PACKING LINE DEVELOPMENT FOR ABB DRIVES PRODUCTION

ABB Case Study

Lappeenranta–Lahti University of Technology LUT

Technology and engineering science Bachelors thesis

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ABSTRACT

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Packing line development for ABB Drives production

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Production engineering is a success factor of modern industry manufacturing. In this thesis the focus will be on designing a packing solution for ABB Drives factory in Pitäjänmäki. There will be a analysis in to modern production methods and tools. The methods focus on the lean methodology which was introduced to production by Toyota and made world known trough the "Toyota way". The thesis will introduce automation methods such as robotic arms, AGV (automated guided vehicle) and automatic storage.

After the deep dive into production and automation tools the studied information will be used to break apart the case study into more sizable problems that can be analyzed. This will help with the final design for the packing solution that will be proposed at the end.

The results of the study conclude that modern production tools and methods are a key element to effective production, altough the application varies depending on the type of product and the capacity required. In ABB case the high amount of product variation in packing stage results in a compromise solution between automation and manual operations. Part of the process has such high variation that it would be too risky and complicated to automate thus it is best suited to manual labour. However, by using lean it is possible to select areas where automation can be used to make the process more efficient. These results balanced the work environment of humans and machines to maximize redundancy and output.

ACKNOWLEDGEMENTS

Thank you to the ABB Pitäjänmäki DP development team for offering an interesting and challenging topic.

SYMBOLS AND ABBREVIATIONS

Symbols

Q	Force	(N)
r_n	Moment arm	(m)
M_n	Moment	(Nm)

Abbreviations

ABB	Asea Brown Boveri, Global automation corporation
AGV	Automated Guidance Vehicle
CPL	Area of ABB Pitäjänmäki factory dedicated for assembly of small and medium drives
Cycle time	Total time of turning raw material to finish product
DP	Drive Products, One division in ABB
Drives	ABB’s frequency converters and motor control units
ESD	Electrostatic Discharge
GPS	Global Positioning System
Lead time	Time between start and end of the production process
Small & Medium drives	ABB drives with frames from R1 to R6
Takt time	Rate at which product needs to be finished to meet demand
6S	The 6S system is a lean manufacturing tool that improves workplace efficiency and eliminates was

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1 Introduction

This Bachelors thesis has been made for ABB Drive Products division in Finland. In this work I intend to research and develop a viable plan for a packing line in CPL manufacturing and testing area in Pitäjänmäki. I plan to learn from the existing packing system and later design the modern packing system which would be a possible enhancement for existing system. This thesis will touch on modern production methodology and automated systems which will be used in the development of the new design.

1.1 Background information

After having been a summer intern for one summer at ABB Drives factory in Pitäjänmäki in the production development team I became very interested in production development. The combination of the people and business needs in production is a complex and fascinating balance where the production engineers must meet ABB Drives production goals and build world class frequency converters for a huge vary of uses. The Production line for small and medium drives in Pitäjänmäki was upgraded in early 2022 and this has resulted small and medium drives packing line not having sufficient capacity for the future production goals. The pressure to have higher volume has raised inefficiencies in the packing and prepping method while also reducing ergonomics and decreasing safety in some areas.

There is a need to modernize the prepping and packing area in a way that the needed volumes of products can be met. It is also essential that ABB being a technology company can also have a world class packing area where the heavy labor is either automated or assisted in a way that it is possible to be completed by any operator despite of their strength and ability.

1.2 Problems and questions

The production output vary highly on the customers demands. Products must leave from packing either on pallets for company logistics center or on pallets destined for customers. The products must be however tested before packing and travel from production to testing and from there to packing. When the products arrive to packing, they are not in the order which it will be loaded on the euro pallets for transportation to the customer.

Ergonomics is another issue as the volume in the packing line has increased causing manual labour routines as well to increase. This has made previously working process unacceptable from the ergonomic perspective.

1.3 Goals

My goal for this thesis is to study the current state of the packing method and to design and prove a viable replacement option. The replacement option should be safer, more ergonomic, and efficient in packing before sending products to the shipping. I intend to study what modern packing and production methods can be utilized to make a productive, streamlined and safe packing area.

The main requests from ABB were:

- Automation of moving, lifting and storage
- Safety and Ergonomics
- Optimized flow
- Efficiency of manpower
- Organisation of products post testing

1.4 Methods of the study and scope

The thesis will follow a structure where first there will be a literary study on the topics of production development and different methods of automation in production and packing processes. This includes existing technologies that are used around the world in production and analyse the goal behind the design. This thesis will also study production methodology and theories that have been implemented in modern factories.

The thesis then discusses the current form of the packing area and analyse its strengths and weaknesses according to my research from before. The theory studied will be used to understand the view that the current system was designed around and to analyse the areas it needs change for the upcoming volumes.

Finally, the thesis will use presented information to create a new design, which would be a viable replacement for the old packing area. This includes using the theory to improve flow of the packing and increasing the volume. It will also include improvements in package handling and specifically focus on the mechanical engineering side of the designing of the packing system.

This study is limited from certain details to protect confidentiality which could give an advantage to the competitors of ABB. For this reason, the thesis will not go into details of the production process of the company nor its products design principles what comes to product design related manufacturing.

2 Insight to methods of Production Development

Production flow optimization is a highly complicated process. Many variables must be considered to achieve an accurate picture on how production will flow and act within a factory. The methods section of the thesis will study the current methods being used around the production and assembly world. This information will be used to then analyse the ABB case study.

2.1 General view of automation

Automation has become a key aspect of any modern production method. It allows for greater safety and efficiency. Automation has been able to relieve humans from repetitive and unsafe tasks which before needed to be done manually. For example, in the past most of the lifting tasks needed to be made by hands, but with the invention of overhead cranes and ergonomic lifts this has been revealed. The current trend is that this lifting won’t be needed at all since robotic arms and other automated systems can do the heavy moving and lifting. Automation can also improve the output quality of production. This again is especially noticeable in repetitive and boring tasks for a human who can lose interest and care. Meanwhile automation excels in simple and boring tasks.

In this chapter there will be a literature review of existing forms of automation and automation systems that can be implemented in the ABB case study.

2.1.1 Robotic arm as a tool in automation

Robotic arms have been used in production for decades now. There has been a massive improvement in lifting force and accuracy at which these arms are able to operate. The main function of a robotic arm is to relieve a human from a repetitive and high strain work.

Automotive factories have become the pinnacles of robotic arm integration due to their immense production flow resulting in a lot of repetition and due to components weighing a considerable amount. This is the type of work that would be uncomfortable for a human operator but ideal to automate with a robotic arm. Due to the high volume, it makes the return of investment in a robotic arm very attractive.

Due to the increasing popularity the robotic arms have become highly valuable in processes needing repetition, precision and quality. This can be seen in the precision of modern robots as claimed by Tilley: “While today’s general-purpose robots can control their movement to within 0.10 millimeters, some current configurations of robots have repeatable accuracy of 0.02 millimeters.” (Tilley 2017 p70).

Other advancements are the ability to co-work in harmony with humans. This kind of harmonious work requires extra safety measures but allows human operators to be efficient in utilising their skills and intellect in complex tasks while relying on robotics for the hard and repetitive labour. Another benefit of collaborative work is better space utilisation as enclosed robot cells can require vast space that could be utilised better with collaborative working area. To ensure a safe harmonious work area robot must be limited when humans are around so no injury can happen. As written by Michalos: “Safeguarded space at the maximum workspace dimensions could result in the enclosure of an unnecessarily large area. Limiting the motion of the robot can be achieved by the robot’s integral system” (Michalos….2015 p249-252).

2.1.2 AGV as a tool of automation

AGVs also known as Automated Guidance Vehicles have become a staple of modern factories. They relief humans from the simple logistical tasks and help resources to be redirected into more complex tasks, which need human intellect.

The main purpose for an AGV is to move items from place A to place B. They do this by navigating the surrounding automatically. This eliminates the need for a human to move the item. This improves efficiency and is highly cost efficient as the operation costs of AGVs are often much lower than a forklift driver and a forklift combined.

AGVs are often used to improve workflow. This can be done by splitting the assembly or manufacturing area up into stations and connecting them with AGVs. For example, if an assembly process needs metal treatment in different stages of assembly it would be disorganised to include multiple metal treatment workstations along the assembly line. Instead, it is possible to specify the area for metal treatment and use AGV to keep the production flow separated from any special work areas which need extra protection. This not only enhances production flow but also increases safety and organisation.

AGVs can also increase workspace. They can eliminate the need for conveyors freeing space for more traffic. It is stated: “Sometimes space is the issue. By not needing cumbersome conveyor or gantry systems AGVs become space saving modes of transportation in many factories.” (Prime Test Automation p12)

Navigation technology:

AGVs use multiple ways to navigate. The common ways are by using gyroscopic navigation where there is conductive wire placed withing the factory floor which the AGV can follow. This is the simplest form and is known as “dumb AGV” since it only requires the simplest programming. This form of AGV is hard to reprogram, as it requires rework of the factory floor to function.

The next form of navigation is vision guidance. Vision guidance uses LIDAR or cameras to visualise the environment around and bases its path through that. “These can often be ideal because they require no modifications to the workplace. There is no tape to lay down, no wires to install, and no sensors to affix around the room. All a vision guidance system requires is the vehicle and its programming” (Prime Test Automation p7)

The most advanced navigation method currently available is geo guidance. In this guidance mode the AGV can use GPS location and LIDAR and cameras to identify its location. This allows the AGV to have more autonomy and change its path depending on the environment. It lets the device determine the optimal path through the environment to achieve its task. It is claimed: “One of the greatest benefits of this system is that adjusting the AGVs task is as simple as changing the programs input and can be done with nothing more than your computer and requires no installation.” (Prime Test Automation p7)

2.1.3 Automated material storage as a driver for layout design

Automated material storages are becoming a lot more common. These storages can range from small lifts which can store light items efficiently and cleanly to larger organisers that can store pallets. The major benefits of these lift storage systems are the amount of space they save and the ease of use. They eliminate the need for shelves and forklifts as there is a set height where all items can go in and there isn’t need to lift high. By removing shelves and forklifts the safety is increased and the factory logistics ways don't need to meet forklift standards further saving space.

Vertical storage units help with efficiency too. Having the shelves always at an ergonomic height and in similar organisation helps operators find necessary tools easily and fast. "Industry studies have shown that vertical storage solutions can increase workforce productivity by up to 85% because one operator is able to handle the same volume of work previously performed by multiple operators." (Modula 2022)

2.2 Working Ergonomics in packing cases

Ergonomics are an essential part of the packing and production process. Well trained and capable workers are the most important asset of company as they ensure the quality and timeliness of each step. Bad ergonomics can lead to work related injuries and take an essential worker out of the work force for days. Therefore, it is critical that they can work in a way that doesn't stress their body and hinder their health. In production the main ergonomics concerns come from body positioning and lifting weights. Even if these weights are low, it is possible that the lifting process happens frequently which induces strain from the number of repetitions. For example, throwing a single shovelful of dirt won't stress your body but shovelling for 10 minutes straight will strain certain muscles and induce stress due to the repetition. (Health and Safety Manual handling operations Regulation 1992)

2.2.1 Handling of masses

The key points to handling masses is to make sure you can use the strongest muscles and your whole body in the process. If using wrong body posture, it is possible to overstress certain muscles, which then results in stress or injury.

According to Health and Safety Manual handling operations Regulation 1992 the ideal handling of materials safely is as close to the body and natural arm height as possible. This is due to the fact as the further the item is to the body the moment of the downwards force induced by the item being handled grows. Since the formula to calculate moment is:

$$M_n = r_n Q$$

An individual’s handling capability reduces quickly the further the item is being lifted as seen in Figure 1. The moment force is multiplied as the object is further from the body resulting in high strain with small movement.

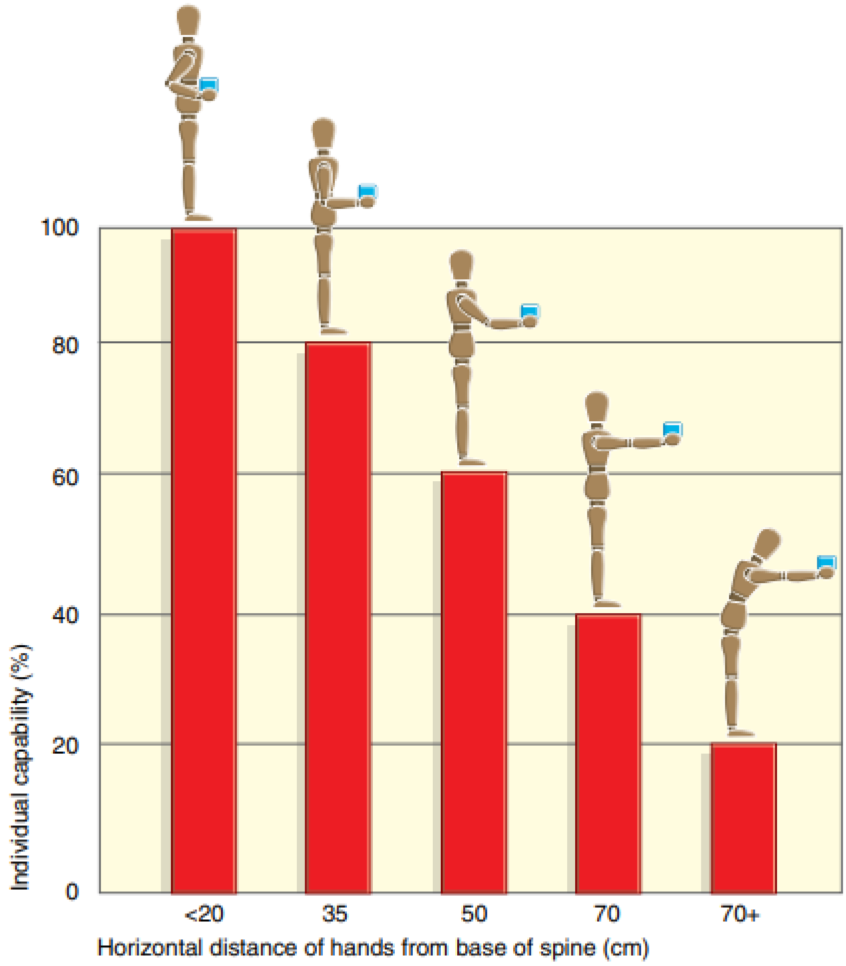

Figure 1 Lifting capacity at different positions highlighting influence of workplace ergonomics. (Manual Handling Operations regulations 1992, p31)

Another key aspect in handling masses is to keep your whole body in line. The legs and upper body are working in harmony and in alignment. Unalignment of the upper body to legs can easily strain the body by using the muscles unequally.

2.3 General view of production flow

Production flow can be defined as the flow of materials and the product through the factory to create the final product. This needs to be timed and balanced in a functioning production and it needs to be optimised and filed to make a world class production. Production requires tools, skilled labour and materials or components. Good flow of production is when all of these aspects can be used in a way that maximises the results. (Loshin, 2011)

Troughout history, multiple different methods have been created for adjusting each of these aspects, but Toyota's lean production has clearly been the most successful. .

2.3.1 Basics of lean methodology in production flow

Lean is a methodology where the focus is on removing waste. It was originally first implemented with great success by Toyota Production System(TPS). The key idea behind lean is to shave the excess off the process and focus on the core cause and eliminating waste around it. When referring to waste lean has organised it in to 7 categories which are:

- Over production

  This is when production is constant and not adjusted to demand. This results often in storage being used for unsold products and results in inefficiency.

- Defects

  Cost of a defect is large as it takes time and resources to correct it.

- Waiting

  Any time waiting for the next step or production interruptions are a waste as resources are not being used.

- Motion

  Any movement that doesn't add value to the customer or unnecessary moves products without adding value is wasted time and energy.

- Inventory

  Stocking finished products or products halfway done take unnecessary space.

- Transport

  Similar to motion this is the fact that any excessive movement is a waste of energy.

- Over processing

  Any processing to compensate for design faults and bad production quality.

These are the Waste or “muda” in Japanese which do not add value to the customer and increase cost. This is the core behind lean and the Toyota way. It is about testing and cropping out waste whenever it is noticed. “This is not, however, because the Toyota Way is so mysterious that it must be intuited but simply because it is a “learn through doing” system.” (Liker & Meier 2018)

After the establishment of lean values in a larger project the usage of lean changes. A big part of lean is continuous improvement which has the Japanese name of Kaizen. This is the section where the ball is already rolling well but each member of the work team is asking “How can I do this better, more efficient?”, “What is slowing me down or distracting?” “What can be changed to make the work easier?”. All these questions are ones that can lead discussion on identifying problems and help continuous improvement. By doing small changes continuously it is possible to make big gains in the long run according to the lean ideology. (Kouri, 2010)

Kaizen consists of five parts:

1. Plan
2. Do
3. Check
4. Act
5. Continue

This is the steps that build the spine of kaizen. As mentioned, before it is a do and learn process where ideas are implemented and measured to deduce the results. Kaizen is a tool which is used after the process is already running well.

3 Introducing ABB Case study

ABB currently is producing a variety of products in the small and medium drives production area which is called CPL. This case study focuses on the CPL packing area which is at the tail end of the CPL production line and testing system. The products made in this area can be categorized in to two types.

The types are ACS580 and ACS880 drives. These drives are typical example of small to medium sized power electronic products. Both drives have 6 power ratings and 3 size variant which are called frames. These are categorized in frame size ranging from R4, R5 and R6. Each type and frame have different packages with R4 being smallest with a cardboard bottom pallet and with R6 Being the largest with a wooden pallet as the base.

In this research the focus was on a packing line which consists of 6 different frames and 12 different products which then must be packed into pallets for consolidation and shipping to customers. These pallets can be a mix of products or a batch of just single product for storage. The packing line must facilitate the two different options. The current area is designed such that there can be up to 8 pallets being completed for shipping which takes a lot of space and is highly inefficient. Some pallets can wait an entire shift before having the order completed.

3.1 Efficiency in eyes of lean

ABB is using and striving to follow the foundations of lean. There is already a high focus on using a pull system in production and a focus on minimising waste. However, since there has been changes to the production and testing the packing area has become unoptimised for the current production model. Due to external changes, there has been unnecessary motion, waiting and inventory added to the process. This has decreased the efficiency and flow of the packing stage.

3.1.1 Current facility space

Another Key aspect of Lean principle is the efficient use of space. In the Pitäjänmäki factory space is at a premium since the factory floor space has been the same since the 80s while capacity requirements have increased significantly. This means that every square meter of the factory has become more efficient and productive.

However, the current packing area for the CPL production lines is not as efficient with space as it could be. Mainly it is noticeable that there is unnecessary space being taken by waiting pallets which are not completed for delivery. This problem is the cause of a product testing system before the packing which spits the product out in a random order. This means that there are multiple orders being palletised at a given time since there is no order in the output of the packing line. This contributes to the leans wastes of inventory and waiting.

3.1.2 Need of manpower

Another aspect we can view lean trough is the productivity of the operators. In the current packing line operators are completing multiple tasks. The tasks currently done manually are equipping the supporting parts to the drives such as user manuals, packing the drive-in cardboard and securing holders, strapping the packed drive with shipping straps, using a suction lift to lift the packet and move it to destination pallet, confirming pallet and securing it with straps and finally moving the pallet from packing to shipping area.

When looking the current line through lean principles, there are clear wastes which can be identified. The most noticeable one is intellect. In the current system there are tasks which are done manually that would be better suited for automation since they are repetitive and unergonomic. However due to the complexity of the prepping stage due to variations in product operator intellect is essential for the success of the process. To maximise the output the process must be optimised based on this lean principle leaving intellect demanding tasks to operators and automating the rest.

Another waste identified is motion and transportation. In the current system the pallets are being taken away from the packing area through the production lines and then to the shipping area. This is unnecessary motion and transportation which also requires an operator.

3.1.3 Pull methodology

There is clearly a focus on doing things in a lean manner in the current line. There is a utilisation of FIFO “first in first out” and pull the products to line only the orders require that. Another practice where pull methodology is used is material presentation by means of kanban trolleys which have a set amount of parts that are used in the line and when the parts are used a new kanban trolley is brought. This reduces material space in the line and prevents over production. In this aspect the current packing system is very good.

3.2 Safety considerations

ABB do not compromise with safety. The most important asset to the company is a high skilled employee. High workplace safety is an essential driver in employee’s engagement and health. It is essential that the work routines are designed such that it can be performed long time without creating any kind of strain or injury.

With several years of relentless effort in improving safety culture and work safety and engaging entire organization to improve safety with hazard reporting and Safety Observation Tours, the current safety is very good with very low risk throughout the process. However there has been a target on becoming lift free as a large part of the lifts being used work with pneumatics. In a case of loss of pneumatic pressure ongoing lifting could lead to injury. For example, in the packing area there is a lift to move the packed product to the euro pallet. This lift grabs from the top of the package and uses suction to hold the load. In the case of loss in pressure the packet can fall on the floor injuring the worker and damaging the product.

The benefit of a pneumatic lift is that they are very quick to grip and intuitive to use. They don’t need accuracy to grip, and they are functional to many different sizes of packages.

3.3 Ergonomics

The ergonomics of the current system have been designed for operators with different physical sizes. ABB has a huge variety of packing workers ranging from 150 cm up to 200 cm. As a result, the current system shows a lot of adjustability for the operators fit to purpose. It also provides a lot of assistance in lifting and moving of the drives and packages tough the packaging process.

However, altough the operator ergonomics having been a focus in the design of the packing line, it is clear that there are improvements that need to be made to further ensure, that the process is ergonomic for all sizes of packages. It is also essential that the processes meant to aid the ergonomics are kept simple and easy to use so that other unergonomical methods of the same process aren’t going to be tempting to save time or to simplify the packing.

3.3.1 Ergonomics of pallet lifting

In the current format of the packing area there is a necessity to lift packing pallets with weights ranging from 4 kg to 5 kg. This is on the edge acceptable according to the Manual Handling Operation Regulations 1992 most recent version. What makes it unacceptable is the number of repetitions done in an hour.

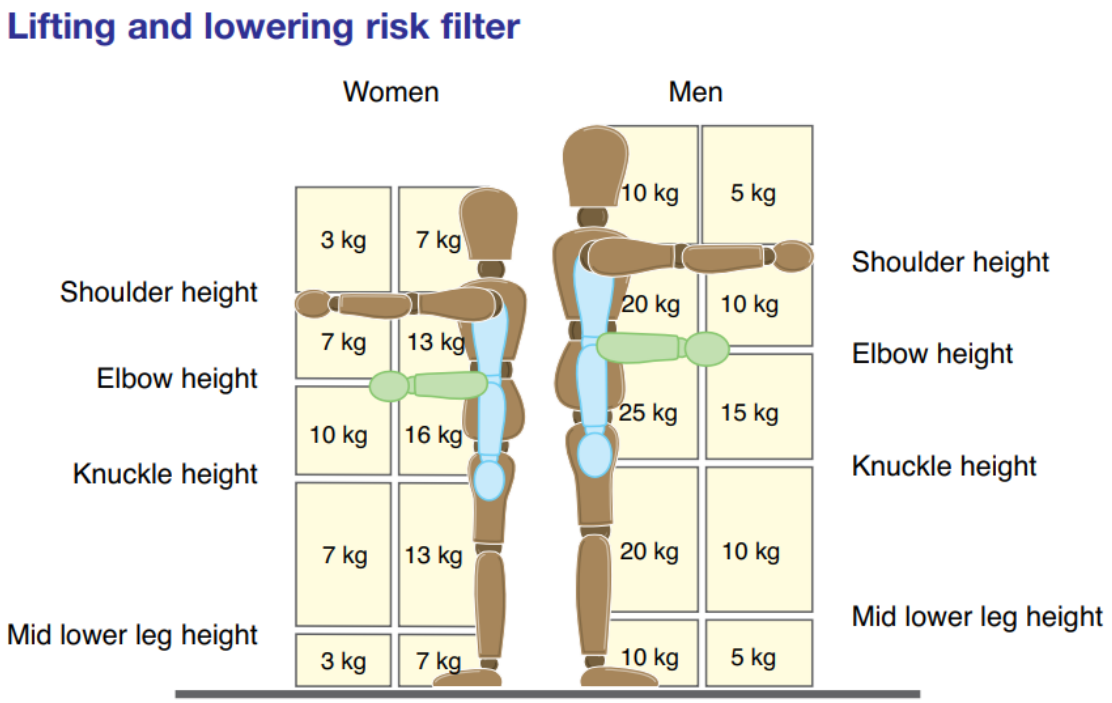

Figure 2: Diagram used by ABB Pitäjänmäki to determine ergonomic lifting. (*Manual Handling regulations 1992, p54)*

As seen in the diagram figure 2 above, referencing the HSE standards used at ABB the lifting capabilities of men and women. Since this task should be achievable by both men and women the task needs to be modified to be compatible for both genders. In the current format the task needs consideration of the operator's physical capability which limits the candidate pool and favours one gender unfairly.

3.3.2 Workstation

The workstations used currently have been made to be optimised for each worker. The stations are meant to be operated while standing up and have variable adjustment for the worktable height and the tools are all in ergonomic reach.

The working station ergonomics are also improved by using 6S methodology to increase organisation. The places for tools, screws and parts are all marked intuitively and in such a way that they are standardised and easy to find. This reduces time wasted in finding items and improves ergonomics as everything is at a reaching distance that doesn't cause stress to the worker.

3.3.3 Ergonomics of lifting packed products

In the final step to get the fully packed product off the packing line to the pallets a suction lift is used. This lift uses pressurised air to create a suction on to the top of the cardboard box of the packed product to grip it.

The major benefit of pressurised air as suction is how fast and simple it is to use. It is a favourite amongst the operators as it allows for easy attachment and detachment of the packed drive. However, on the safety side it has a critical flaw that in the case of a loss of pressurised air it is possible to drop the packed drive. With the combination of need to walk the packed drive to the pallet using the lift, the used routine creates a dangerous period where the packed drive is located above the floor, and this is the moment the package could drop on to the workers feet.

4 Results

This results section has two parts. Part one consists of general results which can be implemented in production in general and second part will focus on the ABB case study. The general results is a conclusion drawn from the previous research and time spent learning about production. The general result will be a base and a proving ground for the case study solution. It will also be used to measure success of the case study result.

4.1 General result pyramid

This sub-chapter describes the general result. It is based on the results of literature review presented in earlier chapter.

To have successful modern assembly or production there is a clear importance order that needs to be met. Depending on the industry, some areas become more important than others. The goal is to compose this understanding into something that is easily readable and understandable. The method chosen for this is to make a pyramid of importance in production. The base of the pyramid being the basic needs to make the production work and as we get closer to the top it is optimisation.

This pyramid presented in Figure 3 works as a tool that can be used for production engineering purposes. It creates a hierarchy of areas of focus which need to be met. They depend on each other and starts with the base being the foundation of any production and as the pyramid climbs it becomes more efficient and competitive.

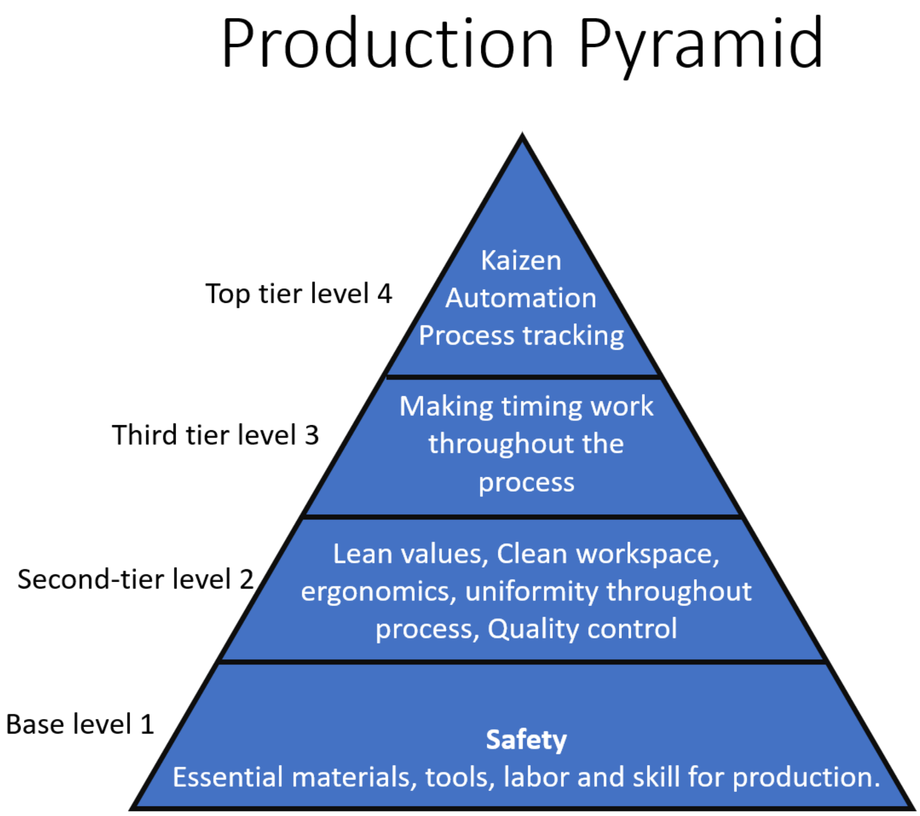

Figure 3: The proposed production pyramid. Inspired from similar production tools it is a indicator of importance order in production.

is the pyramid is split in to 4 tiers with the base being the most important and essentials and with the tip being the target. The tiers work from being functional production at the bottom and optimised production at the top. The tiers go as such:

Base tier basic needs:

These are the necessities for production to work. You need a safe working environment that your trained skilled workers stay safe and can produce the product. You need the necessary tools for the job and the necessary materials for each step of the process. This is the foundation to any production that can work.

Second tier Lean process:

This is the foundation of modern production. It revolves around the lean principles that were brought up in the Toyota way. This means that the work area becomes more ergonomic, clean and uniform throughout the factory. This not only increases quality as mistakes can be noticed easier, but it also increases worker productivity and engagement. This is where there is the introduction to pull systems and focus on the 6S and reduction of “Muda” (waste). Completing this step means that efficiency and productivity increase drastically, and the work becomes streamline and lean.

Third tier management of time:

This is where the main optimization starts. This is where the pull system is timed and measured so that material arrives at the right time but there isn’t an excess of it. Also, the steps throughout the production are timed so that each step takes the same amount and is efficient. This is the tier when Takt time, cycle time and lead time are optimized for the process. All of these are lean principles as well, but they are implemented after the basics of lean are already achieved. This is where the optimization is really honed, and the production becomes efficient and highly productive. Since everything is done by workers it is easier to implement changes and optimize things still since human labor is flexible.

Final tier automation:

This is where we can finally think about automation and process tracking. After the base of the pyramid is built this is where we start gathering data from the process so we can stay on track how everything is working. This is also where we can start identifying parts of the process which can be automated. This section of the pyramid is where there are investments in to cutting edge technology, but it only happens at the very end as the foundation of the production must be solid before technology is brought in to help. Technology is a helper in production, but it isn’t what makes production that is why it should be in the focus only when the flow and lean have been achieved.

4.2 ABB Case study results

In the development phase I developed a solution to the needs set by ABB. I used the research conducted in the earlier chapter to engineer a suitable packing and outfitting solution that was proposed to ABB case. I used the proposed production pyramid as a spine and a measuring tool for my decisions. The results focused a lot on lean methodology and the use of automation. Through these methods it was possible to meet the requirements set by ABB.

4.3 Improving the capacity of ABB case study packaging line

To increase the capacity flow of the packing stage the process must be described. Despite there being a Kaizen mentality at ABB, the production lines leading to the packing area have changed and increased capacity so much that the current process and system has fallen behind. The biggest gains currently are to be found in the later part of the packing line where the process currently is the least lean.

Capacity can also be increased by automation. Since automation relieves operators from repetitive and time-consuming tasks the efficiency of the operators can be increased. Therefore, automation will be a big part of the solution as well. However, automation does have its limits as ABBs packing process has a lot of variances since certain customers have specific options which are required in packing process. This is highly complex work which would be risky to automate so it will need to stay as a manual task. However, since the workload decreases from the current system to the proposed one, the capacity increases.

4.3.1 Using lean in improving the packaging process

The focus for leaning out the process is to focus on intellect, motion, and storage aspects of the current system. Since the workstations follow lean principles well there is marginal gains to be made. However, the largest gains can be seen on the tasks which operators complete that are not on the correct intellect level for the operators.

First task is strapping the package. This is a task which does not match the skill level the operator has potential and thus is waste of intellect. This is also a task that has multiple automated solutions existing already.

Secondly and thirdly in the same process the operator lifts the package with a suction lift to the correct pallet. This wastes intellect in sorting and lifting as both tasks are ones which add low value to the product compared to the operators potential. These are areas where the intellect aspect of lean must be honed out.

4.3.2 Comparing flow of the original packaging line to proposed packing process

For the proposed solution there is a focus on the pull idea of lean and the direction of flow trough the factory. There is already a focus on pull throughout ABB and it can be seen in the usage of first in first out (FIFO) material buffers and set packets where only the necessary number of items are brought to the workstation.. This is something that must be kept in the new process as it is used factory wide.

However, in the process itself there must be a system that will be able to have a constant clean pull throughout the process that utilises the resources as efficiently as possible. To aid with visualising the process a flowchart of it has been created.

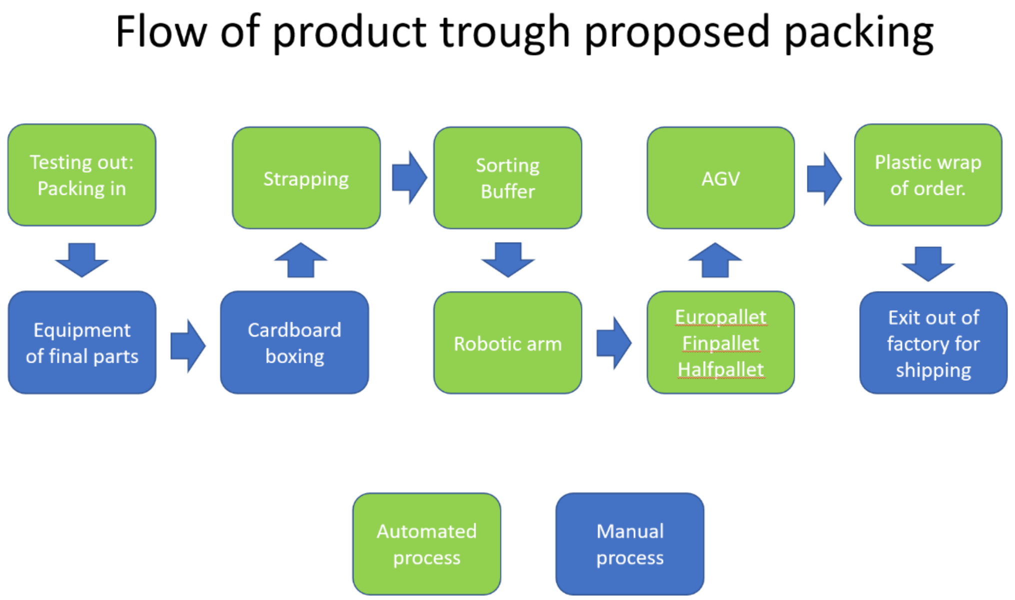

Figure 4: Flow chart of proposed solution for ABB case study

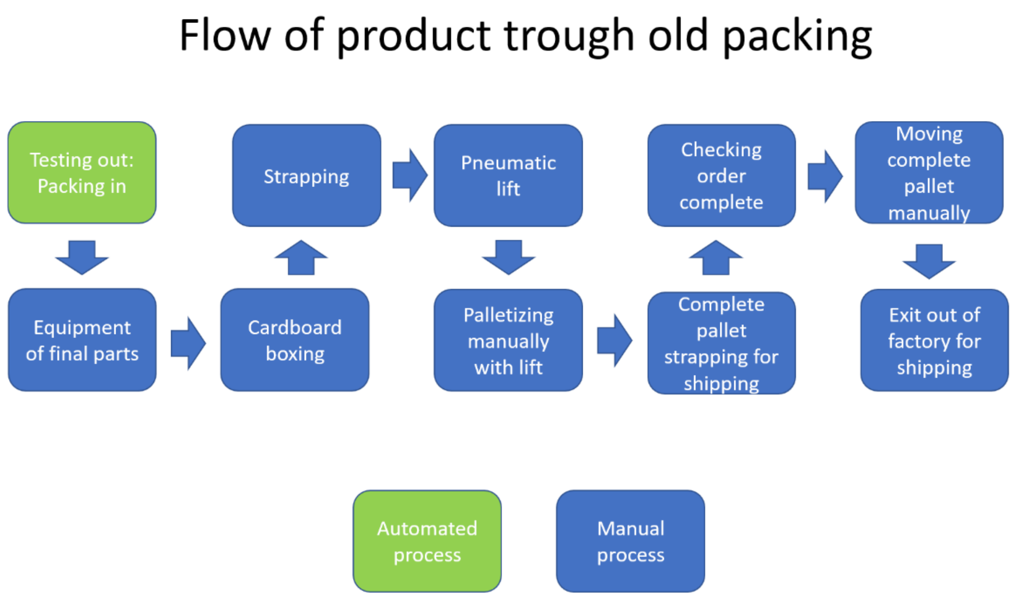

Figure 5: Flowchart of current system in ABB case study

As seen in the flowchart the only point that needs a skilled laborer is the equipping part. This is a tactical decision as a operator works in 8 hour shifts and with two 15 minute coffee breaks and one 30-minute lunchtime this equates to 7 hours of working time. Meanwhile the automated parts can work 8-hour shifts. This means that to use the automated parts as efficiently as possible there needs to be a buffer which can be filled up for the coffee breaks and lunch breaks that the automation can then work at and empty during the workers downtime. This is what the sorting buffer is for and that splits the automated and manual labor. This allows for a split in the timing.

4.4 Using automation and other technical solutions in proposed line

To develop the processes and capacity it is essential to automate the areas which are not necessary for human operators to perform. We can reduce Leans definition of waste by ensuring that the tasks executed by the operators are only tasks, which need the skill, flexibility and intellect that the human labour has. The simpler tasks must be automated or eliminated to ensure a Lean packing line.

The areas which have been identified to be automated are all lifting and moving tasks. The packing preparation and adding the covers and final configuration. The reason behind is due to the large variation of products and even larger variation of special attachments depending on the customer's order configuration. This means that it needs skilled work which is not possible to automate with current available solutions and reasonable investment.

4.4.1 Utilization of robotic palletising

The first task on the list of steps that can be automated is clearly palletising. Palletising in the current process is the largest danger and waste of resources. It is the part which takes the most space, wastes intellect of labour and it is the least safe part in the current process. By automating this process, multiple goals set in chapter 1.3.can be improved.

Primarily I want a robot cell that is compatible with human work. Therefore, similar to the case in the Science direct study, the most viable option is to use HRI where human interacts with robot technology. This requires a perimeter set around the robot which senses if there are people inside operating zone. First it slows the robots' movements and then eventually stops the robot when the human gets close enough. This ensures safety and ensures that nothing can hit or get flung at any human in the operation area. By choosing HRI option over an enclosed robot cell, we improve the space use and accessibility around the factory.

Choosing the correct robot is also essential. Compared to what is used in car industry with high precision placement and part manipulation in palletising it is not necessary to have 6 degrees of freedom. In fact, the minimum needed is only 4 degrees of freedom since the end effector needs to only be pointing down and does not need to gimble. This simplifies the robot making it cheaper and less maintenance dependant. Also, specific palletising robots are designed to carry much heavier loads than part manipulation robots.

For these reasons it is decided to choose the ABB IRB 460 as it has a maximum payload capacity of 110 kg which is well above our needs, and it can run through 2190 cycles per hour with a 60 kg load which is well above our need. However, with choosing a robot with more capability than needed it allowed for more lenient design on the end effector since the heaviest package we will be lifting is 70kg it leaves 40kg safety margin and as mass for the end effector. The cycle time of the robot is also well above what we need but since there will be HRI this will slow certain movements or require stoppage at times so having the ability to overachieve at the optimal work situation is a plus. (ABB 2022)

4.4.2 Utilization of Automatic sorting system

In the ideal packing solution for ABB, there has been outlined that the storage and space area need special focus it is concluded that an automatic storage unit can fix these problems and improve safety and ergonomics. By doing this I intend to get rid of the overcrowded palletising area and reduce simple work from operators. This will help me achieve the lean principles and redirect human labour to more worthy and complex tasks where it is needed for.

The specifications that have been decided on the automated storage system are that it must accommodate the current volumes of products and the future volumes and reduce the final pallet number to an amount that a single IRB 460 Robot can palletise. It must be able to read and organise the packaged drives into orders which can be fed to the robot to be palletised. There must also have an ability for manual operations in case of maintenance or single product orders.

To meet these requirements, it has been decided to spec a special built sorting system which can house and read products. The packaged drives would be scanned on their way into the storage and then assigned a spot. After the last package of the order reaches the scanner, it would then unload all the order specific products out of the sorting system to the palletising robot which will palletise the order.

The capacity of this storage and sorting automation was calculated so that it can hold roughly one shift worth of products. The minimum requirements would have been that the system is possible to hold a mix of any possible combination palletised products. However, since this information is one area of key to success in ABB and part of the confidential information, the numbers will not be published in this paper.

4.4.3 Role of AGV in proposed line

Finally, I decided to use AGV’s for moving the drives. this will improve safety, efficiency, and space. By adding an AGV to do the logistics beyond the palletising frees the same space for other use compared to a conveyor. Also, since the logistics are automated this does not trigger the palletising robot’s slowdown mechanism and it can run at 100% even with pallets being added or removed.

ABB has experience with AGVs especially ones made by Omron. These AGVs are GPS and lidar guided modern navigation equipped AGVs. They make them very easy to implement with no need for the environment around to be changed. Omron has the HD-1500 model which has a payload capacity of 1500kg. It meets the requirement for this work, and it also has the option of being ESD fitted which would make it suitable in handling electronics.

4.5 Resulting ergonomics

By implementing the automation, the new packing line design removed the part of the old process which have been the worst for ergonomics. The new process has gotten rid of the movement of the packaged products to the pallets by humans which was the biggest safety and ergonomic factor. This is a massive improvement.

One area that still requires some attention is the lifting of the small pallets where R5 and R6 drives are placed on since these come in batches that require the worker to bend low to grab the last few and reach high to grab the first few. This isn’t very ergonomic since this task is repeated multiple times a day so it has been suggested that an ergo lift table would be used to offset the pile to the optimum height throughout the process. This would increase the ergonomics of the process and help with efficiency as well as the reaching would take less time.

4.6 Proposed layout-based production flow, technical solutions and lean.

Since available space for the process was quite small area, I had to design the layout of my process very carefully. The layout would indicate the workflow direction and a rough estimate how much space each part of the process would take. The proposed layout will be present a rough estimate of the area. It does show the robots reach and sizes of pallets and FIFO cages which will be placed, and it will show the sizes of the conveyors, but certain aspects of the area are left purposefully not as detailed as not to give other companies a competitive advantage.

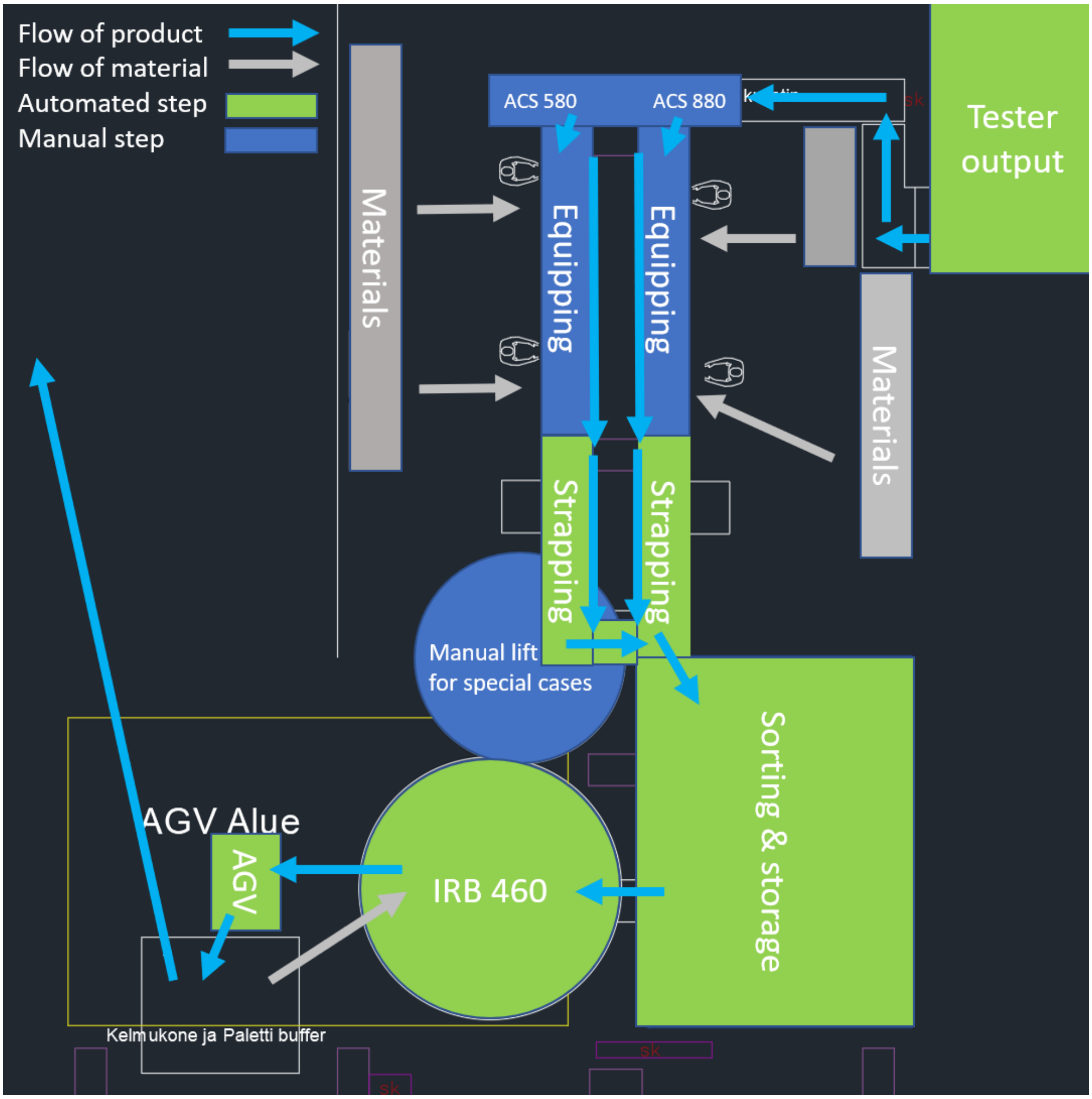

Figure 6: Floor plan of proposed solution for ABB case study

Figure 6 is the factory floor setup proposed. Flow is from the top right to the bottom left. This keeps the flow throughout this section of the factory in one direction. Not only does this help with material sorting as the flow can stay directional but it also helps to keep the area clean and understandable. With this design the workers are kept at a safe distance of any machinery for example no workers will need to go near the robotic arm and there won't be any need for forklifts to be in this area which increases safety. Any movement of material will be done by hand or by hand pulled trolley.

This process has been designed according to the pyramid example as it focuses on safety as the spine of everything, then utilises lean methods and finally uses balanced timing and automation to make a competitive packing area.

4.7 New and old comparison using production pyramid model

Now after developing the packing line and process for ABB and finding the technical solutions it is time to see how it compares to the system before when using the pyramid to analyse. There will be analysis of each level and explain the strengths and weaknesses of each system.

Current	New design
Pyramid level 1: The current format is very safe and has everything necessary to complete the tasks. The current system fulfills the task well.	Pyramid level 1: The new format keeps the good parts from the old one. The resources to complete the packing will be organised in a similar way but slightly clearer. The biggest improvement on tier 1 is still the removal of the suction lift and replacing it with automated solution. This increases the safety.
Pyramid level 2: The second level of the pyramid in the current system has some work to do. Despite the work area being lean already and there being an emphasis on making the ABB production very lean this current format is not as lean and clean as it could be. Due to there being old needs the old format was optimised to spread in to two different packing areas but since it is not needed anymore it is more of an hinderance now.	Pyramid level 2: In the new design flow has been linearized and the work area has been cleaned up and organized so the distance to materials is shorter. Other than this the tooling and tool organisation is great to move from the old one and the same is with the uniformity throughout the workstations which are not uniform only to this line but the whole drives production.
Pyramid level 3: The third tier is where the old system has the biggest problems. This is where the timing of the whole system doesn’t match	Pyramid level 3: The reliability will be kept from the old line, but the main change is staging the process. This will prevent the end being clogged by

up which clusters the products into the end of the line for unnecessary amount of time. This is the biggest drawback but otherwise the line pulls trough relatively smoothly and it is redundant and reliable.	the products that have reached it too early and wait for the orders to be filled. This will be done by the sorting and storage system. The sorting and storage system are automated and so is everything behind giving it 3 more working hours per day so it can be timed differently. This gives a better takt time and allows the whole process meet a higher demand.
Pyramid level 4: The final tier is where the current form is lacking the most. The only part which is used here is tracking and that is also only partly. SAP is used by ABB to track the stages of the process and what parts go into each product however this is by far not the level that a modern factory could be at. Also, there is no automation at any part of the process.	Pyramid level 4: Here is where the new format makes its gains. The tracking of the process will better especially on when each shipment will be ready, and the largest gains will be in automation. By automating the repetitive tasks, we can improve efficiency and the competitiveness of the process goes up as well.

Table 1: Tired comparison of proposed packing system to current one.

5 Discussion of results

In this chapter I will analyse the validity of the findings. I will discuss the limitations and how they have affected the results. I have concluded on and defend the results I have found.

Through this process my focus has been solving the task given by ABB thus making the focus of the study be very specific to it. As seen, I have focused only on technology which ABB is familiar with and is willing to implement in their factory. This has made the research scope narrower than if I were to study production in a broader scale. However, despite this being the case I believe that the result I have landed on is still highly valid.

The pyramid is based on the research I have done into the history of production in general. From the base it starts with the basics which are necessary for any production, and it builds up on each step from the ones below. The implementation of these parts cannot be organised in other way as they won't be beneficial to the production then since each higher level relies on the one below. The lower levels are based off the Toyota way theory but since the Toyota way was developed in 2001 the top levels are then the extensions which introduce modern technology to improve the competitiveness of production. The pyramid design which I landed on is a tool which can be used in any kind of production and not just this specific case even if the conclusion was gotten through this specific problem-solving process.

I landed on the pyramid theory after being inspired by the history of production and learning from other kinds of production systems. Every time the production would focus on the aspects at the pyramid order if not extremely close to it. The only difference I truly noticed was that the volume of production would greatly affect the importance of each step of the pyramid. For example, with Toyota a car manufacturer having volume of 1 vehicle every 66 seconds roughly (Toyota 2022). Will also need to focus much more on automation compared to my case study of ABB with a product every X seconds. This can even be seen in my friend's workshop who does a part in an hour or so how ever he only has a focus on the two base levels of the pyramid as it is the only ones needed to be competitive. Therefore, despite assembly and manufacturing being a wide area the findings of this study still prove to be accurate and true. This study was similar to other studies conducted by (Ranta, 2021)

For ABB it was clear that to maximise the packing line. For the new needs it would need to be viewed through the same lens. In the end the result was a partially automated but partially manual production line which would leave complex tasks for operators while relieving them from unergonomic and repetitive tasks. Through this split it is possible to time and buffer the system in a way that the system can handle the new capacity with the same space. Since the study used the case study of ABB as the building block it was focused and trough that limited into production methods used by ABB.

In the future it would be interesting to try to split the results of this study into small subsections and attempt to dig even deeper into each section of the pyramid to find tactics different industries and manufacturers use. Since this is a bachelors thesis the findings in this study area generalisation and a scratch on the surface on the real depths of the production industry.

Conclusions

Through this project on finding a suitable solution for ABB it became clear that the modern production is a refinement of skills and methods learned throughout the years. Technology has changed the layout and production flow, but the base principles have stood the time since the first production line by Ford.

In the beginning of this thesis the goals set by ABB to design a successful successor for the current packing line were:

- Automation of moving, lifting and storage
- Safety and Ergonomics
- Optimized flow
- Efficiency of manpower
- Organisation of products post testing

These have been able to be met. By using the presented production pyramid, they could be set in importance order and achieved.

The basics of successful production are safety, tools, and competent workforce. This is then followed by lean principles and the findings made by Toyota in their production reform. Finally comes the correct utilisation of technology and automation. Technology and automation are the current focus in production as they can greatly increase competitiveness with speed, flexibility, and repeatable quality. However, these can’t be implemented in a way that would benefit the producer unless the basic foundations are already well in place. This is true on the ABB case study, and it is scalable to other production industries as well.

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