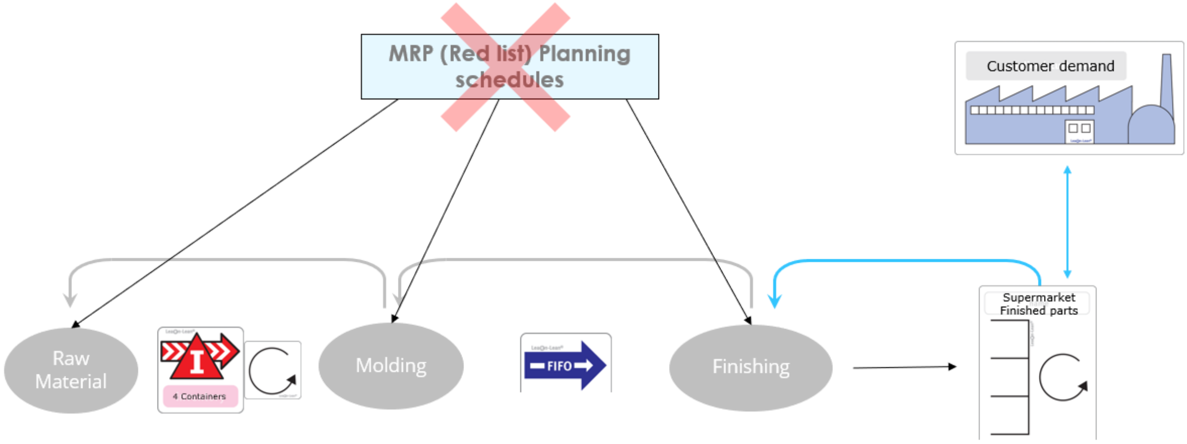


Figure 53 Future State - Production Planning

On the future state, MRP planning schedules (Based on the red list) are eliminated for 53 roto-molding parts, which are 78% percent of all the roto-molding parts running in the Stavanger plant. All parts were evaluated and sorted to get Kanban candidates, and this was validated with an ABC /XYZ matrix analysis supported by MRP historic and forecast data given by Laerdal. The Kanban proposal was run for just the "A" parts category (12 products) to shorten the analysis. Still, the methodology used could be applied to calculate the rest of the products.

According to an interview with the plan manager. He usually spends two hours weekly planning the production and 30 minutes replanning urgent parts, which happens four times per week. We can say that in a year (52 weeks), Laerdal has spent 208 hours on planning the production (2 hours planning + (30 minutes * 4 changes per week due to urgent parts) * 52 weeks).

I can conclude that Laerdal can increase the efficiency and eliminate waste of time in production and production planning management planning by imitating trigger points with the implementation of a Kanban system for most of the roto-molding parts. Referring to the diagram again, it can be noticed how the future state gives the roto-molding area a promising pull system, where the production would be trigger by real-time customer demand. The product used in each process material is drawn from previous Kanban signals. This is how Kanban could reduce or eliminate the material planning and be replaced by an automated replenishment system (Kanban)

Moreover, this system could bring much more benefits, such as minimizing WIP and finish parts stocks, short delivery times, preventing overproduction, better reaction times (more flexibility), and production without constantly changing priorities (one of the pain points in roto molding planning).

Is Laerdal ready for Kanban? I'm sure they are!

Further work

Time was my only limitation that prevented me to further develop on this lean manufacturing project (Master thesis). When we talk about continuous improvements projects, there are never-ending opportunities since there is always something that can be improved. I could have talked and reviewed many other kaizen points that we found during the value stream map instead I want to summarize the following points as the next steps I will follow to extend my work:

- The lack of digitalization in the area was an important aspect to address separately. Deep dive into the possibilities to integrate MRP with an app platform to develop a digital Kanban and work order system.
- Deep dive in a possibility to increase the efficiency on the roto-molding cell by moving from two shifts to one shift model by identifying and eliminating possible wastes (seven wastes)
- Deep dive on the possibility to introduce problem-solving methodologies, real-time scrap, detailed failure data capturing, and reassess approval criteria on the scrap.
- Deep dive on a possibility to introduce SMED (Single minute exchange of dies) on molding area to reduce lead times.

The analysis was done and validated with different hypotheses. Lean is focused on continuous improvements of the company's processes and becoming as efficient as possible. I believe that when the methods and concepts are applied and implemented correctly Laerdal will become much more competitive and significantly increase its profits. I know that the application could be challenging for Laerdal, and sometimes seeing that journey through the end can be a major challenge, but I'm sure that it will be worth it in the future!

List of References

(2022). Retrieved 8 January 2022, from https://answerstoall.com/miscellaneous/what-years-was-the-ford-model-a-produced/.

6 Best Safety Stock Formulas On Excel | AbcSupplyChain. AbcSupplyChain. (2022). Retrieved 8 January 2022, from https://abcsupplychain.com/safety-stock-formula-calculation/.

7 Types of Waste in Lean Manufacturing. Planettogether.com. (2022). Retrieved 10 January 2022, from https://www.planettogether.com/blog/seven-types-of-waste-in-lean-manufacturing.

A Brief History of Lean - Lean Enterprise Institute. Lean Enterprise Institute. (2022). Retrieved 8 January 2022, from https://www.lean.org/explore-lean/a-brief-history-of-lean/.

A Shared Goal - One Million Lives. One Million Lives. (2022). Retrieved 8 January 2022, from https://one-million-lives.azurewebsites.net/a-shared-goal/.

Bozdag, E., Asan, U., Soyer, A., & Serdarasan, S. (2015). Risk prioritization in Failure Mode and Effects Analysis using interval type-2 fuzzy sets. Expert Systems with Applications, 42(8), 4000–4015. https://doi.org/10.1016/j.eswa.2015.01.015

Cambridge.org. (2022). Retrieved 8 January 2022, from https://www.cambridge.org/core/services/aop-cambridge-core/content/view/S1049023X00043569.

Chapter 3 Research methods Continuing research. (n.d.). https://base.socioeco.org/docs/research_methods.pdf

Cimorelli, S. (2017). *KANBAN FOR THE SUPPLY CHAIN : fundamental practices for manufacturing management, second edition. Pages 1-12 , 23-24*

Cms.gov. (2022). Retrieved 8 January 2022, from https://www.cms.gov/medicare/provider-enrollment-and-certification/qapi/downloads/fishbonerevised.pdf.

Consultant, H. (2022). *LEAN – c4g.in*. C4g.in. Retrieved 8 January 2022, from https://www.c4g.in/process-optimization-through-lean/.

Dockrill, P. (2022). *How a Dead Girl in Paris Ended Up With The Most-Kissed Lips in History*. ScienceAlert. Retrieved 8 January 2022, from https://www.sciencealert.com/how-dead-girl-paris-ended-up-most-kissed-lips-in-history-l-inconnue-de-la-seine-resusci-anne-cpr-annie-death-mask.

Doggett, A. M. (2005). Root cause analysis: a framework for tool selection. The Quality Management Journal, 12(4), 34.

Duggan, K. J. (2017). Creating mixed model value streams: practical lean techniques for building to demand. Productivity Press. Pages 13-11, 45-50

Edouard ThieuleuxFounder of AbcSupplyChain | Supply Chain Expert | 15 years experience in 6 different countries –> Follow me on LinkedIn. (2021, October 11). ABC XYZ analyzes to optimize your inventory. AbcSupplyChain. Retrieved January 8, 2022, from https://abcsupplychain.com/abc-xyz-analyse/

Hessing, T. (2022). *History of Lean*. Six Sigma Study Guide. Retrieved 8 January 2022, from https://sixsigmastudyguide.com/history-of-lean/.

How Many Kanbans – The Kanban Formula, Part 1 | AllAboutLean.com. (2014, May 4). https://www.allaboutlean.com/kanban-formula-part1/

Jacobs, S. D. (2018). A History and Analysis of the Evolution of Action and Participatory Action Research. The Canadian Journal of Action Research, 19(3), 34–52. https://doi.org/10.33524/cjar.v19i3.412

Kanban Software for Agile Project Management. (n.d.). *Gemba Walk: Where the Real Work Happens*. [online] Available at: https://kanbanize.com/lean-management/improvement/gemba-walk.

Laerdal History. Laerdal.com. (2022). Retrieved 8 January 2022, from https://laerdal.com/gb/docid/1117121/Laerdal-History.

lean. Dictionary.cambridge.org. (2022). Retrieved 8 January 2022, from https://dictionary.cambridge.org/dictionary/english/lean.

Original Resusci Anne. Warehouse 13 Artifact Database Wiki. (2022). Retrieved 8 January 2022, from https://warehouse-13-artifact-database.fandom.com/wiki/Original_Resusci_Anne.

Pearson, S. (2017, October 31). *Value Stream Mapping: Definition, Steps, and...* Tallyfy; Tallyfy. https://tallyfy.com/value-stream-mapping/

Planview. (n.d.). *Why We Need WIP Limits*. [online] Available at: https://www.planview.com/resources/articles/wip-limits/.

Rother, M., & Harris, R. (2001). Creating continuous flow: an action guide for managers, engineers and production associates. Lean Enterprise Institute. Pages 1-16

Scientific Management: Taylor and the Gilbreths. Kolibri.teacherinabox.org.au. (2022). Retrieved 8 January 2022, from http://kolibri.teacherinabox.org.au/modules/en-boundless/www.boundless.com/management/textbooks/boundless-management-textbook/organizational-theory-3/classical-perspectives-29/scientific-management-taylor-and-the-gilbreths-165-4019/index.html.

Seven Steps for Effective Problem Solving in the Workplace. Mediate.com. (2022). Retrieved 8 January 2022, from https://www.mediate.com/articles/thicks.cfm.

SimMan 3G PLUS - Immersive training for emergency care procedures. Laerdal Medical. (2021). Retrieved December 26, 2021, from https://laerdal.com/gb/products/simulation-training/emergency-care-trauma/simman-3g/.

Sinocchi, M. (1970, January 1). The best candidates for a kanban system? The Best Candidates for a Kanban System? Retrieved January 8, 2022, from https://leaninsider.blogspot.com/2013/02/the-best-candidates-for-kanban-system.html

The Four Principles of Kanban. Planettogether.com. (2022). Retrieved 8 January 2022, from https://www.planettogether.com/blog/the-four-principles-of-kanban.

The Future of Manufacturing: 2020 and Beyond IndustryWeek Special Research Report. (n.d.). https://www.nist.gov/system/files/documents/2016/11/16/iw_kronos_research_report_2016.pdf

Tony. (n.d.). Using Kanban to Calculate Your JIT Bin Quantities. ToughNickel. Retrieved January 21, 2022, from https://toughnickel.com/industries/Kanban-Calculation

Understanding the Five Whys. (n.d.). Creative Safety Supply. https://www.creativesafetysupply.com/articles/understanding-the-five-whys/

What is FMEA and what is it used for? • Infraspeak Blog. (2020, October 23). Infraspeak Blog. https://blog.infraspeak.com/what-is-fmea/

Claudia Y. Burgoa Quotes | BukRate. (n.d.). Bukrate.com. Retrieved January 22, 2022, from https://bukrate.com/author/claudia-y-burgoa-quotes

Produkte - Learn-Lean | Spezialisten für Wertstrom- und Produktionsplanung. (n.d.). Www.learn-Lean.de. Retrieved January 22, 2022, from https://www.learn-lean.de/de/produkte.html

International Organization for Standardization. (2015). Release of products and services (ISO Standard No. ***9001:2015****). In clause 8, Operations. Section 08.06*

CFR (Code of Federal Regulation). (2020). *Food and drugs, Chapter 1 Food and drug administration, department of health and human services, Subchapter H - MEDICAL DEVICES (Volume 8, Revised as of April 1, 2020, CITE 21CFR820)*

A Liberal Deacalogue by Bertrand Russell. (n.d.). Www.rjgeib.com. Retrieved January 22, 2022, from https://www.rjgeib.com/thoughts/russell/russell17.html

A quote by Henry Ford. (2019). Goodreads.com. https://www.goodreads.com/quotes/904186-if-you-always-do-what-you-ve-always-done-you-ll-always

List of Appendices

Appendix A

Failure Mode and Effect Analysis (FMEA) Criteria

In this appendix the criteria used to develop FMEA (Failure Mode Effect Analysis) is presented for:

- **Figure 54 FMEA (Not detailed) (Failure Mode and Effect Analysis) - Page. 51**
- **Figure 55 FMEA - Viscosity Test (Failure Mode and Effect Analysis)- Page. 56**

Source: *Bozdag, E., Asan, U., Soyer, A., & Serdarasan, S. (2015). Risk prioritization in Failure Mode and Effects Analysis using interval*

Severity scale		
Rating	Effect	Severity of effect
10	Hazardous without warning	Very high severity ranking when a potential FM effects safe system operation without warning
9	Hazardous with warning	Very high severity ranking when a potential FM effects safe system operation with warning
8	Very high	System inoperable with destructive failure without compromising safety
7	High	System inoperable with equipment damage
6	Moderate	System inoperable with minor damage
5	Low	System inoperable without damage
4	Very low	System operable with significant degradation of performance
3	Minor	System operable with some degradation of performance
2	Very minor	System operable with minimal interference
1	None	No effect

Probability of occurrence scale		
Rating	Probability of occurrence	Failure probability
10	Extremely high: failure is almost inevitable	>1 in 2
9	Very high	1 in 3
8	Repeated failures	1 in 8
7	High	1 in 20
6	Moderately high	1 in 80
5	Moderate	1 in 400
4	Relatively low	1 in 2000
3	Low	1 in 15,000
2	Remote	1 in 150,000
1	Nearly impossible	<1 in 1,500,000

detection scale		
Rating	Detection	Likelihood of detection
10	Absolute uncertainty	Potential cause/mechanism and subsequent FM cannot be detected
9	Very remote	Very remote chance of detecting potential cause/mechanism and subsequent FM
8	Remote	Remote chance of detecting potential cause/mechanism and subsequent FM
7	Very low	Very low chance of detecting potential cause/mechanism and subsequent FM
6	Low	Low chance of detecting potential cause/mechanism and subsequent FM
5	Moderate	Moderate chance of detecting potential cause/mechanism and subsequent FM
4	Moderately high	Moderately high chance of detecting potential cause/mechanism and subsequent FM
3	High	High chance of detecting potential cause/mechanism and subsequent FM
2	Very high	Very high chance of detecting potential cause/mechanism and subsequent FM
1	Almost certain	Potential cause/mechanism and subsequent FM will be detected

The Risk Priority Number (RPN) is the product of the Severity (1-10) and the Occurrence (1-10) ranking.) RPN = (S)× (O)

Appendix B

Kanban proposal for "A" Parts

Table B.1 In this appendix the "A" parts obtained results for the Kanban implementation are presented, after a descriptive table with the parameters, sources and formulas used.

Kanban Proposal for "A" Parts																	
#	Part Number	Description	Image	Yearly Demand (Pieces)	Takt Time (Hours)	Average Demand (Pcs. Per Day)	Lot Size (Pieces)	Lead Time (Days)	Kanban size (Standard package for all cells)		Minimun number of Kanban cards into the system calculated without buffer (Min-Kanban level)	Kanban Levels Location : FIFO / Supermarket		Material preparation - Raw material			
									Pieces (Quantity)	Image (Package)		Min Kanban cards	Max Kanban cards	Color	Recipe Number	Pcs.weight (Kg)	Min Batch size (Kg)
1	20-11488	Arm Skin R SimMan 3G		1320	3	5,3	100	9	50		2	1	2		R 6356	0,6	66
2	20-11489	Armskin L SimMan 3G		610	6	2	70	10	35		1	1	2			0,6	46
3	N1013	Leg skin right		786	5	3	90	9	45		1	1	2			1,2	118
4	N1015	Leg Skin left		706	5	3	80	9	40		1	1	2			1,2	105
5	N0618-D	Torso skin		313	12	1	30	10	15		2	1	2		R 6355	3,250	107
6	N0618-M	Torso skin		452	8	2	44	10	22		2	1	2			3,250	157
7	N0618	Torso skin		2343	2	9	150	10	25		7	4	6			3,250	536
8	H61	Høyre (right) Arm Resusci Baby		1280	3	5	150	10	75		1	1	2		R 6337	0,135	22
9	H63	Høyre (right) Bein Resusci Baby		1273	3	5	150	9	75		1	1	2			0,24	39
10	V61	Venstre (left) Leg Resusci Baby		1285	3	5	150	9	50		2	1	3			0,135	22
11	V63	Venstre (left) Leg ResusciBaby		1273	3	5	150	9	50		2	1	3			0,24	39
12	N0631	Hand Right		1712	2	7	200	9	25		5	2	8			0,225	49

Parameters	Source /Formula
Yearly Demand	**MRP (QAD)**: Historical data from Stavanger Plant: Jun-21 through Nov-21 Forecast data from Stavanger Plant: Dec-21 thought May-22
Takt Time	**Takt Time** = Available work time / Yearly demand
Average Demand Per Day	**Average Demand Per Day=**Working hours per day / Takt time
Lot Size	**MRP (QAD):** Historic data June 21 - Nov 21 : Avergae lot size registrered on that peroid
Lead Time	**MRP (QAD)**: Historic data June 21 - Nov 21 : Average time between work order relese and close date
Kanban size	**From all the packages, one was taken to standardized and adjusted the capacity to the lot size**
Kanban Cards into the system	**Min-Kanban =** (Demand *Lead Time + Safety Stock) / Kanban size
Min - Level Kanban	**Min - Level Kanban=** Safety stock (Safety days needed (Lead time) * Average demand pcs per day)
Max - Level Kanban	**Max - Level Kanban=** Min-Kanban + Lot size (Translated to kanbans)
Min - Raw material batch size	**Min - Raw material batch size =**(Weight per piece * Lot size) + 10 % (Scrap)