Aalto University
School of Engineering

Master's Programme in Mechanical engineering

Improving material flow for large electrical chain hoist production

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Abstract of master's thesis

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Työn nimi Materiaalivirtojen parantamista sähköisten ketjunostinten tuotannolle

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Tiivistelmä

Tämä opinnäytetyö tehtiin nosturivalmistaja Konecranesille materiaalivirtojen parannuskohteiden löytämiseksi suurten sähköisten ketjunostinten tuotannossa. Sen sijaan, että työssä parannettaisiin tiettyä tuotantolinjaa, tutkimus keskittyy parannettujen materiaalivirtojen ja layout-suunnitelmien selvittämiseen ketjunostintuotannolle yleisellä tasolla hyödyntäen olemassa olevaa tuotantolinjaa. Ketjunostinten tuotantolinja Hämeenlinnassa on ollut alasajon alla kohdistuen pieniin ketjunostimiin. Tämän ansiosta voitiin keskittyä tuotantoon jäävien suurten ketjunostinten materiaalivirtojen kehittämiseen. Työn tekijä keräsi tietotaitoa osallistumalla nostinten asennukseen sekä paikalliseen kehitysprojektiin tehtaalla, mikä oli elintärkeää päätösten teossa materiaalivirtojen parannuskohteita selvittäessä.

Tutkimuksen kirjallisuusselvityksessä määriteltiin materiaalivirtoihin vaikuttavia tekijöitä, malleja, ohjesääntöjä sekä esimerkkitutkimuksia liittyen materiaalivirtojen ja layout-mallien suunnitteluun, visualisointiin ja parantamiseen. Kehityssuunnitelma saatiin aikaiseksi hyödyntäen tuoterakennetta, tuotannon nykyistä tilaa ja kirjallisuudesta saatuja malleja. Kapasiteettivaatimuslaskuissa käytetyt arvot olivat peräisin Konecranesin tietokannasta. Tuloksia selvityksestä vertailtiin myös ketjunostintuotannon kehitysprojektia edeltäneen ja jälkeisen tilan kanssa.

Selvitys johti kahteen parannettuun layout-malliin ja materiaalivirtakonseptiin vastaten kahta kysyntätilannetta. Päälöydökset materiaalivirtojen parantamiseksi käsittelivät muutoksia kokoonpanojärjestykseen, keräilyprosessiin, materiaalien säilytysmääriin, välivarastojen ja työpisteiden sijaintiin ja layout-malliin kysynnän kasvaessa. Opinnäytetyössä käytetyt keinot tarjoavat järjestelmällisen tavan selvittää tuotannon materiaalivirtojen parannuskohteita ja tutkimuksen tuloksena nostettiin esiin ketjunostintuotannon kehitysmahdollisuuksia Konecranesin hyväksi.

Avainsanat Materiaalivirta, kokoonpanoprosessi, keräily, tuotannonkehitys

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Abstract

This thesis was made for the industrial crane manufacturer Konecranes to find areas of material flow improvement for large electrical chain hoist production. Instead of targeting a specific production line for the improvement, the thesis focused on investigating improved material flow and layout designs for electric chain hoist production in general, while referencing an existing production line. An electric chain hoist production line at Hämeenlinna had been under ramp-down for small frame hoists. This created an opportunity to focus on improving the remaining large frame hoist production material flow. The knowledge gained from visiting the production line and participating in a production line development project was essential for the author to have sufficient competency towards determining the areas of material flow improvement.

The methods used for the research included a literature review to identify the factors affecting material flow. The literature review also compiled frameworks, guidelines, and case examples for designing, visualizing, and improving layouts and material flows. Along with a current state analysis of the product and production line, the thesis used frameworks from literature to determine what changes or logistics concepts could be implemented to improve the current production process material flow. The data for calculating capacity requirements for electric chain hoist production were collected from Konecranes database, and the results from the investigation were compared with the results from the development project and the state of electric chain hoist production in summer, 2021.

The material flow investigation resulted in two improved layout designs and material flow concepts to account for two demand scenarios. Main findings for improving material flow included changes to assembly order, picking process, stored material quantity, buffer storage and workcenter placement, and layout to account for increased demand. The methods used in this thesis provide a systematic process for finding improvements for a production process material flow and the results highlight further production development opportunities for Konecranes.

Keywords Material flow, assembly process, picking, production development

PREFACE

With this thesis, my studies have come to a well-deserved end. My academic interests from the start have been with material sciences, new technologies and production processes, and I am glad that I was able to study everything interesting for me from the start by majoring in Mechanical engineering. The study effort spanning more than six years in Aalto University have been the best time of my life so far and I cannot wait to start a new chapter in my working life. The bachelor's thesis was the first true academic challenge, which proved that I could tackle the upcoming challenges of the master's degree. The bachelor's minor in industrial engineering together with study focus on production engineering prepared me for working in projects related to production development.

My relationship with Konecranes started in summer 2019, when I was employed as an assembler at the Konecranes Hämeenlinna factory for small wire rope hoist production. By working there, I was introduced to the working principles as well as the local personnel. I was able to make a lasting impression and I was allowed to continue working there in the following summer, albeit as a purchaser. This was significant for my career because it was the first time, I got to use my knowledge from studies in practice. At the end of my working contract, I asked my previous supervisor for contacts regarding master's thesis opportunities, which led me to working in my current team for production development and writing this thesis.

I could not anticipate the effort, which was eventually required to finish this thesis. From the introduction to a completely new product and working environment to determining the thesis focus and contents, the challenge was outstanding. However, I would like to thank all my co-workers, friends, relatives, and my mother that have supported me throughout my working life and studies, but special thanks are reserved for my thesis advisor Patrick Lindahl and thesis supervisor Sven Bossuyt for their guidance in completing this thesis, and production supervisor Aki Lampinen and development engineer Siiri Valkeajärvi for cooperation in the production line improvement project for Hämeenlinna.

Hyvinkää, 28th February 2022

Valtteri Saari

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ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
5s	Lean tool: sort, set in order, shine, standardize, and sustain
ACF	Chain hoist electric provision
APAC	Asia-Pacific region
ATO	Assemble-to-order
Bin	Buffer storage shelf space
BOM	Bill of materials
BPS1	Blank paper scenario 1
BPS2	Blank paper scenario 2
CC	Contol cycle
CLX	Standard chain hoist motor type
CRANE	Chain hoist electric provision
CTO	Configure-to-order
CWH	Central warehouse
DFA	Design for assembly
DMAIC	Define, measure, analyse, improve and control
eBOM	Engineering bill of materials
ECH	Electric chain hoist
EMEA	Europe, Middle East, Africa region
ERP	Enterprise resource planning
ETO	Engineer-to-order
EX-proof	Explosive proof
FAT	Factory acceptance testing
FL02	Small frame chain hoist size variant
FL05	Small frame chain hoist size variant
FL10	Small frame chain hoist size variant
FMS	Flexible manufacturing system
Gemba	Lean tool: visiting and evaluating a production line
GLS	Rotating geared limit switch
HH1	Konecranes Hämeenlinna factory 1 for small wire rope hoists
HH2	Konecranes Hämeenlinna factory 2 for large wire rope hoists
HH8	Assembly area in HH2 for electric chain hoist assembly
IoT	Internet of things
JIT	Lean tool: Just-In-Time
K16	Large frame chain hoist size variant
K25	Large frame chain hoist size variant
Kaizen	Lean tool: continuous improvement
Kanban	Lean tool: identification method for workflow scheduling
KHH	Konecranes Hämeenlinna factory area including HH1, HH2, KHT and HH8
K-hoist	Konecranes chain hoist (FL02-FL10, K16/K25)
KHT	Konecranes Hämeenlinna gear factory
KPI	Key Performance Indicator

Lean	Production improvement philosophy derived from Toyota production system
LINE	Linestock
LSS	Lean six sigma
mBOM	Manufacturing bill of materials
MFAM	Framework for material flow assessment in manufacturing
MRP	Material resource planning
MTO	Make-to-order
MTS	Make-to-stock
NECH	New electric chain hoist
NEO	Small electric chain hoist product variant with inverter and SLX motor
oBOM	Order bill of materials
PDCA	Plan, do, check, act
PHAN	Phantom assembly
PO	Production order
PRIO1	Priority 1
PRIO2	Priority 2
PRIO3	Priority 3
PTO	Purchase-to-order
PTS	Purchase-to-stock
SAP	A commercial enterprise resource planning software
SCM	Supply chain management
SIPOC	Suppliers, Inputs, Processes, Outputs and Customers
SLX	Special chain hoist motor type
SOLO	Chain hoist electric provision
superBOM	Super bill of materials
SUPPLY108	HH8 supply area for small electric chain hoist materials
SUPPLY109	HH8 supply area for large electric chain hoist materials
SWOT	Strengths, weaknesses, opportunities, threats
TO	Transfer order
TPT	Throughput time
TRAV MACH	Trolley travelling motor
WIP	Work-in-process
VSM	Lean tool: value stream mapping

1 INTRODUCTION

Under the changing markets of the industrial equipment industry, production efficiency and ability to forecast and react to changes is crucial for maintaining competitive advantage and customer relations. Modern manufacturing companies collect a substantial amount of data from suppliers, customers, and various steps of different production processes. This data as well as technologies, such as real-time monitoring, and internet of things are used to create accurate models about the operating costs, future trends, and production and logistics performance. However, despite having access to the data, determining the potential areas of improvement, and reacting accordingly is often proven to be challenging for large industrial equipment manufacturers. Frameworks, such as Six sigma have been developed to increase production quality, and methodologies, such as Lean are used in production improvement by providing a stepwise approach for eliminating redundant processes. Combining these production improvement approaches often results in increased productivity and production efficiency. This thesis uses a systematic approach for determining the areas of material flow improvement and the most efficient material handling strategy for an industrial equipment production process.

In this chapter, we will go over the background and objective of the research regarding material flow improvement for a specific product type. The introduction will be followed by a showcase of research questions, research focus, restrictions, and structure, and finally, we will be introduced to the company for which this thesis is done.

1.1 Background and problem statement

Electric chain hoists (ECH) are fast and easy-to-use workstation hoists primarily used in material handling tasks of mainly indoor manufacturing and assembly processes. This thesis focuses on the ECH product family of industrial crane manufacturer Konecranes. Internally, the ECH products of Konecranes are called K-hoists, and the product family of K-hoists is divided into small and large frame sizes. We will be introduced to Konecranes as a company in chapter 1.5 and we will go in more detail of the K-hoist product structure in chapter 3.2.

Konecranes manufactures K-hoists in Europe, USA, and China, and has access to markets across the world as a result. The European chain hoist production has been the most important production site, since both the hoists as well as sub-assemblies needed in the other K-hoist production facilities are produced there. The production process of K-hoists has previously had numerous research and development projects, which have included both assembly process optimization and product structure iteration. Currently, the assembly process of K-hoists involves mostly manual labor, since production flexibility is critical for a configurable product such as the K-hoist. However, differences in the production process exist between regional facilities.

The K-hoist production line in Finland was set up in 2019 at the Hämeenlinna factory (KHH), and the product scope of the factory includes small frame size K-hoists FL02, FL05 and FL10 as well as large frame size K-hoists K16 and K25. The main purpose of the K-hoist production line in Hämeenlinna is to support the global K-hoist production, until the re-design and ramp-up of the new electric chain hoist (NECH) model is established in Wetter, Germany and Jinjiang, China. The production line in Finland was designed from the start to be a temporary production line and the production ramp-down would be conducted sequentially as the orders for the older product could be converted to the new model. In short, when the production capability of the NECH product is ready in the other locations, the subsequent ramp-down of the Hämeenlinna production line is followed through.

Currently, the ramp-down process has already been started in Hämeenlinna, which causes the production for orders of small frame size K-hoists to be significantly reduced and eventually seized completely. This change in future production volumes provides an opportunity to improve and optimize the material flow and storage of components still used after the small frame size K-hoist components are no longer needed. Therefore, the focus of ECH production line development in Hämeenlinna should be in component storage relocation, layout redesign and assembly process enhancement so that the production line better serves the production of large frame size K-hoists.

This thesis focuses on determining the means of material flow improvement in large ECH production, and how the material flow of such production processes can be assessed. An optimized material flow for large K-hoist production in general is later investigated to provide a recommendation for ECH production material flow improvement.

1.2 Research questions

The research questions of this thesis direct the literature review to find answers important for production process material flow improvement. The questions are listed below. The first question is about determining what production process material flow is for manufacturing industry instead of process industry. It is important to understand the topic and differentiate the terms used in research, since similar terms are also used in other industries. The second and third questions are the most fundamental questions for material flow improvement in this thesis. The factors affecting material flow and means used to improve material flow should be known and addressed before creating a case specific plan for improvement. The fourth question goes more in-depth about determining the internal logistic possibilities and the fifth question is significant for the comparison in chapter 5. All in all, the research questions form a structure needed for systematic material flow improvement process.

1. What is production process material flow?
2. Which factors affect production process material flow and how?
3. What means can be applied to improve production process material flow?
4. What logistic strategies exist for material handling in factory environment?
5. How can a production process material flow be evaluated?

1.3 Research restrictions

This thesis focuses on the large frame size variants of the electrical chain hoist product family. While the small frame size hoists are still relevant in production and need to be accounted for during the ramp-down, the thesis strives to assist the remaining production of large frame sizes until the production of large K-hoists in Hämeenlinna is ended. However, the research conducted for determining factors influencing material flow in production as well as means for assessing material flow performance can be used and reflected also for other production processes and ECH production in general. The data available for material flow optimization in this research is based on interviews and existing information about the K-hoist assembly cell in Hämeenlinna, production process, logistics involved as well as available literature about material flow improvement and relevant topics.

This thesis will determine the areas of material flow improvement for ECH production, and key performance indicators (KPIs) and metrics used to evaluate and assess the material flow of K-hoist production. The result will include a recommendation for an optimized material flow and an improved layout design for general large K-hoist production while including improvements for material storage and transportation and material replenishment principles. The performance and capacity of current state production in Hämeenlinna will be used to determine the capacity requirements for ECH production in general and the results from the investigated material flow improvement will be compared with the Hämeenlinna production line.

Since, the recommendation will be based on research and assessment, and the performance cannot be tested in practice in the timeframe of the thesis, the results will have an aspect of subjectivity and uncertainty. Currently, the available factory floor space, production line exits and entrances, and the quantity of buffer storage materials provide physical restrictions for the material flow in the Hämeenlinna production line. However, the improved material flow recommendation for general ECH production will only be restricted by estimated demand and product mix.

Material flow is analysed across the entire production process, but the focus will be on the factory operations between production planning and packing of the finished goods. Therefore, physical material flow from external suppliers and the outward logistics are excluded. The sales process and product configuration process will not be part of the thesis focus but were studied by the author as part of the introductory period of the thesis contract.

1.4 Research & thesis structure

Before conducting the research regarding material flow improvement, it was critical to have a thorough understanding of the sales process, product configuration, product structure, assembly process of the K-hoist as well as the material management of K-hoist components in SAP ERP software. The first two months of the thesis contract period was reserved for introduction to the product, which was followed by 1,5-month on-site factory floor practical training to the assembly process at Hämeenlinna. Following the practical training period, a 1-month production development project was initiated regarding material mapping, storage re-design and layout changes for the K-hoist production line, which the author was participating in.

The research of this thesis was conducted to support the systematic material flow improvement process and it consists of multiple parts displayed in Figure 1, beginning with a literature review. The review is followed by current state analysis of the K-hoist production process, determination of the areas of improvement regarding K-hoist production and investigation of an optimized material flow using findings from literature and knowledge from the practical training. Finally, the performance of the proposed material flow is assessed and compared with the state of ECH production before and after the Hämeenlinna production line improvement project. Comparing the results gives us insight on whether the improvement project was successful and what changes would improve the ECH production material flow in general.

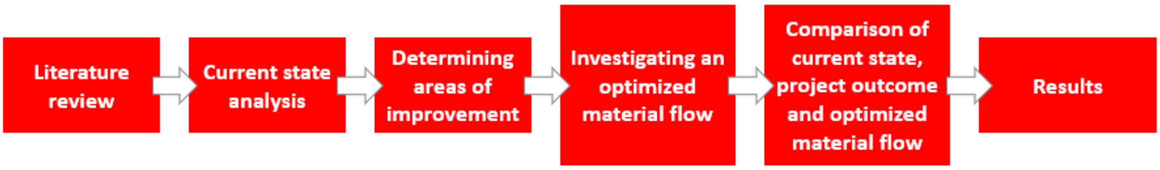


Figure 1: The structure of the material flow improvement research

The thesis structure follows closely to the structure of the research. The structure of the thesis is shown in Figure 2. The thesis consists of six main chapters. This introductory chapter is followed by the literature review. First, the literature review is done to assist the reader to better understand what is meant by material flow in industrial equipment production. The second goal of the literature review is to determine the factors influencing material flow and elaborating the means of material flow improvement by showing the results from existing research on the topic. The literature review is followed by a current state analysis of the Konecranes ECH manufacturing facility in Hämeenlinna. The "current state" in this case refers to the state of ECH production in July 2021. The chapter starts by explaining the background of K-hoist production, which is followed by detailed display of the product family and structure as well as the production process in Hämeenlinna. The current state analysis also includes details about the layout, material flow and information about the production process flow.

After understanding the product and the state of K-hoist production in Hämeenlinna, we will discuss the areas of improvement regarding material flow in the current state. This is followed by the showcase of the KHH production development project results, and the investigation to determine improvements to the ECH production material flow. The results of the investigation are then compared to the current state case and to the development project results and evaluated to provide a final recommendation regarding material flow improvement.

The final chapter is about conclusions from the comparison and finding which performance factors are important for material flow analysis, what effect the changes had on the performance of the Hämeenlinna production line, and what changes would improve the ECH production material flow in general.

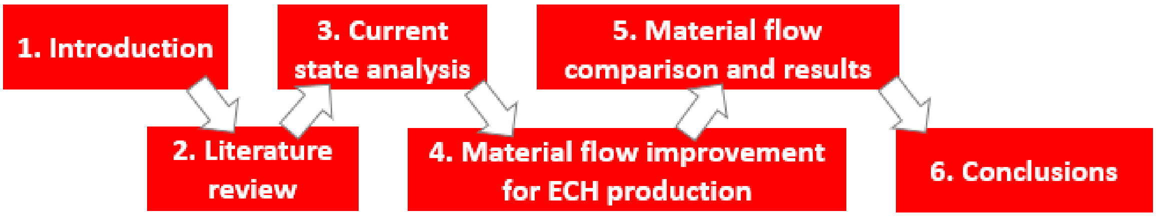


Figure 2: The structure of the thesis

1.5 Company introduction

This thesis is done in association with Konecranes Finland Oy. Konecranes is the world largest industrial crane supplier that offers lifting solutions and service for manufacturing and process industries as well as for shipyards, ports, and terminals [1]. The main business areas of Konecranes can be divided into three categories: service, industrial equipment, and port solutions [2]. The sales distribution is quite even across the different business areas, while service still being the largest source of sales revenue as of 2021 (Figure 3). The basis for the service is systematic, preventative maintenance and consultancy for different customer needs [2]. The methods used for conducting service and utilization of real-time data of the on-site equipment are the focus of research and development as digitalization is adopted more thoroughly in the operations of the company [2]. Automation is also in the forefront of the latest development in industrial equipment and port solutions [2]. Konecranes already utilizes fully automated and semi-automated processes for the manufacturing of commonly used parts and components, such as gears and shafts but the automation of other factory processes including testing, product confirmation and material transportation still involve mostly manual labor.

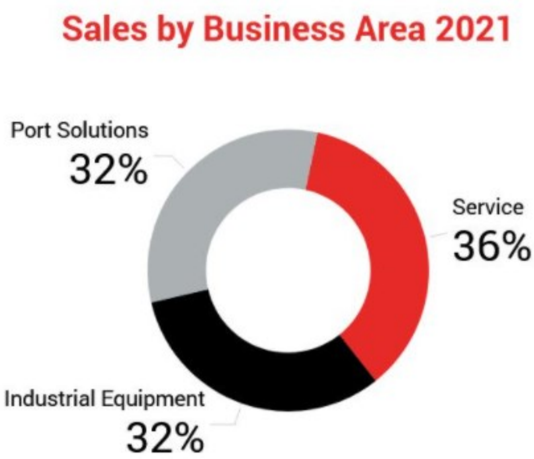


Figure 3: The sales distribution of Konecranes business areas in 2021 [2]

Konecranes manufactures a range of various lifting equipment. These lifting products are either configured-to-order (CTO), where the configuration is chosen by the customer from a selection of features, which usually consist of lifting capacity, lifting speed and height of lift. Other products include engineered-to-order (ETO) products, where the hoist or equipment is unique and built precisely according to customer specifications.

The topic of this thesis is included in the industrial equipment business area. The Konecranes industrial equipment lifting products include a range of workstation lifting equipment, such as workstation cranes, jib cranes, air balancers, manual products, and electric chain hoists [4]. In Figure 4 we can see examples of the Konecranes branded ECH products, K-hoists (small frame size on the left and large frame size on the right).

Figure 4: Konecranes branded electric chain hoists [22]

Other Konecranes products include wire rope hoists, rope hoist technology, hoists for hazardous environments, such as nuclear power plants and waste management facilities, container handling systems, carriers, shipyard cranes, lift trucks as well as licenses for AGILON automated storage system. In addition to the wide range of products, Konecranes also provides world-class service and expertise for new and existing Konecranes-branded lifting equipment, and for products of other crane manufacturers, which is unique among most competitors. [4]

Currently, Konecranes employs 16,900 people in 50 countries around the world [1]. The company headquarters is in Hyvinkää, Finland along with the factory for large wire rope hoisting equipment. Other key locations include the factories in Hämeenlinna; Finland, Springfield; USA, Jingjiang; China and Wetter; Germany. The Wetter factory is the most recent addition to the factories that manufacture under the Konecranes partner businesses [5]. The factory is the result of the MPHS business acquisition of Terex Corporation [5]. MPHS is a large lifting equipment manufacturer that produces chain hoists and other services under the brand Demag. As a result of this acquisition, the Demag brand was added to the Konecranes partner brands.

During previous business acquisitions, Konecranes has adopted the multi-brand strategy with their products and services. Some previous notable business acquisitions, which resulted in different branded products in the Konecranes product range include R&M Materials handling, an US hoist brand, Verlinde, a French chain hoist brand and MAN SWF Krantechnik, a German hoist brand. The strategy of offering a range of multi-brand products ensures that customers, with business history with set brands, stay satisfied and are keen on maintaining relations and staying as customers. The current strategy of the company focuses on strengthening its core competencies [2]. These include a diverse and strong customer base, level of knowledge regarding hoisting systems and processes, the use of latest technology, and the systematic approach on service [2].

The latest venture for Konecranes was announced in 2020 that the company would merge with the container handling equipment manufacturer Cargotec [3]. Both companies benefit from the agreement since the level of competence in port operations and material flow handling is substantial with both companies and the combined venture would place Konecranes and Cargotec as the global leader in sustainable material handling. The direct benefit of the merging is the possibility to share knowledge from research and development projects, possibility to share resources, and it would also allow other projects in the future to be conducted by joint efforts. The deal also would combine the existing customer base of both companies and increase the global customer service network in each continent. The merger of the two companies is estimated to begin in the mid of 2022 if all the conditions of the agreement are met. [3]

2 LITERATURE REVIEW

Material flow has a significant effect on the efficiency and productivity of any production facility. Manufacturing companies strive to optimize the material flow through the entire production process to improve lead times and reduce work-in-process (WIP) and inventory holding costs. The materials in "material flow" in this case refer to raw materials, components, semi-finished goods, sub-assemblies, documents, waste, or finished products that are needed or resulting from different stages of a production process. Instead of specifying the term used in different stages of a production process, engineers, production planners, workers and related staff often refer the components flowing through the process as materials or items.

In this chapter we will discuss the effects of material flow in a production process and research conducted on material flow improvement. First, we will elaborate material categorization as well as material flow as a concept to have an introduction to the topic. Second, we will discuss the factors affecting material flow in production and the different strategies for material handling. Finally, we will showcase the results from a Lean approach for material flow improvement and existing research on material flow improvement for different production processes.

2.1 Material categorization

Materials are often categorized by type, such as actual material and production method, e.g., cast or rolled steel components, or by properties that support supply chain management (SCM). Management of materials and services needed in the process of transforming raw materials and other resources into finished products are essential to allow products to be delivered customers. For manufacturing companies, one of the most useful material properties is whether the material is purchased, manufactured, or configured either to stock or for orders. This information about production materials is important in SCM because by understanding the supply chain operations and the manufacturing or procurement strategy of materials involved, companies gain significant competitive advantage in changing and evolving markets by managing production requirements more effectively [6]. These requirements include for example logistic needs, stock placement, lot size and buffer replenishment strategy for each material [8, pp. 549-550].

Through digitalization, modern companies have adopted the use of enterprise resource planning (ERP) systems in managing the data and information of enterprise operations [7]. Specific data can be generated and collected from different ERP software tools such as material requirements planning (MRP) tools. MRP is used to generate procurement proposals, which are designed to either create demand proposals for internally manufactured materials or for materials that are procured from external suppliers [8, p. 545]. These two types of materials require different planning steps and therefore can be categorized under separate planning processes: MRP for in-house materials and consumption-based planning for procured materials [8, p. 547].

Materials that are manufactured in-house and used later to produce products for customer orders can be categorized further based on the manufacturing strategy and complexity of the material [9]. Companies can opt to produce materials belonging in one or multiple different categories. Example categories for in-house manufactured materials are listed below [9, 10].

1. ETO Engineer-to-order
2. CTO Configure-to-order
3. MTS Make-to-stock
4. MTO Make-to-order
5. ATO Assemble-to-order

ETO materials are completely designed based on individual customer requirements and are often the result of an entire manufacturing process. They are highly customizable products possibly consisting of several components which might need completely new production methods or molds to be manufactured. These production steps need additional planning and engineering, and the production lead times are often long compared to products in other material categories. CTO materials are often the end-products of a production process or modules of another ETO or CTO product, but unlike ETO materials, they are configured and assembled from a selection of modules. These modules are pre-determined and designed so that they are modular with each other, and the production methods and materials needed are already known for each module. This makes the CTO products highly customizable while maintaining short production lead times. [10]

Most in-house manufactured materials, which are used in sub-assemblies and in later steps of a production process, are MTS or MTO materials. The differentiating factor between the categories is the manufacturing strategy [9]. Materials manufactured to stock are common parts of an assembly and the consumption of stock materials is consistent. Since MTS components are stored without a specific usage date, they bind manufacturing and inventory holding costs. MTO materials are only manufactured when the demand proposal is generated based on confirmed customer order [8 p. 524, 9]. These materials can be too large for storing, expensive or the consumption of the material might be irregular, which make the materials undesirable to be manufactured directly to stock.

ATO materials are hybrid materials where production strategies of both MTS and MTO materials are utilized. The production strategy for ATO materials includes manufacturing sub-assemblies and collecting components and required parts beforehand based on demand estimates. However, the final assembly is done only after the customer order for the product is confirmed. ATO production is favored instead of MTO production when it is desirable to increase production volumes and product customizability is low. [9]

In contrary to the planning of in-house manufacturing, procurement planning is mostly based on the stock quantity and consumption forecast of materials. Typical material categories for externally procured materials are listed below [11].

6. PTS Purchase-to-stock
7. PTO Purchase-to-order
8. LINE Linestock

PTS materials are the most common material types used for production processes in most cases. These materials have a consistent consumption history and procurement proposals for PTS materials are created after the stock quantity drops below the re-order point. The re-order point for a material is assigned based on the delivery time provided by the supplier. Stock materials also have a safety stock to prevent the stock quantity from reaching zero and to better adjust to variations and changes in delivery times. PTO materials are ordered only after customer orders are confirmed. The advantage of PTO procurement strategy is the more accurate supply practice than with PTS materials. It also supports a pull-type production, where production and procurement are initiated only after orders have been received. [11]

Lastly, nuts, bolts, and other fasteners and sealings used in the production process can be categorized under linestock materials. This material category is commonly referenced internally at Konecranes and is more likely a practice specific to Konecranes. These materials are most often ordered from a local supplier and the supplier automatically replenishes the stock of linestock materials directly to the production line when the stock reaches the reorder point. The consumption of individual linestock materials is not usually counted, instead, the replenishment occurs when an entire box of these materials is emptied. The act of opening a new box of linestock materials is marked, which notes the supplier about the current stock level. The production line often contains two or more boxes of a specific linestock material to prevent the materials from running out.

Other sub-categories can exist for manufactured or procured materials, for example if it is useful to determine whether a component is procured from a sub-contractor or if the material is part of consignment stock. A material can also consist of several other purchased or manufactured components or assemblies. These assemblies which can be configured from multiple options but are always maintained under a higher-level assembly in the bill of materials (BOM) of a specific material, are called phantom assemblies (PHAN). A BOM is a list of all the materials required to manufacture a specific product and the possible variations of the product. Phantom assemblies cannot be manufactured to stock, instead, they are always made for the parent assembly or the following assembly process. The name of the material category stems from the fact that phantom assemblies do not consume the materials in the MRP, but the materials are consumed when the assembly is used to make a higher level BOM item. They can consist of both MTO/PTO and MTS/PTS materials as well as linestock materials. [8, pp. 72-78]

The category of each material is determined by certain material properties. Companies can use different parameters for determining a specific material category and the methods for maintaining the information about the material properties varies based on the resource planning method used. In SAP, an ERP system, SAP demand management is used to manage planning strategy for each material that passes through a production process. Planning strategy identifies materials that follow either MTS or MTO production strategy, or that require planning for sub-assembly or final assembly operations [8, p.522].

In SAP, Material master is assigned for each material used in the production process, which contains all data and information of the materials needed for MRP and demand management. Parameters for identifying material categories are saved in the material master data of each material. These parameters include for example procurement type, special procurement type code, bulk material indicator, individual/collective indicator and whether the material is configurable. Example conditions leading to a specific material category is presented in the Table 1 below. Procurement type F is assigned for purchased materials, E is for manufactured materials and X is assigned if the material can be acquired in both ways. The individual/collective indicator signifies, whether the material is acquired for orders (1) or based on current stock level (2). [8, pp. 204-210]

Table 1: SAP Material categorization conditions [8, pp. 207, 522-548]

Category	Procurement Type	Special Procurement Type Code	Bulk Material Indicator	Individual Collective Indicator	Material is configurable?
LINE	F		Yes		
SELECTION.PHAN	E	50			Yes
PLANNING.PHAN	E	60			
PHAN	E	50			
CTO.SUB		30			Yes
CTO					Yes
PTO.SUB	F	30		1	
PTS.SUB	F	30		2	
CONSIGNMENT.PTO	F	10		1	
CONSIGNMENT.PTS	F	10		2	
MTO	E			1	
MTS	E			2	
PTO	F			1	
PTS	F			2	
MPTO	X			1	
MPTS	X			2	

2.2 Material flow

As discussed in the previous section, categorization affects the storage type of materials used in production process. The storage type and storage location as well as the processing location affect how materials are moved through the production process. This handling and movement of materials in and out of a production process and the logistics involved are referred as material flow [12 p. 223].

To understand the steps of a supply chain and the relation of material flow in logistic processes, we will elaborate the general concept of production process flow further in the following sections as well as the factors impacting material flow performance.

The process flow of Konecranes electric chain hoist production is detailed later in chapter 3.3.

2.2.1 Process flow & logistic processes

The entire order-to-delivery process of a manufacturing company starts from the customer ordering process and ends when they receive the ordered product (Figure 5). In between the beginning and end of the order-to-delivery process is the production process, which is often unique to the company in question. The network of stakeholders and process steps during the production process is the supply chain of a manufacturing company, and the movement from one step of the supply chain to another is called process flow. [12, p. 224]

During the order-to-delivery process, materials are transported from the supplier to a storage location based on the storage and warehouse management information of the materials. The information about the status of the materials in the storage enables the material handling and material flow operations to start in the production facility. The materials are later consumed during the production process. Finally, the finished goods are dispatched to the customer and thus, the order-to-delivery process is finished. [12, p. 224]

Figure 5: Order-to-delivery process flow (modified) [12 p.224]

The movement of materials during the different supply chain steps is conducted via logistic processes. Logistic processes involve material transformations tasks, which are completed by material flow operations. Transformation tasks change the material status regarding characteristics, such as time, place, quantity, configuration, appearance, or information. For example, a transformation task can be about relocation of certain components from supplier's storage to a production line buffer. This relocation process changes the place where the components are held, the duration the components are held at the new location, and possibly the quantity of the total sum of existing components, if not all components are moved out from supplier's storage. This relocation is completed by material flow operations usually in the following order: components are collected from the storage, material handling and transportation is done to prepare and deliver the components to the right location and finally, the components are distributed to the correct buffer storage. The components might also need to be packed for transport, which is done to complete the transformation task about change of material appearance. [12 p. 228]

2.2.2 Information flow

To manage the process flow and logistic processes through the supply chain, and to be able to produce and deliver products to customers based on desired specification, a flow of information about materials and different processes needs to be sustained through the entire supply chain. In production facilities, the information flow consists of functions required for preparing and conducting logistics processes and production processes. This information is maintained using information systems. Information systems include the software and physical devices used to plan, control, and manage production related tasks, material storages, and to communicate between operators, managers, and production engineers. [12 p. 365-366]

Data can be submitted to information systems manually or automatically. The physical medium of the information flow can be for example written notes or Kanban identification about the state of assembly process or production orders. Kanban is a practical solution to reduce unproductive time and to support a pull-type production principle. The Kanban notes and identifications can be manually inputted later directly to an information system using on-site digital devices or computers. Data can also be collected automatically, for example about the quantity of specific components in a buffer storage. This can be done by automatically reducing the number of total components in a buffer with the quantity of components consumed for products during the assembly process. In production facilities, the information systems are software systems, such as ERP systems or ERP tools, which are used to manage all production processes and data about material requirements in the supply chain. [12 p. 366]

The main purpose of information systems is to assist production planning and production preparation. One of the main challenges in operating production facilities is to maintain the balance between maximum capacity utilization and flexible production while minimizing process costs. One method to maintain the balance is to seamlessly integrate the information flow with physical material flow during production process. If the information about the procurement and distribution of materials is not recorded properly, it affects the material flow performance during the production process by increasing issues for practical material handling and creating misinformation about the state of material storage. Therefore, it is more beneficial for a production facility to consider both information flow and physical material flow during production improvement process instead of focusing on only material flow design. [12 p. 366]

In production facilities, material flow optimization is often one of the goals of production development projects. The tasks that need to be considered during such project also involve information flow planning tasks. Examples of such tasks are coordination of flows in the production process, defining the evaluation method for the information flow performance, selecting an information flow system, selecting logistics principles, selecting suppliers, creating a simulation model of the process flows and developing the storage method for the information system data. Once considered, these tasks support both the material flow optimization process as well as order workflow. [12 p. 243]

Order workflow depicts the order in which tasks and operations are done after a customer order is received. The operations in order workflow include both physical material flow and information flow. Information flow consists of flow functions, which are conducted in a specific order. The flow functions in order workflow are displayed in the Figure 6. From the Figure 6, we can differentiate the information flow functions and their relations. Often overlooked aspect of the information flow is the last function, data backup, which is critical in ensuring the ability to react to data losses and errors during order workflow. Data processing is done in similar functions for other order workflow processes as well. [12, p. 368]

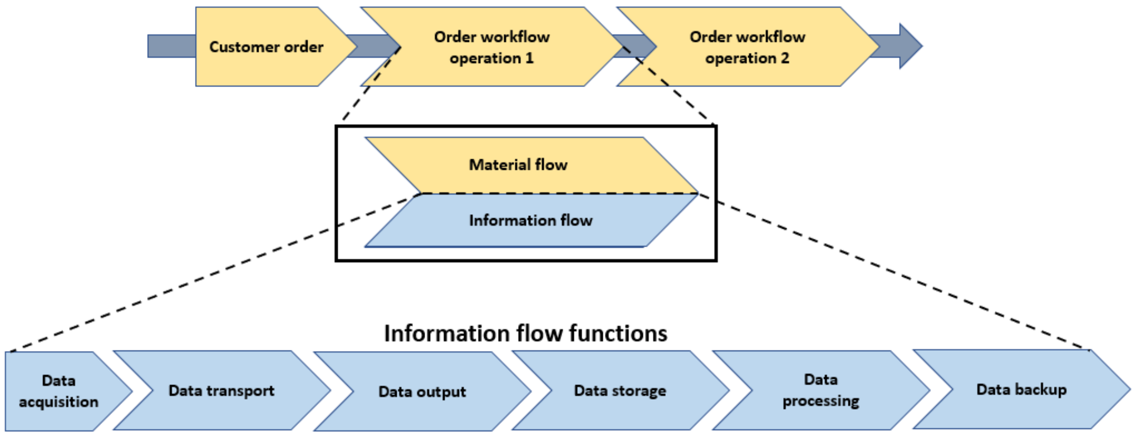


Figure 6: Order workflow information flow functions (modified) [12, p. 368]

Despite being an integral part of order workflow in production facilities, information flow and collaboration between warehouses, production facilities and logistics are significant challenges to overcome. Qu et al. [14] discuss the effects that increasing production output has towards available floor space. They discovered that often increasing the production output consumes inventories faster than they can be replenished, which results in a need for larger inventories. In practice, inventory and buffer space is limited, so one solution to the problem is to integrate a real-time dynamic synchronization of production logistics and resource replenishment. This can be done for example by applying Internet of things (IoT) solutions [14].

IoT refers to a network of digital devices and sensors embedded in a production process to automatically analyse and evaluate real-time data from the condition of production equipment or the state of a production process. This data can be used to create dynamic models for monitoring the performance of the production process and to forecast storage changes and maintenance requirements. Real-time monitoring is often used simultaneously with software-based manufacturing execution platforms, such as cloud manufacturing platforms, which are used to organize the use of resources and allocate service for manufacturing processes. [14]

2.2.3 Internal material transport principles

Internal as well as external transport tasks require planning similar to logistic processes based on material categorization. While the costs resulting from transport tasks are not as high as they are for logistics processes, they are directly influential for the flexibility of the production process. Without material specific internal transport principles, risks of material shortages occurring in the production line are significant [12, pp. 246]. Internal transport principles for production facilities can be divided into material picking and material storing in buffer storages [12, pp. 248, 253]. In SAP, the transport principles, e.g., picked for orders or supplied to buffers, are also referred as control cycle (CC), and the CC information of each material directly affects the material categorization. For example, picked materials are most often PTO materials, while buffer materials are MTS/PTS materials.

In SAP, the stock materials (MTS, PTS) have replenishment values assigned to their individual material master information. The replenishment information includes the minimum and maximum stock quantities and the replenishment value i.e., the quantity of materials that are supplied to the buffer storage at a time. The buffer materials are usually replenished by one pallet or container at a time. Therefore, the size of the package or pallet as well as the frequency of consuming materials during the assembly process influences the replenishment quantity. An optimized strategy for replenishment, and the quantity of replenished materials can directly improve the material flow and costs of material holding.

Picking in a production process means gathering and preparing of materials, components and raw materials required for a specific step of an assembly process. In practice, this involves material movement from one or multiple storage locations closer to the assembly area and compilation of the materials into one storage container or containment area. The decision regarding which materials should be picked and which should be always kept close to production line depends on the usage of the materials. Picking is mainly required for materials that are already subassemblies, require fixturing, measuring, testing, or are procured or manufactured for specific orders. However, different priorities for production efficiency create exceptions and other criteria influencing the decision can also include the size and weight of the material as well as consumption frequency. [12, pp. 248]

To support an efficient picking process, the strategies related to picking process should be considered. The priority in planning the picking process is mostly influenced whether the process is manual or automated. For manual processes, the most important consideration is about the movement between storage areas to retrieve the components using optimal routes to minimize the process lead time. Typical picking strategy examples can be seen in Figure 7. For automated processes, additional strategies need to be considered, for example, how batches are handled with different materials and different volumes. Other considerations include the order, in which the components are retrieved as well as the equipment needed for retrieving the materials. [12, pp. 252]

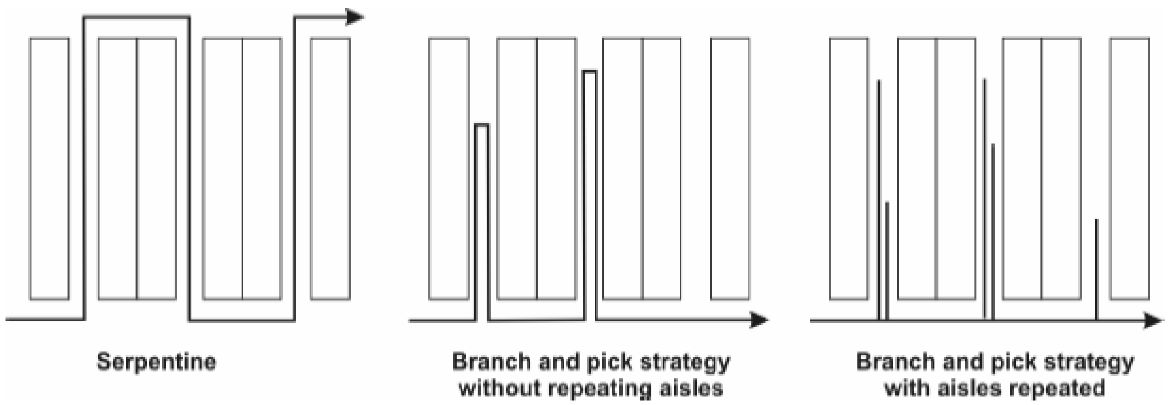


Figure 7: Picking strategies [12, pp. 252]

Since manual picking tasks require additional labor, determining the picking process requirements should be planned before the in-line material storing. In addition to material transport and compilation, picking might also involve labelling, arrangement to sets or pre-assembly processing [12, pp. 251]. Materials should be picked only when the transportation principle supports efficient utilization of production capacity. Therefore, materials not suitable for picking should be maintained in the production line buffer. The performance of a picking process can be evaluated using the following equation (1) and picking parameters [12, pp 253]:

$$Picking\ time = Basic\ time + Travel\ time + Grab\ time + Dead\ time, \qquad (1)$$

where:

- Basic time = time spent on collecting the equipment required for picking process
- Travel time = time spent for movement along the route between storage locations
- Grab time = time spent on collecting the materials from a storage location
- Dead time = time spent on searching and counting the materials

Picking quality is mainly affected by the number of picked goods and picking accuracy [12, pp 253]. Maintaining high picking accuracy is challenging when components are picked from multiple locations and the number of total components picked is large [12, pp 253]. Production processes that include long picking times, picking quality can have significant impact on the production productivity and efficiency. The impact of picking quality errors increases when the travel time of the picking process increases because fixing the issues requires the personnel to return to the storage area, and if the travel time is long, fixing the picking issue also takes longer. Standardizing the picking instructions would alleviate the risks involved in the process.

Buffer storage serves as the in-line storage space (bin) reserved for fast moving and frequently used components in an assembly process. Buffers can be reserved for work-in-process (WIP) materials between working areas, and they can also be divided into stationary and moving buffers [12, pp. 253-254]. Stationary buffers are more common in pull-type manufacturing facilities since assembly is initiated after a production order is received, which requires components to be readily available so the assembly process can begin as soon as possible. In process industries, automated buffers, such as conveyors are more common since processing is done at much faster rates and larger volumes. One of the goals for an efficient production process is to reduce WIP storages because having unfinished goods in the production process binds costs, increases lead times and if the order is cancelled during production, unfinished goods risk not being able to be sold or salvaged. However, having buffer storages for both common materials and WIP increases the flexibility of the production line and ability to react to workload changes. This improves both the production adaptability and competitiveness.

Usually, companies choose the storage principles based on the product related requirements or existing practices. Neither principle is optimal for all manufacturing processes. Therefore, the practical solutions include both types of material storing. A storing principle, which utilizes elements from buffer storing and picking is in-factory material picking or “supermarket” principle [31]. The principle is based on the milk run practice, where only one route is taken during which all necessary materials for manufacturing are picked and supplied to different locations in the production line [31]. The route and schedule for a milk run can be pre-determined based on product type and multiple milk runs can exist for different product variants [31]. The milk run practices are commonly used for example in automotive industry [32]. The milk run routes can be maintained for different production processes based on the SAP routing information for specific products. SAP routing includes all workstations required in the assembly process of a product. The workstations are presented in the routing in the correct order and the information of the process cycle times are included for each workstation individually. By adding the cycle times of the workstations together, we can estimate the routing duration for the assembly process. The name “milk run” stems from the early practice of milk delivery, where empty bottles were replaced with full bottles of milk and after all bottles on the route were collected, they were brought back to be washed and refilled [32]. The concept and name have been adopted in many industries and factories which utilize Just-in-Time (JIT) production principle [32].

Klenk et al. [31] investigated the common milk run concepts of automotive industries, ranging from the general conditions (material source, handling unit and replenishment principle) to organizational structure (routes, human integration, control principles), which were used to compile six coherent milk run processes. The studied processes can be divided based on the main storage system in use (supermarket, manual or automated storage system) as well as the supply or loading strategy (self-loading, pre-picking, buffering, manual and semi-automatic loading) [31].

The general concepts based on the main storage systems are visualized in Figure 8, Figure 9 and Figure 10. The six main concepts that Klenk et al. [31] investigated can be derived from the three main process concepts by adding a buffer storage between the storage and assembly areas. The performance of the concepts was evaluated for continuous routes and with adding an additional buffer storage in between the factory areas. Figure 8 represents the supermarket concept which details the route which the picking personnel takes to pick and distribute the components to correct workstations in the assembly area. At the end of the run, the empty containers and packing materials are unloaded to corresponding places in the storage area next to the supermarket. Generally, the supermarket concept is favoured due to its simplicity and practicality. The process can be operated entirely without external management and verification since the process is suited for Kanban order management. Therefore, the process can be maintained directly from the factory floor. However, the concept is not without its flaws. The picking process from a supermarket is a manual process and can take most of the overall milk run cycle time. The inclusion of a buffer to the replenishment strategy provides shorter milk run cycle times but increases overall lead time. This divides the personnel needed in the milk run since one worker can conduct the picking from the supermarket and the other can conduct multiple assembly area milk runs faster. While the buffer adds flexibility for material picking and supply, both the assembly area milk run, and the material picking must communicate effectively to prevent excess buffering and to ensure stability in the production process. [31]

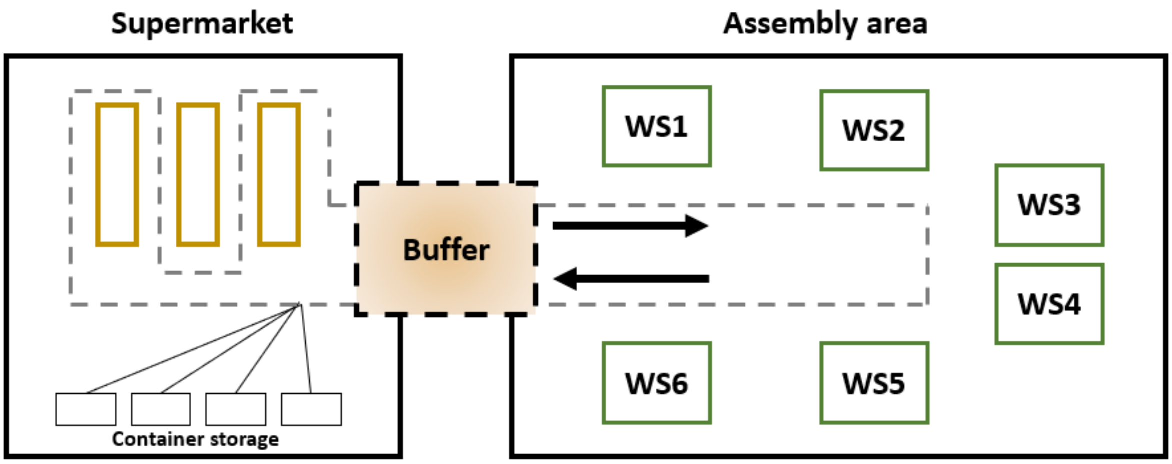


Figure 8: Supermarket Milk run process concept (modified) [31]

Manual storage (Figure 9) differs from the supermarket in a sense that the materials are delivered on pallets one material type at a time. This ensures fast milk run cycle times with minimal effort but only a limited number of components can be delivered using this method without increasing loading complexity. Therefore, the method is not suitable for manufacturing highly customizable products such as the ECH. The method is more suited for small sub-assembly or component manufacturing, where Kanban order identification is not required, and the product structure is simple. The process also often requires both milk run supply personnel as well as forklift driver to retrieve the required pallets manually from the storage area. [31]

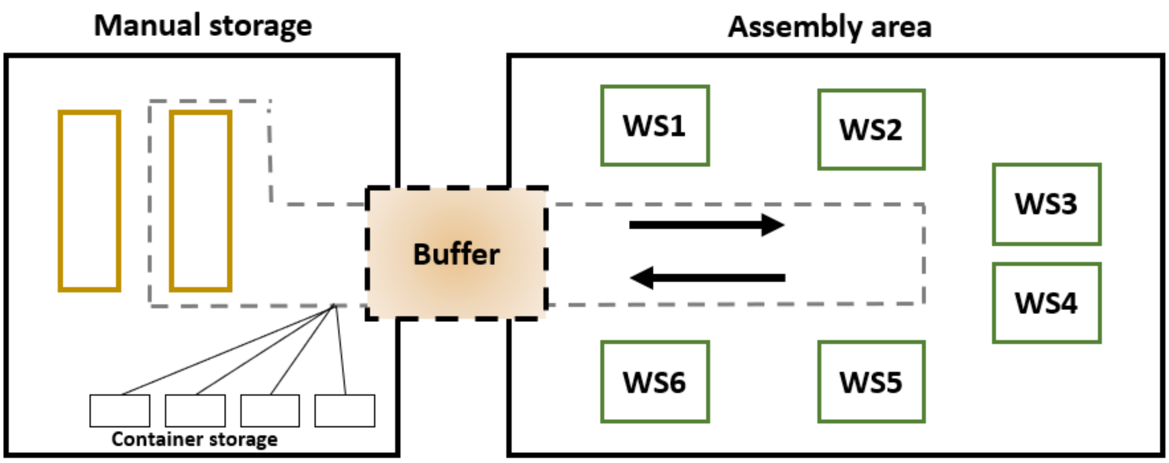


Figure 9: Manual storage Milk run process concept (modified) [31]

Automated storage milk run process concept (Figure 10) includes a more advanced storage type for the material holding than with the other concepts. The materials are retrieved from an automated storage system, which delivers products either on pallets or storage containers. Systems can be built so that by feeding the production orders into the production queue, the storage system automatically distributes the correct materials form to the loading area. The storage system can be either an entire storage shelf with multiple levels and high capacity or it can be a smaller storage with revolving shelves for specific materials. A single operator can load the materials from the automated storage area and be tasked with the milk run. However, by including the buffer between storage and assembly areas, flexibility of the material supply can be increased. While process automation reduces risks for errors caused by human error, the system needs substantially more planning, development, and personnel training to reach more optimized production lead times than with the more manual processes. However, the automated storage system is often one of the best approaches to reduce errors in material picking. [31]

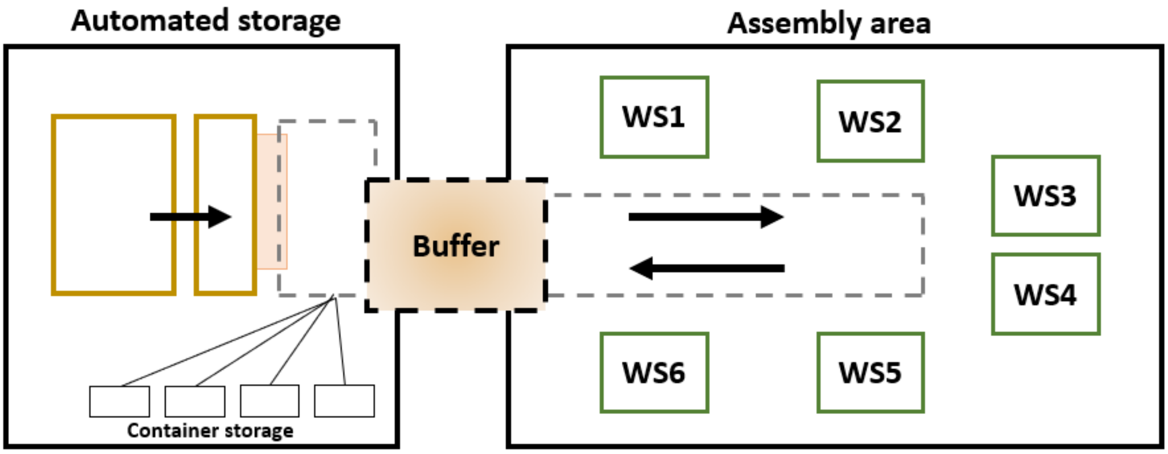


Figure 10: Automated storage Milk run process concept (modified) [31]

2.2.4 Material flows and layout types

Logistic processes are depicted using features, such as demand, topology, flows, resources, and restrictions [12 p. 230]. The main purpose for depicting a material flow is to visualize the distribution and consumption of materials during a production process. This alleviates the process of determining bottlenecks and evaluating production process performance. The creation of demand is dependent on push or pull production strategy [13]. If the production facility utilizes push production strategy, the demand for materials is leaning more towards the supplier. In practice, the impulse for supplier's material flow operations is based on re-order points for materials, stock quantity and consumption forecasts. Pull production strategy leans more towards the producing company, where the demand, production and logistic processes are dictated more by customers [13].

Topology in logistic processes refers to the travel routes and pathways which are used to transport materials a certain distance [12 p. 230]. The importance of the route can be visualized by enlarging the path compared to others or it can be made of dashes when the route is used for a specific transportation task [12 p. 230]. Material flows can be modelled primarily by a graphical flow, block diagrams or by other static models depicting the geography of a production line and the physical locations for materials [12 p. 230]. The static models are easier to construct, and the diagrams often consist of commonly used symbols and flows (Figure 11). In addition to static models, dynamic models, such as simulations and 3D visualization software with moving elements are more tangible representations of the actual flows and material movement. However, the models require significantly more time to construct, and considerations and compromises need to be made regarding the materials that are included in the model. For example, creating a fully functioning production line simulation with all included materials is difficult since the finished products may consist of tens or hundreds of components and the transportation of each component within the production line is not necessary to depict in material flow through visualization models. Therefore, most simulation models are targeted for the material flow of the most common materials.

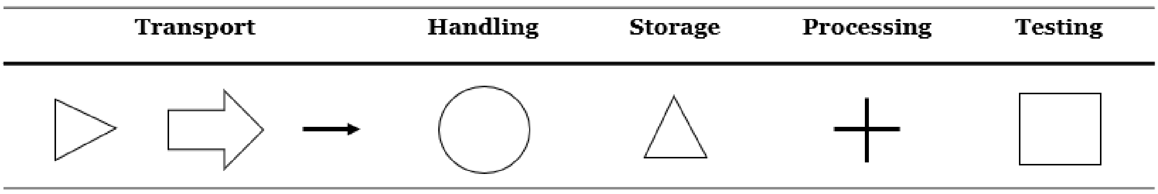


Figure 11: Common material flow process symbols (modified) [12, p.231]

A simple material flow process can be depicted using the common material flow symbols as seen in Figure 12. In the example process, the different states of the material storage are visible. First, the materials are moved from the supplier to a central warehouse or factory storage are using logistic processes. Second, the materials are transported to production line buffer or picked into the specified picking area. Third, the materials are processed, and the finished products are tested and checked for quality. Finally, the finished products are moved to the shipping area storage. This material flow model helps to understand the principles of material movement during a production process but does not go into specifics about the details of material handling and transportation requirements or topology in the production line.

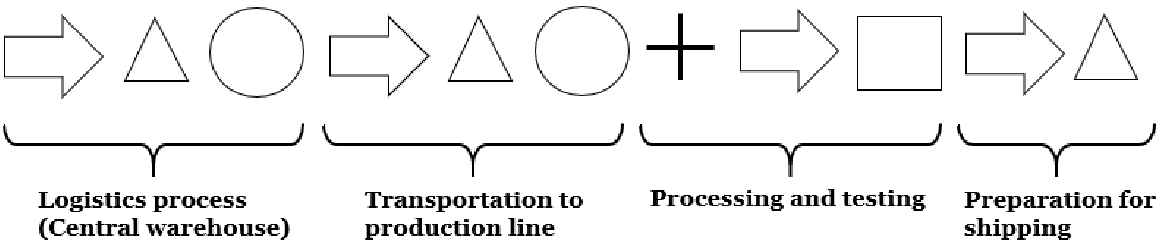


Figure 12: Example material flow process using common symbols

These symbols can also be fitted into a layout depicting the production area. However, if it is more desirable to show the layout as well as more detailed intensity of the material flow between processes, a different flow model can be used. One of these models is the Sankey diagram [12, p.12 & p.231].

While Sankey diagrams are mostly known to be used in process industries to visualize the substance flow, they are also used in manufacturing industry to elaborate sources and sinks in the production material flow and the intensities of the flows. Sankey diagrams can be made for different purposes and to focus on visualizing different aspects of a material flow. In Figure 13, the Sankey diagram is an example of material flow visualization which focuses on the depicting and differentiating the production process steps and when materials are introduced or leave the process. From the diagram, we can differentiate when jigs, additional materials and testing equipment are used and when purchased parts are brought in the part assembly step. The diagram also displays the production steps which require energy in terms of labor, electricity, or fuel as well as the flow of information in and out of the process. However, this diagram does not go into detail about the factory layout. For such specification we can use the Sankey diagram seen in Figure 14. [12, p.12 & p.231]

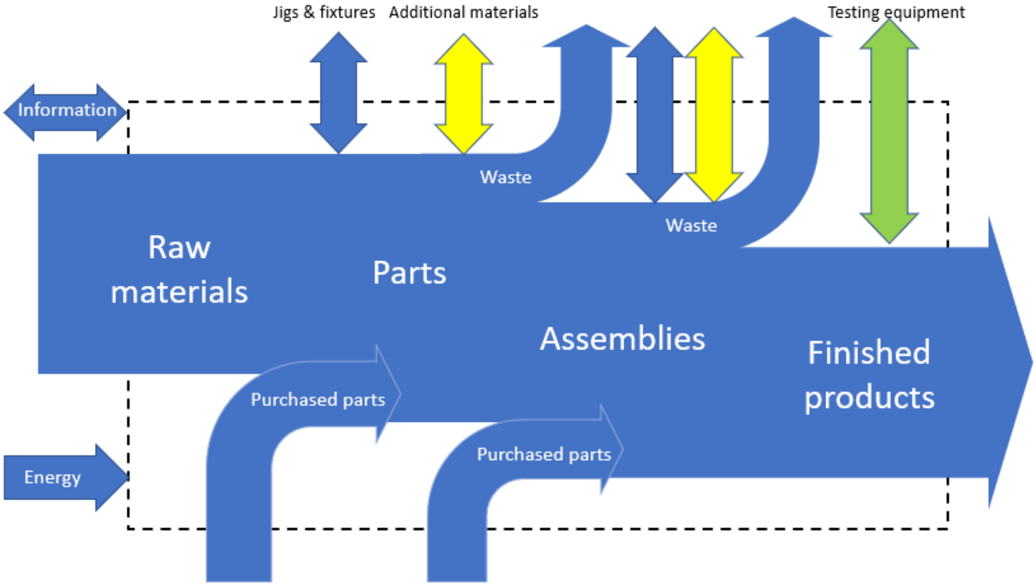


Figure 13: Sankey diagram for material flows and volumes (modified) [12, p.12]

The diagram in Figure 14 is more focused in showing the relations between each production process and how the material flow is networked between the different processes. The diagram emphasizes the material flow intensity by highlighting more significant flows with thicker arrows and the location of process steps is differentiated more than in Figure 13, but they are still not in scale. This model also differentiates the flow types as in the more general diagram. The locations, where the production steps are conducted are visible, but they do not necessarily represent the actual factory floor layout. A location specific Sankey diagram can be used to also depict the flow intensity, flow type and a more accurate process step positions regarding the factory layout (Figure 15). The model shows the flow intensities in each process step, but it also shows the flows merging which might be accurate in some cases for example when depicting waste management, but in terms of production process flow, it is less accurate. [12, p.12 & p.231]

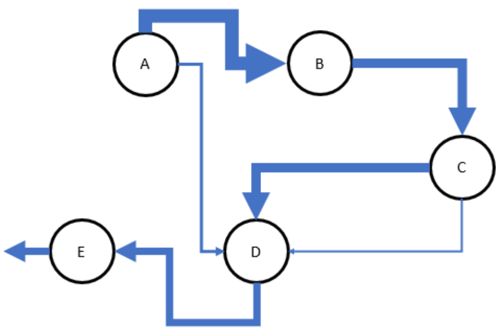


Figure 14: Sankey diagram for flow intensities and process direction (modified) [12, p.231]

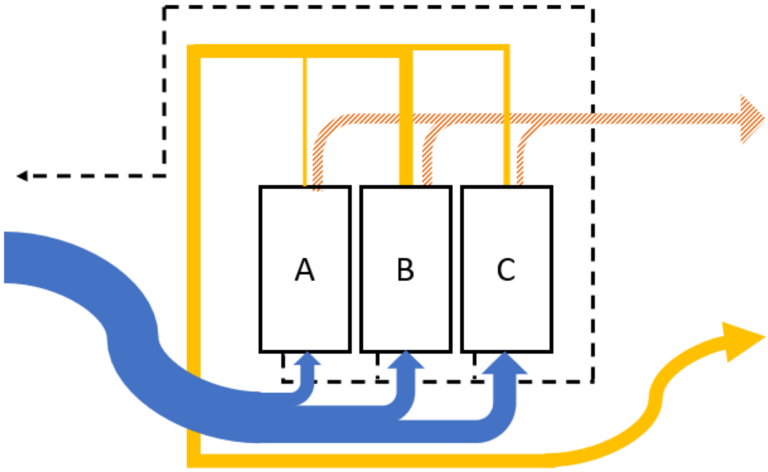


Figure 15: Sankey diagram with more accurate processing locations (modified) [12, p.231]

In addition to common material flow symbols and Sankey diagram, computational models and graphs conclude the static models used for depicting material flows. Dynamic models, such as simulations and 2D and 3D models and representations more accurately present the spatial and resource requirements to maintain material flow in a production process [12, p.231]. Simulation models can be made to use actual production parameters, which turn the simulation into a data-based representation of the production process. The practical material flow performance in these simulation models can be verified by including different material types which correspond the number of materials used in the actual production process. These simulation models are also effective in determining how small and large adjustments into production parameters affect the material flow performance [12, p.231].

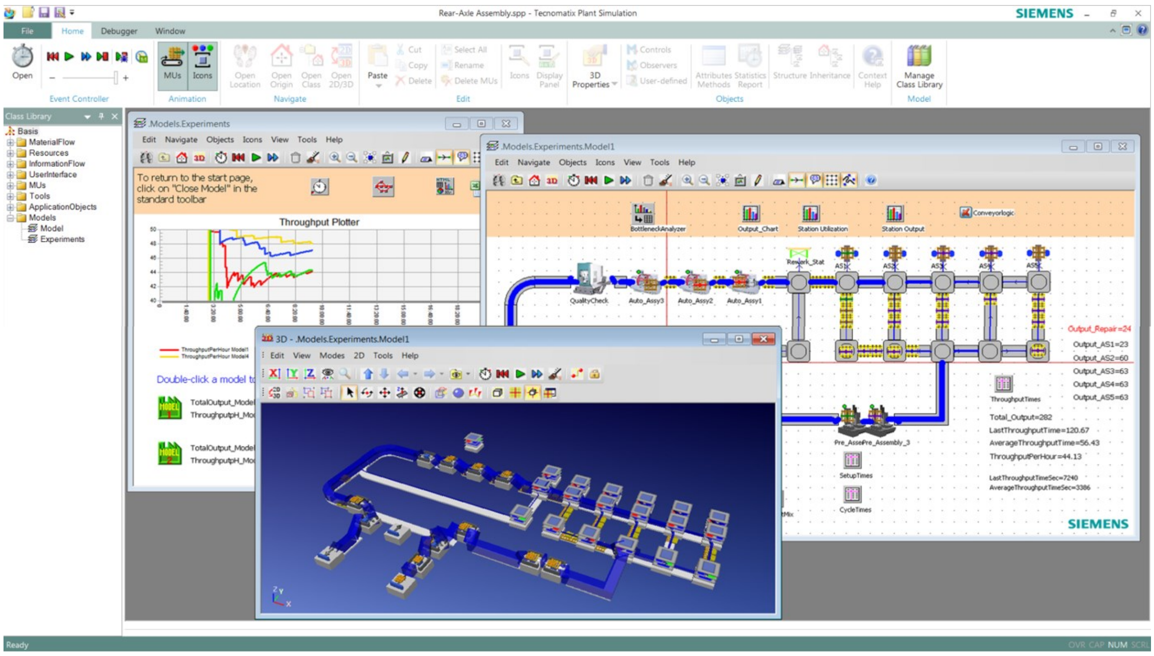


Figure 16: Siemens Technomatix 2D/3D simulation [29]

While simulations, static diagrams and models offer statistical and graphical representations of the different steps of a production process and how different types of materials are transferred between the steps, 2D- and 3D-models provide a realistic visualization with a focus on displaying actual scale and relations of labor and equipment. 2D- and 3D-models visualize geometry, distances, human-machine interaction as well as situations that occur during production [12, p.231]. They can also be used to simulate the production process by inputting parameters, such as process step cycle time, production capacity and Work-in-process (WIP). Siemens offers multiple solutions for production related simulation software, and examples of software used to simulate production processes are the Technomatix (Figure 16 & Figure 18) [25, 27, 29] and the Intosite (Figure 17 & Figure 19) [26, 28] software products. The Technomatix software is digital manufacturing solution, which is used to model and simulate the transformation of raw materials into products [25]. The digital manufacturing model allows users to evaluate the efficiency of the manufacturing process by analysing the relations and performance of engineering tasks during the simulated production [25]. Where, the Technomatix is more focused on simulating heavy machinery and singular manufacturing processes, the Intosite instead aims to provide an entire factory level simulation and virtual representation of one or multiple production processes [25, 26]. The Intosite can directly utilize data from various sources maintained by the company ERP, such as Siemens Teamcenter [26], which allow the models to be based on real-time data and up-to-date information about product revisions.

The performance of these models can be visualized by 2D- or 3D models, or by creating a virtual environment, where the performance of the manufacturing process can be viewed from the simulated factory floor. The advantage of manufacturing and production simulations is that they can depict the production process in significant detail by including parameters for routing, material transportation and storage in addition to the manufacturing steps.

Figure 17: Siemens Intosite model [28]

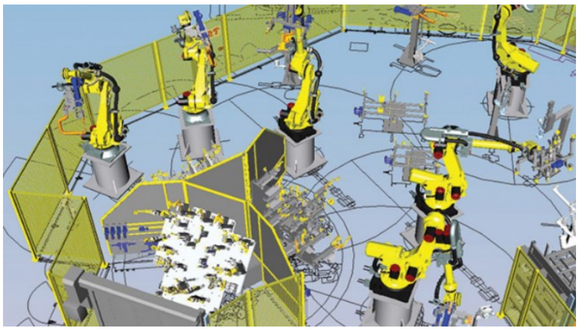


Figure 18: Siemens Technomatix model [27]

Figure 19: Intosite factory level digital twin [26]

The flow of materials is depicted in the static models by using common symbols [12, p. 231]. However, material flow can be also identified by the form they take. The different form types and examples of where they are typically present are displayed in the Figure 20. The most common, and distinctively, the most efficient material flow form is a linear from [12, p. 239]. Typically, manufacturing processes strive to maintain the flow of materials in one direction regardless of whether the manufacturing layout is cellular, fixed position, function-based layout, or a production line. The linear material flow represents the simplest method to implement Just-in-Time (JIT) production principle and to ensure that the materials are distributed along the assembly line so that non-value-added time is minimized in material handling during the assembly processes. However, in practice linear material flow is relatively challenging to establish, since restrictions such as floor space, existing production in the factory and material category, determine the storage solutions and transport principles chosen for the assembly area layout. Therefore, there is not a single optimal material flow for all types of production, and most assembly line material flows contain elements of the typical material flow forms. In addition to the linear material flow form, other forms include for example U-shaped, converging, ring shaped, diverging and networking forms [12, p. 239].

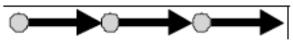
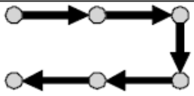
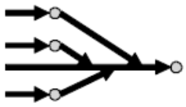
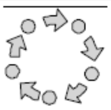
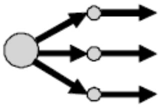
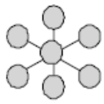
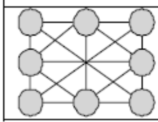
Basic form	Example
	**Linear** Typical for manufacturing and for assembly work-flows with fixed flow sequence
	**U-shaped** Typical for picking
	**Converging** Typical for assembly with connected pre-assembly stages
	**Ring-shaped** Typical for collection rounds
	**Diverging** Typical for disassembly
	**Star-shaped** Typical for assembly/disassembly
	**Network-shaped** Typical for flexible, frequently-changing workflow sequences

Figure 20: Forms of typical material flows [12, p. 239]

The U-shaped flow form is typically used together in linear flow forms for example in automotive industry. Cheng et al. [30] gathered the advantages and main reasons for using a U-shaped production line. They found that U-shaped production line offers better production flexibility than a linear line since the walking distances and the required floor spaces are smaller, the personnel required for operating the line could be adjusted based on the production volume and multiple operators could more easily manage two workstations [30]. In linear production lines, all workstations need to be occupied to maintain designed production flow, which decreases the possibility to reduce the number of operators when production volumes are reduced.

Other notable advantages include the need for fewer workstations, and an increased opportunity for teamwork and quality management. In a U-shaped production line, the operators are positioned inside the curve. Therefore, the possibility to collaborate and detect issues during production is increased. Also, the distance to retrieve materials from buffers is reduced if the layout contains in-line buffer storages. Based on Cheng's and associates' study, the U-shaped production line would offer better quality results when compared to linear production line. However, as they state: "... the shape of the production line is not the most important determinant of product quality" [30], which means that the production line shape is only one factor affecting product quality and production efficiency. Establishing the assembly knowledge, production flexibility and product design so that they support the manufacturing process are required for maintaining competitiveness and production performance. In practice, one material flow form or production line shape is not sufficient to provide sufficient quality and productivity for larger manufacturing processes. Instead, they utilize a combination of multiple production line shapes to achieve an optimized material flow to produce a specific product. [30]

2.2.5 Layout design

Internal material flow is heavily influenced by facility design and production line layout design. Layout defines the locations of storages, equipment, and workstations in relation to the different working areas within the facility [41, pp. 369]. Layout also visualizes the size and distances of transportation paths, routes, exits and accessibility of the working environment [41, pp. 369].

Zupan et al. [40] present the four main production layout principles including on-site, job-shop, flow, and cellular layouts (Figure 22). On-site layout, or fixed position layout, is a process where the manufacturing and assembly is done in one location and all necessary raw materials are delivered to the one workstation. The advantages of this layout are mainly for processes that have a low production volume and many different sizes and types of components. Large components can be stored next to the workstation thus removing the need to transport materials from further away. However, since the process is done only in one workstation, increasing production volume is difficult and is therefore susceptible to issues when production demand is increased and if delays occur in the supply chain. [40]

Job-shop layout consists of multiple workstations which are all designed to accomplish one specific task or process, e.g., machining, grinding, or tapping. In a job-shop layout, the materials and semi-finished products are moved from one workstation to the next, and the assembly of components is finalized in the final workstation. The workstations can be positioned in any order, so the materials do not have a direct material flow through the production area. The layout structure allows a production process to be established quickly but cannot sustain large batch production. Therefore, it is most suitable for prototyping and producing test batches of products. [40]

Flow layout is the most streamlined production layout since all necessary steps and machinery for a specific production process are included along a conveyor or a predetermined path of workstations. Multiple flowlines might exist next to each other. All lines are specified for making a certain sub-assembly or conducting a specific production process which contribute in the making of the final product. Flowlines can also be made to produce different variants completely from start to finish. Flow layout offers the best material flow through a production process while having the best capability for producing large batches of products. However, the weakness of the layout is the cost of establishing a production line since the lines are not flexible in terms of product design changes and customizability. Also, they are prone to significant cost issues if materials cannot be supplied according to requirements since the entire line is dependent on previous process steps. [40]

Finally, the cellular layout offers a balanced approach on production volume and production flexibility. The cellular layout consists of cells or sets of workstations optimized for manufacturing or assembling products or sub-assemblies restricted to similar production processes and required components. In contrary to job-shop layout, the cells are designed to manufacture or assemble a product to a certain extent. Therefore, the cellular layout can be divided into different workstations based on what step it is for the product, e.g., pre-assembly (picking), main assembly and final assembly. The cells contain machinery required for producing the specific sub-assembly or part and all personnel working in the cell must know the process and how to use the required equipment. [40]

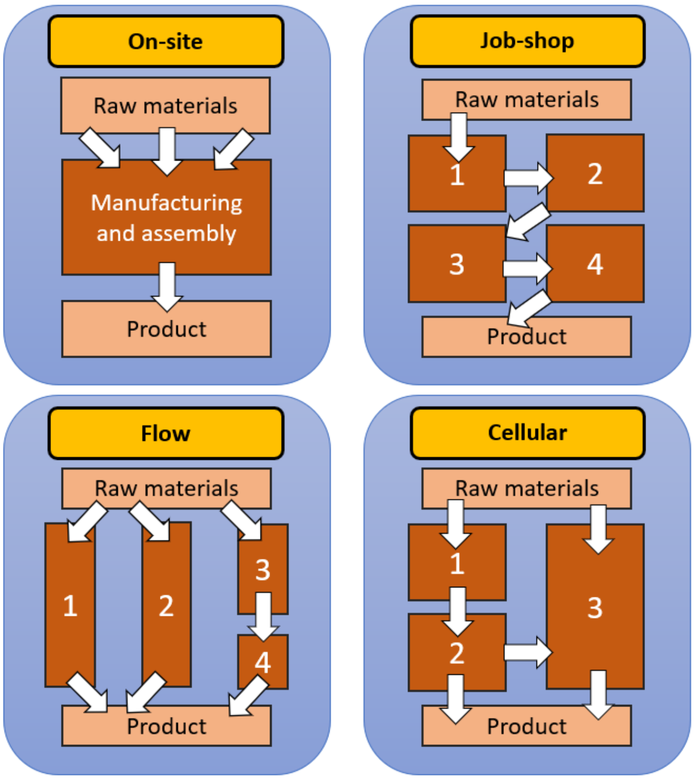


Figure 21: Production layout principles (modified) [40]

When designing the layout for a specific production process, design elements of a good production layout must be considered. Rufe explains the guidelines for efficient production layout design [41, p. 354 & 370]. By assessing each production process step with the guidelines, potential issues and unnecessary movement and waiting can be prevented, which can lead to increased productivity. The guidelines can be summarized into the following criteria:

- Planned material flow pattern
- Straight pathways, exits and entrances
- Minimal backtracking
- Minimal WIP
- Built-in flexibility and ergonomics
- Minimum travel distance
- Embedded quality and cleanliness
- Accessibility and visibility

Another approach for improving material flow and productivity production processes would be considering the shape of the assembly cell. Typical production lines and flow lines have a straight shape since following processes can easily be done by moving the components directly forward in the line. Straight line also allows materials to be supplied from one end of the production line and the finished products can then be shipped from the other end, thus maintaining a direct material flow. However, in practice straight production lines might always not be the most suitable line shape. Cheng et al. [42] investigated the effect of straight and U-shaped production lines on quality. The authors explained the advantages of U-shaped lines including the following [42]:

1. Increased flexibility for production rate
2. Increased working flexibility
3. Reduced number of workstations needed
4. Fewer requirements for material handling
5. Increased visibility and teamwork
6. Reduced impact of rework on production process

While the authors acknowledge these advantages, they emphasize that the shape of the production line alone is not the main influence on product quality. If process capability, product design, repeatability and reproducibility are not up to quality standards, changing the production line shape is not enough to ensure increased production quality. Also, if a production system is already established and consists of mainly automated processes, a straight-line shape could be more productive since changes in material movement direction does not need to be accounted for. [42]

The general approach for layout improvement, besides following effective layout guidelines and considering the production line shape, can be to find ways to reduce and eliminate the seven wastes of Taiichi Ohno presented by Black [43, p. 8], which are listed below. These wastes are present in all types of production processes [43, p.8]. By conducting a stepwise layout design improvement while focusing on creating an optimized structure for the production line workstations, companies can reduce these wastes and increase productivity and competitiveness of their production and logistic processes [43, p.8].

1. Overproduction
2. Waiting
3. Transportation
4. Over-processing
5. Inventory
6. Motion
7. Defects

2.2.6 Production KPIs

Production Key Performance Indicators (KPIs) are direct measurements or a set of derived values which indicate the performance or condition of a production process or a specific piece of equipment within that production process [33]. This KPI information is critical for understanding the production process' level of competitiveness for example when compared to other processes within the company [33]. KPIs also are beneficial in relaying information about the state of production to investors and other stakeholders, who are not that accustomed to production environments. During production management and improvement projects, KPIs can be used to verify whether the changes made were successful or not. Development in the production industry has paved the way for new possibilities in collecting KPI measurement data in real time to have more accurate information about the production processes [33]. By utilizing the real-time data in calculating KPIs, companies can find and solve problems in the production process more quickly, and by having more accurate information about lead times, companies can increase customer satisfaction.

The KPIs used in measuring the performance of a process or equipment are different from each other and different KPIs are also used between industries. A company often chooses which KPIs to use in analyzing their own processes. However, for certain industries and processes, typically used examples exist and are generally proven to be beneficial. Liu et al. discuss the sufficiency of traditionally used KPIs in manufacturing systems. KPIs, such as product cycle time, work-in-process (WIP), production late (tardiness), and scrap rate are generally favored as indicators for manufacturing process performance. However, as the authors state, in modern production industry, new KPIs must be developed and managed to improve competitiveness because detailed and current data about the process is made more accessible due to advancements in technology. Their suggested KPI, flow value is a measure of production logistics performance which can be used to indicate material flow related bottlenecks during the production process. It is the time relation between process WIP time (total time materials stay as WIP in a process) and sum of cycle times in a process. This gives better understanding of the material flow efficiency when the processing times vary between product types and workstations. If the production process has similar cycle times throughout the entire process, WIP is still an effective KPI for material flow efficiency. The occurrence of unplanned WIP in the production process should also be accounted for in both approaches. [34]

While these KPIs are useful in determining the level of material flow performance, other unplanned influences might be more significant when investigating production performance. Often the production processing time is only a small part of the overall lead time. Production lead time is the duration of processing time in a manufacturing or an assembly process [34] while the overall lead time is the sum of all processes starting from customer order creation to product shipment and arrival at customer’s site. Therefore, the efficiency of overall material flow should not only focus the manufacturing or assembly of the products. Instead, there should also be a focus on measuring the time spent in other steps surrounding the manufacturing and assembly process. Digitalization, processing automation and sensor technology have allowed the gathering of real-time data from most steps of a production process, but the key is not only to have access to the data but also to find practical applications for it [34]. Currently, processing efficiency, quality, and accuracy as well as equipment condition and processing state have been the most useful information to collect. The challenges for production performance analysis are in determining the most suitable KPIs to manage in the company’s processes and how to apply and balance these KPIs to gain competitive advantage most efficiently [34].

2.3 Means for material flow improvement

Factory planning is challenging due to time and cost constraints, which often influence the process of setting up a production line. While the initial production line layout and material flows are planned and determined before the production process is started, potential oversights and practical issues are usually discovered after the line has been running for a while at full capacity. Material flow optimization is an important production improvement task and the most common reasons for the improvement arise when changes are planned for the production line layout, product selection and production volume. With an optimized material flow, the production process is better equipped to react to fluctuations in production volumes and to other issues potential to occur during production process [15]. Other benefits also include reduced investments and costs of maintaining material storages, waste management and internal transportation processes as well as increased utilization of labor [15]. These together enable the process of material flow improvement also to be one approach to reduce environmental impact and increase sustainability in the company operations [15, 20].

In the following section, we discuss literature surrounding the topic of material flow improvement and approaches used for conducting the improvement process in practical cases. First, we will go over methods, which are in line with Lean principles, such as value stream mapping and production sequencing methods. Second, we will discuss the process frameworks for conduction material flow improvement and practical case examples of such improvement processes.

2.3.1 Lean approach for production process improvement

Lean manufacturing is an approach for conducting a manufacturing process by utilizing Lean principles and ideology [16, 17, 19]. The goal for companies that envelop Lean manufacturing in their production processes is to increase competitiveness [17] and improve manufacturing efficiency by eliminating unnecessary aspects of production and continuously improving existing processes and process flows [17, 21]. Lean ideology stems from the Toyota production system management style in the late 20th century [21].

Companies can adopt the ideology by following the key practices and utilizing tools of Lean manufacturing [16]. Lean tools, such as reducing inventory and receiving materials only when they are needed (Just-in-time, JIT) [16, 17], and implementation of continuous improvement (Kaizen) [16] are typical examples of how companies utilize Lean in their operations. However, detailed forecasts of consumption, material availability and sales are needed to adopt the practices [16]. By applying Lean manufacturing with material resource planning, companies can reduce inventory costs and improve existing value chain in terms of manufacturing process and material flow improvements [16].

Continuous improvement can be conducted by repeating the Kaizen improvement steps of planning, doing, checking, and acting (PDCA) [17]. Sufficient planning is the key to ensure that the improvement is be successful, which requires a good understanding of the current state [17]. This can be attained by frequently going to the production line and observing and discussing about the line performance and whether issues have occurred [17]. In Lean terms, this act is also called Gemba [17]. The process of applying continuous improvement and lean manufacturing in practice can be structured into four steps [16]:

1. Identify wastes
2. Determine root causes
3. Find solution
4. Test and implement the solution

The first step about identifying wastes is a continuous process and the goal is to determine issues in the value chain of the production process and to find permanent solutions for the issues. By removing wastes in the production process, time and resources are allocated and utilized more efficiently. Wastes occur in every organization and production process. Therefore, it is beneficial to have deep understanding of the processes and practices to identify the actual problems and how they affect the production process. [16]

The next step is about finding the root causes for the wastes after the problems are identified. Root causes or the total impact of the problem are not usually obvious, but the immediate problems are a good starting point in determining the reason for the problem. When determining root causes, it is important to create a network of influencing contributors that lead to the problem and a network of the effects that the problem has further in the supply chain. This helps to identify the effects of other potential problems as well. [16]

Finding the solution is made easier after the root cause and effects are well known. The changes suggested must also be fundamental solutions that do not allow the problem to occur later and do not affect other operation in the supply chain negatively. One method to derive the solutions can be using Lean tools in addition with a SWOT analysis. SWOT analysis is a method for identifying the strengths, weaknesses, opportunities and threats in an organization or a process in a supply chain. [16]

The final step is to test the solution in a test environment to verify the effectiveness before implementing the solution to the supply chain. During the testing process, last changes can still be made quite easily to refine the solution. After deemed acceptable, the solution can be implemented to the supply chain. This implementation process can have a long duration since personnel needs time to adjust to changes and new practices. Also, the benefits of smaller changes are not easily measured based on numerical data in a production environment, instead the verification of the solution often is received from workers experiences after the production process has been running at full capacity for a while. Almost as important as the testing before implementation is to monitor the results and find means to collect and analyze data from the manufacturing process efficiency using KPIs. [16]

Other Lean tools that are used to eliminate waste or unnecessary steps and problems of production include Kanban, Material Resource Planning (MRP), 5s and value stream mapping (VSM), [16]. Gupta et al. describe Kanban as a practical material identification method to enable pull-type production [16]. Kanban system utilizes Kanban cards, which are used to identify the materials and components that are to be supplied to production lines. This reduces the need for material storing within the production line area and streamlines material handling and material flow in the production process. MRP is a system-based tool embedded to the production workflow [16]. MRP generates material requirements for procurement and internal manufacturing processes based on the ordered and engineered product configurations. These material requirements consider the current stock levels, which limits the release of orders into production before they could be assembled in a reasonable amount of time [16]. 5s, short for sort, set in order, shine, standardize, and sustain, is a Lean methodology for maintaining an organized working environment [16]. The methodology is present in many modern manufacturing facilities and its effects can be seen in workstation design, visibility, accessibility, cleanliness, and safety practices [16]. By spending time developing these practices and workstation design, companies ensure employee safety and efficient working practices between shifts and throughout the working year. The efforts taken to implement 5s have been proven to be significant in increasing production efficiency and safety as well as finding potential bottlenecks between workstations [16].

The use and effectiveness of VSM in visualizing and analyzing important processes of the entire production workflow has been acknowledged and accepted in the process of conducting production workflow analysis [16]. VSM can be summarized as a visual Lean-tool, which depicts the process steps of a production process and differentiates the value-added processes [38]. Value-added processes involve process steps that directly lead to the making of a product, such as part manufacturing and assembly [38]. Therefore, material movement, logistics and storing do not directly add value and the time used in these processes should be minimized.

Gupta et al. [16] explain that value stream mapping firstly requires a deep understanding of the currently applied practices leading to value-added processes to produce the manufactured product. This knowledge allows for the creation of a current state VSM, which displays the connections and relations between value-added and non-value-added processes. Together with the current state map as well as frequently visiting the production processing areas (Gemba) allows stakeholders and production developers to point out potential issues and areas of improvement. Rahani et al. [17] explain the inquiries needed from the Gemba visits for VSM formulation including:

1. Takt time
2. Existing bottlenecks and constraints
3. Inventory and queue reduction opportunities
4. Flow improvement opportunities
5. Process improvement opportunities

The information about current state, potential issues and critical processes for production value can then be used to create a future state map, which shows the improvements made in the production value stream and visualizes the waste reduction means and affected process steps [17]. The authors cleverly point out that inquiring information about the production line performance should not be about whether there are opportunities to change something, instead the focus should be on whether there is a chance to reduce waiting time or other unnecessary aspects of production process. This means that depending on the production line, sometimes removing buffer storages from the production line would hinder the production cycle time and cause even more bottlenecking. The goal is to find substantial data and information about the process steps, and the potentially risky process steps can be then discovered for example by analytical means, such as comparing production cycle times with takt time. However, sometimes even if data about the production process is readily available, it might be difficult to make decisions about focusing the improvement efforts due to substantial differences between planned and actual production practices. This is especially prevalent in manual assembly and manufacturing processes. Takt time is the time in which a product or component must be produced to meet existing demand for it [38]. When comparing the process cycle times to takt time, we can determine whether there is a risk for bottlenecking. If any process cycle time is greater than takt time, the process is not efficient for the existing demand, and therefore can lead to WIP build-up and delays in the production flow [38].

$$Takt\ time = \frac{Available\ labor\ time}{demand\ (pcs)} \tag{2}$$

Example:

$$Takt\ time = \frac{110\ 000\ seconds\ (time\ available)}{400\ pieces\ (demand)} = 275\frac{seconds}{piece} \tag{3}$$

While takt time is beneficial for estimating bottlenecks in the production system, it is difficult to scale the same method for a manual assembly process. If products are not manufactured as single-piece flow, but in sets instead, it creates additional challenges to verify the process step feasibility.

Rahani et al. [17], Tyagi et al. [39] and Manos [38] go further and explain that a successful VSM implementation requires an additional plan to reach the future state. Even though the improvements or changes are visualized in the future state map, it is not enough to allow personnel to conduct required changes. These require a formulated plan, which needs to be followed through regularly. Manos [38] lists the necessary contents for a future state plan including:

- Project description
- Team members & project leader
- A schedule including milestones
- Estimated costs
- Priority based on impact in the production process
- Targets for the improvement
- Benefits from the improvement

After the improvements have been made and the projects regarding these improvements are concluded, the final step of VSM is to monitor and inspect the effectiveness of the changes made [17]. Sometimes new issues arise from changes which were not found during planning or implementing process. Therefore, it is important to keep visiting the processing area frequently and collecting information and opinions from the factory personnel.

Rahani et al. discuss the use and effectiveness of Lean tools in practice in their case study about conducting process flow analysis [17]. The case was made to determine the means for utilizing Lean tools to eliminate waste, improve inventory management and product quality as well as to increase the level of control over the process operations for a process industry company. The authors chose to focus on VSM to determine the areas of improvement in the company operations.

Before the VSM could be established, sufficient details and data about the current state need to be collected. The data and KPIs the authors used in the study included changeover time, cycle time, waste time, queue time. They also noted the percentage of the faulty products from the manufacturing process and the percentage of the work-in-progress inventory. The performance analysis was based on measuring the output regarding required labor and backlog quantity. After establishing the current state, VSM could be made to visualize the value chain throughout the production process. Actual means for creating the VSM include the use of common VSM symbols (Figure 22). An example of how VSM is made can be seen from Figure 23, which shows material transportation to the assembly line and the shipping to the customers as well as the inventory time in between the material transportation and shipping processes. The authors used information from Gemba and the current state map to derive a future state map including the improved material flow [17]. The bottlenecks of the process were discovered by comparing the takt time with process cycle times, which lead to improvements in WIP stacking and operator working standards [17]. The study shows that Lean tools, such as VSM can be used to identify and eliminate hidden waste from production processes, which can lead to significant reductions in operating costs, and increase in quality by standardizing working principles [17].

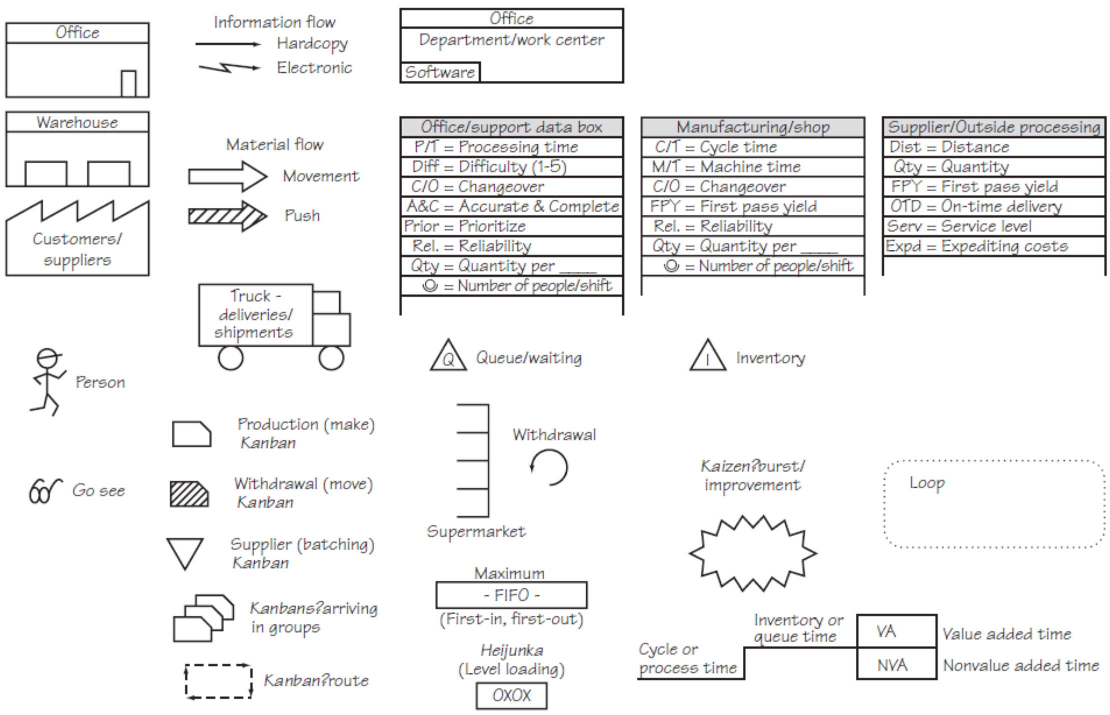


Figure 22: Common VSM symbols [38]

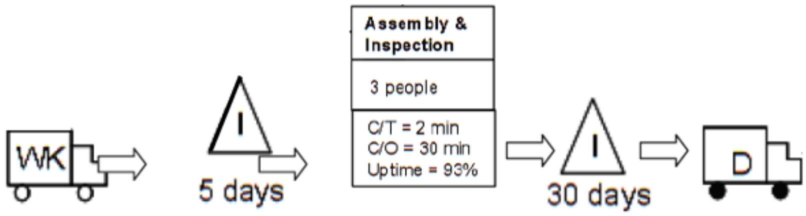


Figure 23: Example use of VSM symbols [17]

2.3.2 Frameworks & case examples

The use of Lean tools is established in production development, but when targeting material flow improvement specifically, different frameworks can be followed, such as for material flow planning and assessment. Shenk et al. [12, pp. 238] discuss material flow planning by separating it into five major steps and a sixth verification step:

1. Performance program coordination
2. Determination of functions
3. Dimensioning
4. Structuring
5. Design
6. Verification of functions using a model

The first step refers to the task of identifying the product, components, and containers. The second and third steps are about determining the required equipment and machinery needed for logistic tasks as well as the number of pieces of equipment needed for the logistic processes. The fourth step is structuring, which means the formulation of a layout regarding logistic resources in relation to production process flow and material flow across different facilities that are part of the production process. The fifth step is about designing a visualization about the production process material flow in relation to the rest of the facility where also other material flows exist. The final verification step is critical for determining whether the formulated material flow model is viable. This can be done by applying dynamic material flow models or simulation models to analyse the material flow functionality in the production process. [12, pp. 238, 246]

One method to follow these planning steps is to have a checklist of rules and recommendations, which can be used to verify the state of current material flow processes. When designing a material flow for a completely new production process, it can often be daunting to determine everything necessary for the production scope. Shenk et al. [12, pp. 242] give examples of the planning tasks needed when formulating material flows for a production process, which can be seen in the Table 2 below.

Table 2: Material flow planning tasks (modified) [12, pp. 242, Appendix C]

	Material flow planning tasks
1	Definition of the flows
2	Analysis of the flow rate
3	Calculation of inflow and outflow capacity
4	Calculation of average duration in the system
5	Calculation of actual labor time
6	Calculation of service time
7	Analysis of system parameters
8	Calculation of system load
9	Calculation of material flow indicators
10	Calculation of performance indicators
11	Calculation of maximum capacity
12	Calculation of shipping time
13	Determination of the routes between the source and destination locations
14	Transport optimization and route scheduling
15	Optimization of empty running
16	Increasing of loading capacity
17	Calculation of traffic density
18	Elimination of points of conflict
19	Planning of transport system

In addition to material flow planning tasks, picking processes need to be planned as well. The following table (Table 3) includes examples of the planning tasks for material picking and storing processes:

Table 3: Picking and storing planning tasks (modified) [12, pp. 243, Appendix C]

	Picking and storing process planning tasks
1	Determination of the picking procedure used
2	Calculation of basic times for picking: ➔ Receipt of order and empty container ➔ Picking + handover of paperwork
3	Calculation of travel times
4	Calculation of sorting times
5	Determination of optimal number of lines for picking orders
6	Selection of basic storing principle
7	Specification of storage sequence (First in First out, Last in First out)
8	Determination of storage organization
9	Calculation of storage indicators

These tasks along with specifications for information flow, equipment, means of transportation, material movement, route and overall capacity form the basic information required for material flow planning. Depending on the scope of material flow planning, the considered processes might include either internal factory operations or the entire end-to-end material flow, which also includes logistics from suppliers and sub-contractors as well as shipping and related logistic processes.

While Shenk et al. [12, pp. 238-246] discuss the individual steps for material flow planning, Gould et al. [18] give an example of material flow assessment framework through a case study. While the authors establish that resource management and material flow optimization in production have been researched previously, the sustainability of manufacturing processes and related material flow is relatively new approach for material flow analysis besides life-cycle analysis. Current research provides only little guidelines for improving resource efficiency in manufacturing systems [18]. The purpose for developing the framework was partially to provide a better understanding on the relation between resources, material flow efficiency, costs, and environmental impact and to understand the means for increasing resource efficiency [18].

The authors developed a 5-phase material flow assessment framework in manufacturing systems (MFAM framework) (Figure 24) [18]. The framework provides systematic analysis and improvement for an existing material flow in a manufacturing system [18].

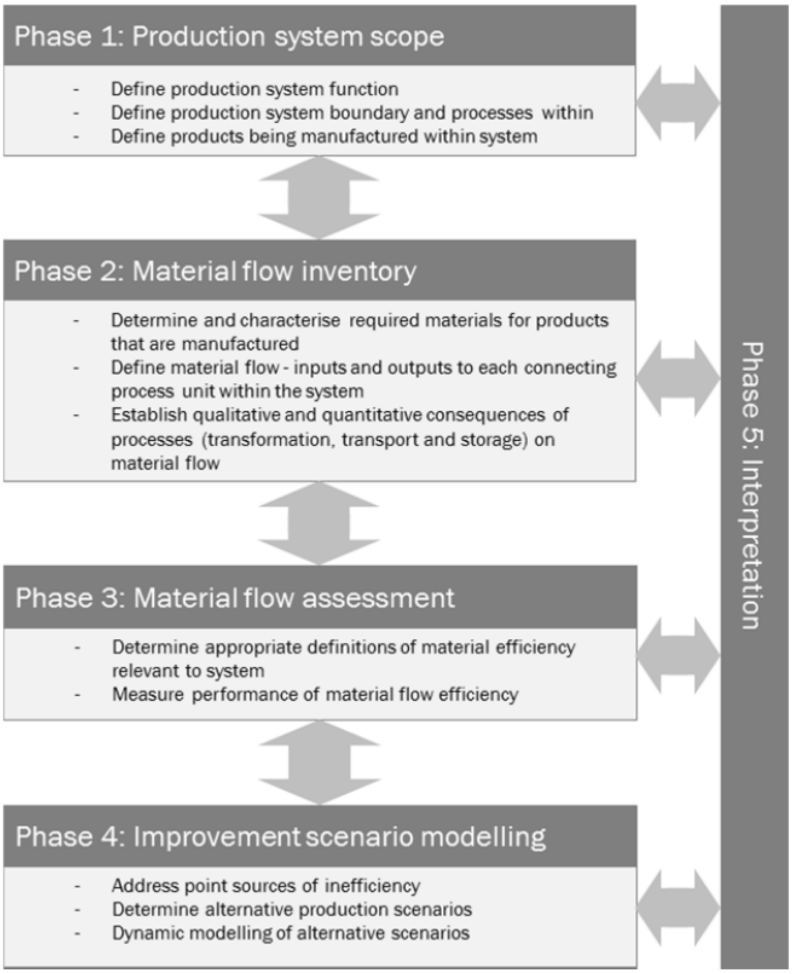


Figure 24: MFAM framework [18]

The production system in the study was a manufacturing facility containing two production lines and manufacturing scope included over 1000 different products manufactured from over 1000 different components and raw materials [18]. The authors define the system scope while acknowledging the potential areas of improvement in reducing material spillages by automation and designing a cleaning protocol for the production line to prevent contamination resulting from subsequent production processes using different materials in the same stations [18]. The authors focused on improving the resource consumption between production steps involving product changeovers [18]. Using the MFAM framework, they were able to determine the key areas of improvement, which allowed them to design an algorithm for production sequence optimization. Through this solution, they were able to show that resource consumption could be reduced by applying the optimized production sequence.

The authors developed a 5-phase material flow assessment framework in manufacturing systems (MFAM framework) (Figure 24) [18]. The framework provides systematic analysis and improvement for an existing material flow in a manufacturing system [18].

These management approaches together provide a management style and a framework, which if utilized correctly, can lead to reduced production costs, improved product quality and faster and more efficient production processes [21]. DMAIC stands for Define, Measure, Analyse, Improve and Control, which are the steps for a LSS quality management process. The authors chose to follow LSS practices by implementing DMAIC to solve case problem of a Taiwanese high precision automation equipment manufacturer. The company faced issues in achieving sufficient assembly efficiency, which lead to the need of materials to be shipped at the factory site earlier than before to prevent bottlenecking. This increase in stock levels further increased inventory holding costs, which was not desirable. [21]

The first step in this improvement endeavour was to define the main issues and the root causes for those issues, which lead to the assembly inefficiency. Methods for determining these causes that Wang et al. [21] mention and are employed in their study include SIPOC diagram (Figure 25) along with a Cause-and-effect matrix. SIPOC, short for Suppliers, Inputs, Processes, Outputs and Customers, is a diagram for highlighting the various business processes and process input and output contents [21]. This is used to gain an understanding of the business areas in focus for the improvement. When the SIPOC has been established, it is then used to determine the relations of different business processes that result in customers receiving the products on time [21]. The evaluation can then be used with a Cause-and-effect matrix to give weights for different processes and determine their significance and impact on the existing issues [21]. This also helps to differentiate the processes, which have an impact on other processes as well. Cause-and-effect matrix includes the process steps, process inputs or impacts on issues, and finally the issues or requirements leading to customer unsatisfaction. The process inputs and processes are then evaluated regarding the effect on the overall issues.

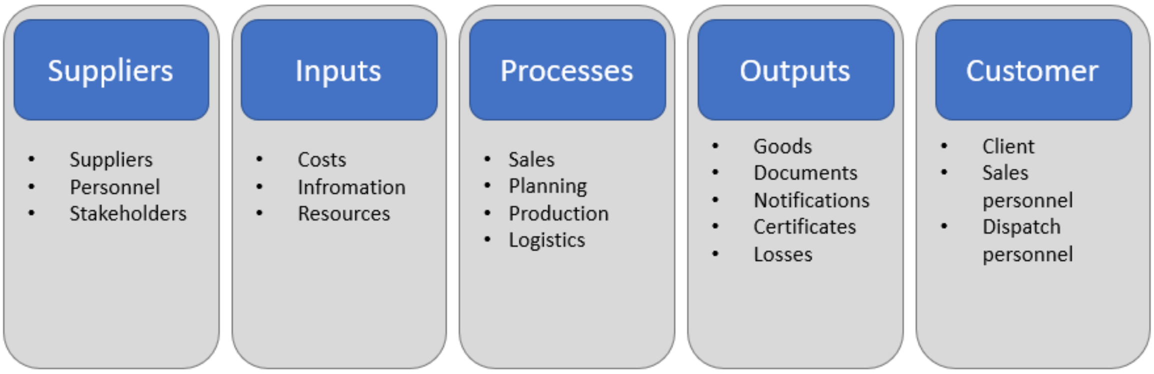


Figure 25: Example SIPOC diagram template (modified) [21]

The authors used these methods to determine that the main reason for the poor assembly efficiency was from production management schedule inaccuracy and too long assembly times [21]. The process improvement then led to VSM which was used to discover and analyse the non-value-assed time in the production cycle [21]. This information was in turn used to determine more optimized production practices, such as JIT sequencing and other minor changes to reduce waiting in between production processes [21]. After applying the chosen improvement for standardizing the assembly process and reducing non-value-added process steps, the authors were able to reach significant cost reductions, which proved the effectiveness of LSS framework in improving assembly efficiency and reducing waiting times between production processes.

3 CURRENT STATE ANALYSIS

The electric chain hoist (ECH, Figure 26) is a modular workstation hoist with multiple customizable variants across the product family. The hoists produced by Konecranes are internally referred as K-hoists. To understand the state of ECH production in Hämeenlinna as well as the modular product, we need to elaborate the details of the product structure, current assembly process and production line layout. This chapter refers to the state of ECH production in July 2021, which was the current state during the time of writing this thesis.

The chapter starts with elaboration of the background for current ECH production, which is followed by the definition of the product family and product structure as well as the variant configuration. After the product structure and variants are introduced, the production process of K-hoists is presented. The production process includes creation of sales orders and production orders, material flow of components, assembly process and production workflow. The focus of this thesis is on the material flow and production of large ECH frame sizes.

3.1 Background of electric chain hoist production

Electric chain hoists have been part of the Konecranes product line since the acquisition of the French chain hoist manufacturer Verlinde. The primary site for European (EMEA) chain hoist production has been the Vernouillet factory in France until its eventual shut-down in 2019. The main reason for the closure of the factory was due to the latest business acquisition which placed another large chain hoist factory to the Konecranes map. As anticipated, the acquisition resulted in synergies between the European chain hoist factories. The ECH product has previously had redesigns in terms of component revisions and a facelift for smaller frame sizes, but an idea for a totally new product design was also developed. This idea was realized when Konecranes proposed plans to produce the new electric chain hoist (NECH, Figure 27), also referred as C-series hoist. The European production site for the NECH was decided to be the Wetter factory in Germany. This resulted in the plans for production ramp-down for the older ECH product in Vernouillet and production ramp-up for NECH in Germany. China and USA plants will also be affected by the new ECH product and will undergo a ramp-down of the ECH followed by a ramp-up of the NECH product.

Figure 26: Example small frame size electric chain hoist (ECH) [22]

Figure 27: New ECH product (NECH) [22]

During the Vernouillet factory ramp-down process, the production of the existing K-hoist products supplied to the EMEA market needed a temporary new production facility until the production of the NECH product in Wetter would gain over the market volume. The temporary production site was decided to be in Hämeenlinna, Finland, which would mainly support the ramp-down process of the Vernouillet factory. The production of the K-hoists in Hämeenlinna started during 2019 and the production capability for the entire product family was realized at the beginning of 2020.

The product scope of Hämeenlinna factory is either configured hoists (standard and special) or ready-built factory bodies to Jingjiang, China. While the ECH production was starting in Hämeenlinna, plans for eventual ramp-down were also made. The ramp-down would be completed sequentially starting from the basic variants of the small frame sizes. Only after the NECH counterpart would be in such a condition that the production capability in Wetter would be established and it could be used to replace the orders for the older ECH variant, the ramp-down could continue. As of writing this thesis, the ramp-down of small frame sizes has been ongoing and the production of customer orders has been reduced significantly. The ramp-down of small frame sizes is scheduled to be completed by early 2022. This is followed then by the similar stepwise ramp-down of large frame ECH products. However, as of writing this thesis, the schedule for the large K-hoist ramp-down is not yet confirmed as the NECH design work for the large frame size products is still ongoing.

3.2 Product family, structure, and variants

Both, the K-hoist and the C-series hoist belong to the electrical chain hoist product family. The product structure of both models is modular and configurable, with multiple brands. However, the product structure does not differ between brands. The branding only affects the type of cover set and brand stickers used in the hoist. The customized variant for the hoist is determined by the customer based on the demand and use. Typical criteria and desired properties for the hoist are height of lift, lifting capacity and hoisting speed. Based on the selected properties, the product structure of the ordered hoist is configured automatically and moved to the material requirements planning and production planning of the production factory.

The K-hoist offers five different frame sizes with distinct features. These include smaller frame sizes FL02, FL05 and FL10 and larger frame sizes K16 and K25. The ‘FL’ in the abbreviation of the smaller frame sizes refers to facelift, which was adopted as the designation after the product structure revision of smaller frames some years ago. The product structure and modules of a FL10 hoist is shown in Figure 28.

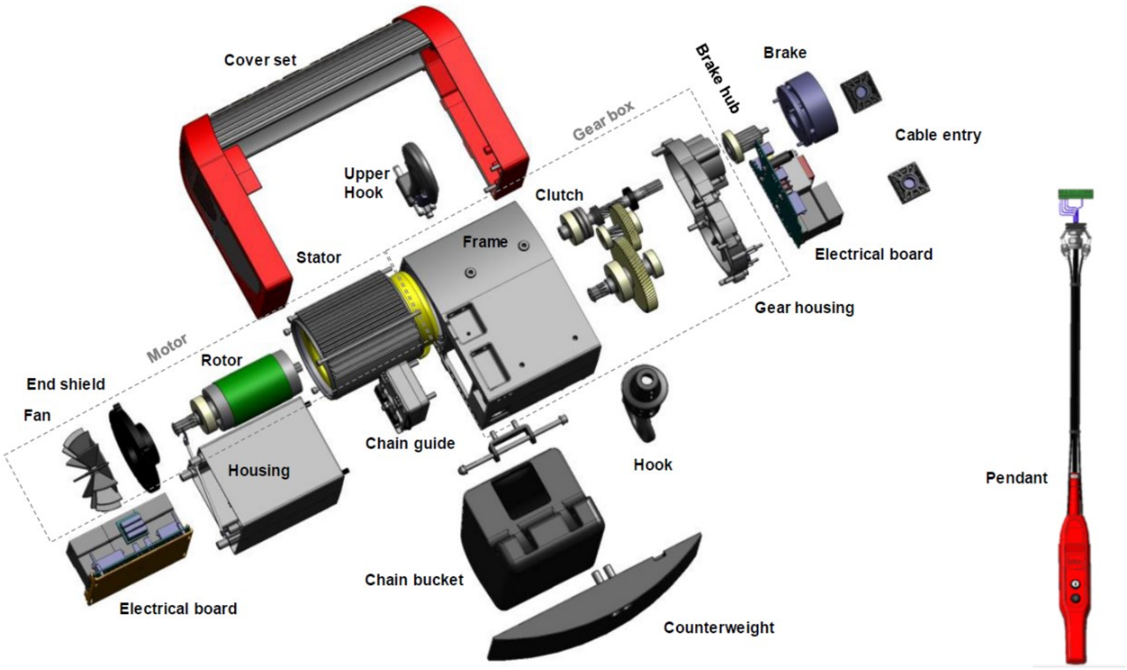


Figure 28: The product structure and modules of a FL10 hoist. [23]

The K-hoist product structure consists of five modules in addition to brand specific cover set and optional trolley. These include hoist body, hook, suspension part, chain bucket and pendant controller. Every chain hoist consists of the same modules, but the modules themselves can be of different type based on the product configuration and variant. The components that are used in the different modules are smaller in size in the FL02-FL10 frames than in K16/K25 frames. The smaller frame sizes are designated for small to medium loads. The product structure is similar between the three facelift frames, but some features are unique among the frames. For example, the gearbox of the chain hoists can be either CLX or SLX type, where the CLX gearbox is the standard model, and the SLX offers an increased speed range but limited hoisting capability. The FL02 frame does not support the SLX gearbox and the gearboxes have 2-step gears except for the FL10 frame, which has 3-step gears like the gearboxes used in larger frame sizes.

Main differences between the small and large frame sizes are the separate suspension part and the lack of counterweights in large frames. The product structure of a large frame chain hoist is shown in Figure 29. The components are also larger, and the gearbox can only have the standard CLX variant in large frames. The purpose of the larger frame sizes is to offer workstation lifts with an increased lifting capacity.

The lifting capacity of the chain hoists is determined by the type of chain, the number of chain falls (reeving) and the type of hoisting motor and gearbox. Increasing chain falls allows greater lifting capacity because the force needed for lifting is divided between the chains attached to the hook. The number of chain falls can be up to four. 4-fall chain hoists are special dual hoists which house two joined hoist bodies, and they have the highest lifting capacity of K-hoists, 10 000 kg. 3-fall hoists have only one hoist body but contain an otherwise similar structure to 4-fall hoists. 3-fall hoists have a lifting capacity of 7500 Kg. Safe working load quantities for each frame size are displayed in the Table 4.

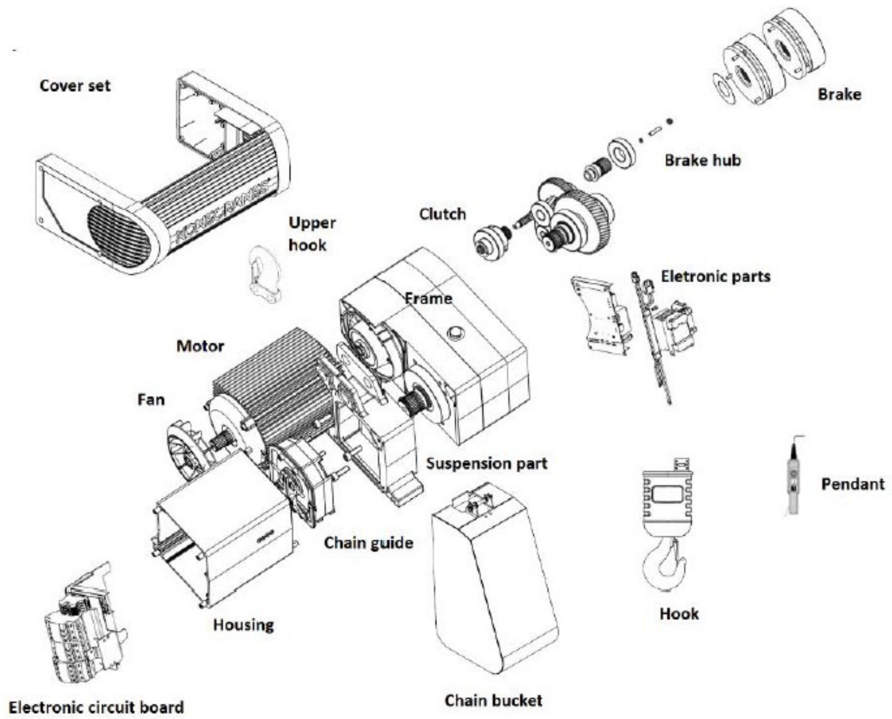


Figure 29: The product structure of a K16/K25 hoist [23]

The K-hoists are operated by a stepwise speed controller. The load can be hoisted slowly by pressing the pendant button halfway, and the load can be also rapidly lifted by fully pressing the same button. The slow mode is mainly used when lifting the load off a surface or when placing the load down. The standard hoist slow speed varies from 1 to 2 m/min and the standard max speed of the hoist is either 4 m/min or 8 m/min.

Table 4. K-hoist carrying capacity for each frame size. [45]

Frame size	Carrying capacity (Kg)
FL02	63-500
FL05	250-1000
FL10	500-2500
K16	800-3200
K25	1000-5000
K25 (3-fall)	7500
K25 (4-fall)	10 000

In the following section we will go over the specifics of the different modules of the K-hoist. The modules are, hoist body, hook, chain bucket, suspension part, pendant controller as well as optional trolley and brand specific cover set.

Hoist body

The hoist body is the main module of the ECH and consists of the hoisting machinery i.e., gearbox, frame, brake, chain guide, electric motor and fan as well as electric boards and a cubicle to contain the motor side electronics. The suspension part is separate in the larger frame sizes, and it is also part of the hoist body.

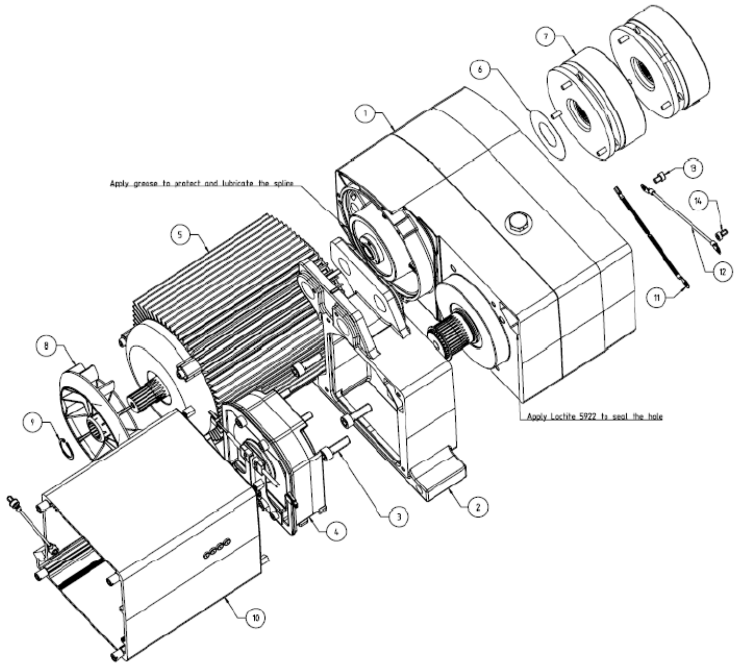
Different variations exist for the gearbox assembly. These variations allow for increased max speed range. There are 21 gearbox variants for small frame sizes and 14 options for large frame sizes. These gearbox variants as well as max speed ranges for each frame size is displayed in Table 5. As mentioned before, the gearboxes can be either CLX or SLX variants. The SLX is equipped with an inverter but is otherwise similar in structure (NEO gearbox). Different motors also exist for CLX variants which offer different main and control voltages as well as operating frequencies.

Table 5. K-hoist speed ranges and gearbox options. (NEO is for inverter motors) [45]

Frame size	Max speed range (m/min)	Gearbox variations
FL02	8-20	8
FL05	8-20	6 (2 NEO)
FL10	8-20	7 (2 NEO)
K16	8-16	6
K25	8-20	8

In the Figure 30, the product structure and BOM of large frame size hoist body is shown. Product types that affect the hoist body structure include the electric provisions. The three electric provisions are: SOLO, which includes all required electric components in the hoist body, ACF, which has limited electric components and the boards are only used for testing and later replaced before the final assembly, and CRANE, which includes a limited set of electrical components. CRANE hoists can contain some of the necessary electric components in the electric cabinet of the crane bridge.

Large frame 4-fall hoists include two hoist bodies: one with SOLO and the other with CRANE electric provisions. The control boards as well as the power supply boards can also be PTO for example when the hoist operating voltage or frequency is different from the standard 400V and 50 Hz. In addition to the variations possible in the hoist bodies, all hoist body gearboxes include a slipping clutch. The slipping clutch ensures that the load does not exceed the safe working load and prevents lifting of loads higher than 160% of the safe working load. The hoists can also be fitted with a double brake as seen in the Figure 30 below.



Position	Description
1	Gear box
2	Suspension
3	Screw
4	Chain guide
5	Motor
6	Sealing
7	Brake
8	Fan
9	Retaining ring
10	Housing
11	Cable interface
12	Rope retainer
13	Screw
14	Screw

Figure 30: The modules of a K16-K25 hoist body with BOM [23]

The limit switch is also part of the hoist body, which can have different variations for same frame sizes. It is attached to the chain guide. The chain guide consists of several components, which together serve as the entry and exit for the chain. The chain guide contains a chain sprocket attached to the output shaft of the gearbox, two cast chain guide halves, a chain ejector piece, fastening screws and a limit switch. The limit switch controls the height of lift so that the chain cannot be pulled all the way through the hoist body. This also prevents damages that an event such as mentioned would cause. Several types of limits switches exist for the K-hoist, but the most common type is the mechanical lever activated micro switch. When the hook or chain stop pushes the lever on the chain guide upwards, it activates the micro switch and limits the travel of the chain in the current direction. Manually adjustable limit switches differ from micro switches in a way that they do not need a lever to determine the location of the chain and load. The limits can be manually set by physically adjusting the limit switch when the hook is positioned at a desired max and min height.

Hook

The hook is a Phantom assembly. The standard hooks for K-hoists are either 1-fall or 2-fall hooks (Figure 31). 1-fall hooks have a unique structure, which consists of a hook assembly, two half casings or hook bottles, a buffer piece, and a chain link. The hook connects to the chain using a chain link. The hook casings are tightened using screws and locking nuts. A rubber cover protects the casings and load stickers show the max safe working load.

2-fall hooks differ from the 1-fall hooks substantially. Instead of attaching the hook to the chain using a chain link, the hook is fitted around a chain sprocket. The end of the chain is attached to the hoist body and the hook is suspended from the sprocket within the hook. The additional components needed for 2-fall hoists include a pin, a slide bearing and the chain sprocket. The 2-fall hoist have larger hook bottles and a larger protective rubber cover. The rubber cover also acts as a limit switch activator. Separate limit switch activators exist for other hook types. In the Figure 31 below, we can see 1- and 2-fall hooks along with the slack chain stop, which is attached to the end of the chain to prevent the chain from falling out from the hoist body. The figure also shows the chain fixing set, which is required to attach the chain, going through the 2-fall hooks, into the hoist body.

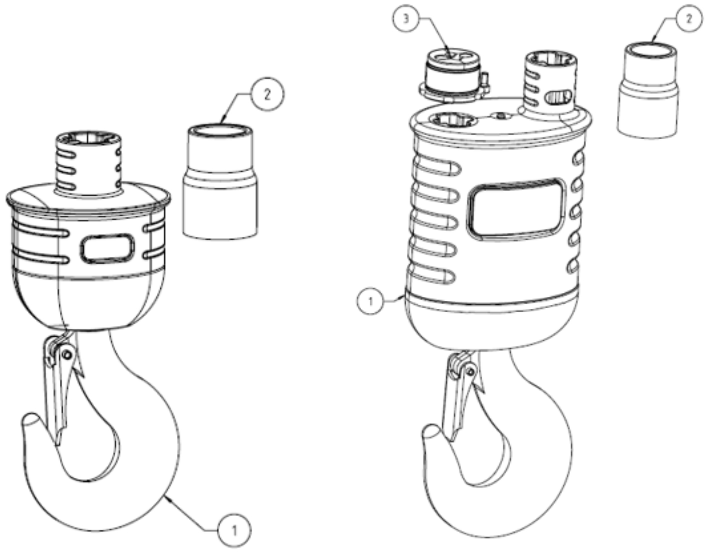


Figure 31: K25 1-fall and 2-fall hook assemblies (1), slack chain stop (2) and a chain fixing set (3) [23]

In addition to the standard hook types, there are also special 3-fall and 4-fall hooks. These hook types are designed for hoists, which have a higher lifting capacity than standard models. The max hoisting capacity with 3-fall hooks is 7500 kg and 10 000 kg with 4-fall hooks. As seen from the Figure 32 below, both special hook types have unique structure when compared to the standard models. The hook assembly requires an additional axle, which connects it with the two side plates. It allows the hook assembly to rotate in x- and y-directions. Another difference between the special hook types and standard types is the chain guides. The chain goes around a chain sprocket in the chain guide as well as in a crossbar. The cross bar is part of the trolley and the supporting structure which connects the hoist to a crane bridge. In 3-fall hoists, the chain end is attached back to the hook block but in 4-fall hoists, the chain goes through two chain guides in the hook and is linked between two separate hoist bodies. 3-fall hoists only have one hoist body.

Figure 32: K25 3-fall hook (left) and 4-fall hook (right) [23]

All hook types have stainless-steel material option. The stainless-steel hooks are designed for outdoor or corrosive conditions. This is the same for small frame hooks as well. Small frame hooks only have 1-fall and 2-fall variants, and but the structure is quite similar to large frame equivalents. The main difference is the component size and different protective rubber around the hook bottles.

Chain bucket

The section of the chain, which is not in use, is contained in a chain bucket. The chain is fed from the chain bucket into the chain guide. A limit switch is used along with a chain stop and the hook to prevent the chain from exiting the hoist completely. The chain bucket is customized for hoists based on the type of chain and length of chain. The length of chain is determined by the desired height of lift and reeving. The chain size is different for each frame size and K16/K25 chains are also coated in protective grease as standard. There is also a non-toxic (NTOX) variant for the chain, which has a specialized grease coating. All hoists also ship with a chain lubricant grease or oil depending on the type of chain used.

The chain bucket can either be made from canvas, hard plastic or steel. Different sizes also exist for each material. Canvas chain bags are more common with smaller chain sizes and steel buckets are more common with large frame sizes. Plastic buckets are used commonly in all hoist types and sizes. The chain bucket consists of the bucket as well as a stud and stud locks, which are used to attach the bucket to the hoist body. The chain bucket is fixed either to the suspension block directly (K16/K25) or to the back of the hoist by a separate fixing part. For special products such as 3-fall and 4-fall hoists, the chain bucket is attached in the front side of the hoist body using a specialized hoist bucket fixing plate. Also, when a steel bucket is used in large frame sizes, a safety chain is added to the bucket assembly. This ensures that the heavy bucket does not fall and cause damage for example if the fixing part fails.

Suspension part

Suspension part is the section of the hoist body of which the hoist is suspended. The hoist can be suspended either from a trolley, a beam or any suitable structure or mechanism that allows the hoist to be operated. In small frame sizes the suspension part is attached to the gearbox frame, which has the suspension part socket integrated to the frame. In large frame sizes the suspension part is attached to a separate suspension block, which is attached to the hoist body during hoist body assembly. For small frame sizes there are several suspension parts. These include for example a hook, an eye or a coupling part. The coupling part is used in small frames for fixing the hoist to the trolley or other structures. In large frame sizes, the only the suspension part is a hook. Otherwise, the larger frames are directly attached to the trolley from the suspension block. In small frame sizes the suspension parts are attached using nuts and screws but in large frame sizes, studs, fixing plate and screws are needed.

Pendant controller

Both the hoist and trolley are operated and controlled using a pendant controller (Figure 33). Typically, the pendant attaches to the power supply board on the brake side of the hoist body. Pendants are configured based on the hoist brand and trolley type. Standard pendants are 2-button pendants, which control the vertical movement. Hoists with motorized trolleys are operated using 4-button pendants, where the other two buttons are reserved for trolley movement control. All pendants also have an emergency stop button and brand specific stickers. The pendant colour is also brand specific.

Figure 33: Pendant controllers for K-hoists [23]

Pendants can also be attached to a socket, which is mounted on the brake side end cap of the cover set. The socket option is reserved for hoists, which have the option for radio control in addition to pendant control. These hoists, which have both radio and pendant, are often used in tall structures, where the hoist is attached high up to the bridge crane structure. When using the remote control, a signal receiver is attached to the socket and a radio pendant, seen in Figure 34, is used instead the regular pendant. The radio pendants have multiple buttons, which can be programmed for different movement types. The radio pendants also have brand specific stickers and an emergency switch, but they are all orange in colour regardless the brand.

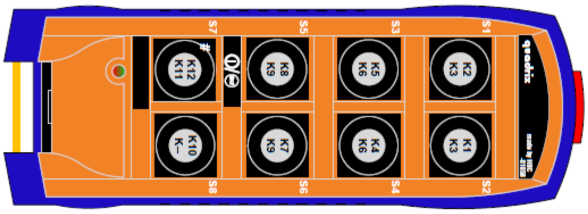


Figure 34: Radio controller for K-hoists [23]

Trolley

A trolley is used to move the hoist along a structure, such as I-beam, jib or a crane bridge. Two types of trolleys exist for K-hoists. These include push-trolleys and motorized trolleys. Push trolleys are moved manually by hand and motorized trolleys are controlled using the hoist control pendant.

Trolleys consist of a cross bar, which is the main structural fixing part to the hoist and for the other trolley components, tie bolts, which allow the trolley to be adjusted and fixed to the target structure, and side plates which house the trolley wheels. The side plates connect to the tie bolts and the trolley motor (or traveling motor, TRAV MACH) is attached to a side plate pinion. The traveling motor is a phantom subassembly. Depending on the trolley configuration, the trolley movement can be limited by buffer extensions or a traveling limit switch. If the limit switch is included in the trolley, a towing arm assembly and limit switch support arms are shipped with the hoist as well.

For motorized trolleys, two variants exist, a normal headroom and a low headroom trolley. The main difference between the trolleys is the type of cross bar used and the number of side plates required. Trolley assembly is also affected by the number of chain falls in the hoist. For example, the cross bar is turned 180 degrees before installing the side plates in 2-fall hoist trolleys. This makes the hoist more balanced rather than if the cross bar would be assembled the same way as 1-fall hoist trolleys.

Cover set

The hoist cover set includes two end caps and a front cover plate. The end caps are also fitted with an adhesive sealing. In large frames, the front cover plate also requires a C-rail fixing part. In addition to end caps and the cover plate, a counterweight is also attached in small frame size hoists. The cover set used depends on the brand of the hoist and the frame size. Different brands used for K-hoists include for example Konecranes, SWF, Verlinde, R&M and Comege. The cover set also has a different sticker set depending on the brand used. Each brand cover set has a unique shape, but the fixture is the same between brands.

3.3 Order-to-delivery process

Order-to-delivery means the process steps from customer order creation to the delivery of finished product to the customer. The details regarding the Order-to-delivery of K-hoists are shown in Figure 35. In large industrial equipment production, the customer almost always initiates the production process, i.e., the products are made only for orders and not in stock. For ordering chain hoists, customers use the Chain System II sales software to configure a K-hoist based on the desired properties. After the sales process, a customer order is created, and the order is transferred to SAP order management. From order management the customer orders are prioritized and transferred to production engineering. After the order are processed in order management, the order confirmations are sent back to the customer to verify the delivery date. Standard orders are moved directly to production engineering but orders for products with special requirements require special product planning. This process is also called order engineering and during the process an order specific engineering bill-of-materials (eBOM) is created and delivered along with the order to production engineering.

Next, the information about the customer order is sent to production engineering. The main tasks of a production engineer include manufacturing BOM (mBOM) or order BOM (oBOM) check or creation. If the ordered product is made from standard configuration, the production engineer verifies that the correct BOM including technical specifications was chosen for the customer order by the SAP variant configurator. After the verification is complete, the configured BOM of the order specific variant is released for material resource planning (MRP). The MRP run engages the procurement process for the materials by creating purchasing and manufacturing requisitions for PTO, MTO and CTO components. Stock materials are refilled and reordered based on current stock and safety stock quantity. Based on the material delivery time, the reorder point is determined to prevent materials from running out of stock. Special requirements might lead into longer procurement times, which affects the lead time of the hoist.

Along with engaging the procurement process, the MRP run generates a planned order to SAP, from where the order specific material requirements are seen. The planned order is changed to a production order by a production planner after doing production scheduling and capacity planning. When production planning is finished, the production order is released to the production line and the assembly process can begin. The materials used in the assembly process are moved to the processing area based on work center and routing information. This is done to ensure that the components are delivered close to the area where they are needed during assembly process. Finally, the finished products are packed and moved out of the processing area and transported to a shipping area storage before shipping to the customer.

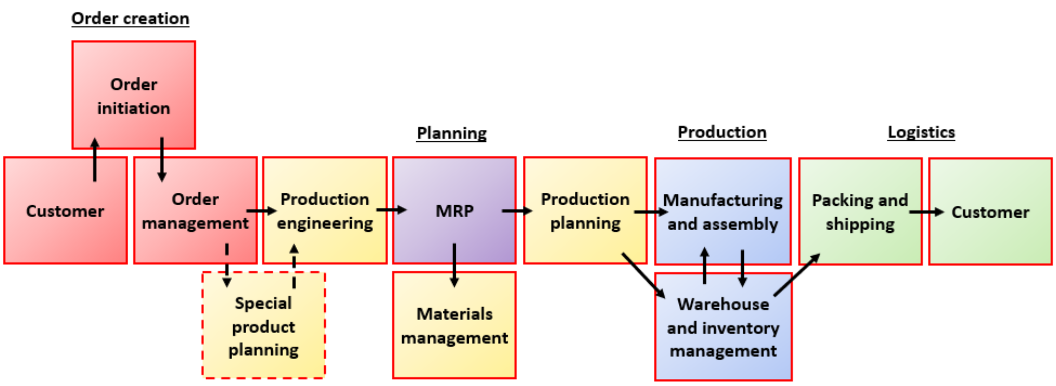


Figure 35: The process flow of K-hoist production

3.4 Assembly process

During the thesis contract period, the author had the opportunity to study and learn the assembly process of K-hoists by attending the assembly process as an assembler at the Hämeenlinna factory. Additional information and supporting material regarding the product structure and assembly process was provided by Konecranes colleagues. The assembly process of K-hoists consists of three main steps and a final inspection step before packing. These steps include hoist body assembly, testing and final assembly, and factory acceptance testing, which is the final inspection for the hoists. As mentioned in chapter 3.1, the two types of hoist orders include CTO hoists for customer orders and factory bodies to be delivered to the Jingjiang factory in China.

In this chapter, the details of the current large K-hoist assembly process steps in Hämeenlinna are explained based on the Gemba walks, learnings, and interviews conducted by the author during the introductory period to the KHH factory. The chapter is followed by the introduction to the production line layout, warehouse management and the workflow through the production line.

Hoist body assembly

The assembly of any ECH product starts by assembling the hoist body or factory body, when referring to bodies shipped to Jingjiang factory for final assembly. The hoist body assembly area is surrounded by storage buffers, and it contains three tables and a hydraulic press as well as in-line storages for linestock materials. The main assembly process is conducted on the two workstations positioned against each other. Both sides are identical but contain different linestock materials. Currently, one side is reserved for the assembly of FL02-FL10 bodies and the other is for the assembly of K16 and K25 bodies.

An assembler starts the factory body assembly by printing a production order (PO) and related serial number and hoist stickers. The production order contains the list of required parts for each step of the assembly. The PO material list is the same as mBOM. After the PO has been printed, the assembly start is confirmed from the PO. The production order also states whether the hoist has special options or components ordered specifically for the order. These PTO components are also collected from a nearby storage shelf, or a forklift driver is requested to pick up the PTO components from the outside storage area. After the production order is printed and the PTO components are collected to the assembly area, the assembly process can begin. In practice, one assembler can assemble from 4 to 12 hoists simultaneously depending on the frame size and order quantity. Customer orders are often for individual hoists and factory bodies are ordered as a batch of 4, 8, 10 or 12 hoists. Large frame size hoists (K16 and K25) only have batch sizes of 4 bodies. Therefore, a single assembler often assembles either a factory body set or four individual customer orders at a time. More special variants of chain hoists can be assembled individually since they might require more time-consuming assembly steps. The steps for basic hoist body or factory body assembly include the installing of the hoist body modules in the following order:

1. Gearbox frame
2. Brake
3. Power supply boards
4. Suspension
5. Chain guide
    i. Sprocket
    ii. Micro switch
6. Motor
    i. Rotor
    ii. Stator
7. Fan
8. Cubicle
9. Motor control board
10. Stickers
11. Suspension part/hook

The assembly of the chain guide as well as the rotor of the electric motor require sub-assemblies. These are usually done at the time they would be needed. However, sometimes assemblers can choose to do multiple sub-assemblies beforehand for other POs as well which shortens the assembly duration by 6-10 mins per hoist. A hoist can have either a fixed suspension hook or a test suspension hook if it is used in a trolley. The final step of the hoist body assembly is to attach the suspension hook. However, if the hoist is going to be used with a trolley, a test suspension hook is attached instead. The test hook is later removed after testing. If a fixed suspension hook is used, the specific hook part is attached by screws which along with screw glue.

After the suspension part and hook are attached, all necessary stickers and cable entries have been installed and the body assembly is confirmed to be completed, the hoists are lifted to the test beam and queued for testing. The difference between large and small frame sizes is that smaller frame size hoists are branded, and the chain is attached while on the test beam before the actual testing. The hook is also attached during the chaining process. Since, the thesis focuses on the large frame size K-hoists, we will discuss the final assembly process after the testing process is introduced.

Testing

As explained in the previous section, the smaller frame sizes are tested using their own hooks and chain, while the large frame sizes are tested using test hooks. Testing is conducted to verify that the maximum and minimum lifting speeds match to the designed values using under a test load and after the test, the slipping clutch is adjusted so that the hoist cannot carry more than 160% of the designed carrying capacity. Other adjustments can also be conducted based on the hoist type. For example, the upper and lower hoisting limits can be set to test values during testing if the hoist is fitted with a rotating geared limit switch (GLS). These values are then readjusted by the customer.

The tester consists of a test beam, testing bench and load weights. The testing process is a semi-automatic process where the tester conducts the required test sequences for the hoist. The operator is needed to engage the test sequence and to attach the bottom hook to the weights, lift the hoist to the right position using an integrated controller and to control the protective barriers around the testing area. The slipping clutch is adjusted from the brake side of the hoist by tightening or loosening the screw at the center of the brake unit until the hoist is within the range of 150% and 160% of maximum lifting capacity. After the adjustment is made, the resulting lifting capacity is verified by closing the protective barriers and lifting the test weights. A skilled operator can adjust the slipping clutch correctly for different frame sizes in one or two tries but for beginners, the task might need more adjustment tries. Therefore, this is the step of the testing process, which causes the most variation in testing times. After the testing process is complete and the slipping clutch is adjusted, the test hook and chain are removed, and the hoist can be moved out of the testing area.

There are exceptions to the testing process for example if the operating voltage is different, if the hoist has an inverter or a rotating geared limit switch (GLS), or the hoist is a 3- or 4-fall hoist. 3- and 4-fall hoists need to be tested with a larger testing weight set and the correct voltage can be selected before the testing process. Different plugs and electrics are used for the different electric provisions: CRANE, SOLO or ACF. Inverter hoists have a different set of testing parameters, and they are set using a separate computer software. The software can also be used to set the hoisting limits for inverter hoists. With GLS hoists, the limits are checked during testing that they are adjusted correctly during body assembly and adjusted again if necessary. The limits are at testing values after the testing process and need to be adjusted later on-site.

Final assembly (K16/K25)

After testing, the hoists are moved away from the testing area to the other end of the test beam. Factory bodies are moved directly to the factory acceptance testing (FAT) but other CTO hoists are set on pallets close to the final assembly area. Final assembly consists of chaining, hook assembly and branding. Trolley assembly is also conducted in the same final assembly area, but since it has its own work center, we will discuss it in more detail later in this section.

The final assembly starts by suspending the hoist body on a chaining bench. The functionality of the motor is verified by attaching electrics and either a test pendant or the actual pendant if the hoist requires one. These controllers are needed also for inserting the chain to the chain guide. The next step is to select the correct chain bucket and to pull the correct length of chain to the bucket. The used chain varies based on frame size and whether the hoist needs a non-toxic or stainless-steel variant chain. Before pulling the chain to the chain bucket, the other end of the chain is fitted with a slack chain stop, which prevents the chain from exiting the hoist completely. The chain is pulled from a pallet box through a counter, which displays the pulled length of the chain, into the chain bucket. The chain is then cut using a chain link cutter.

Next, the chain is fed through the chain guide of the hoist body while using the attached test pendant controller. Depending on the number of hook falls, the hook is either assembled directly to the chain or the chain is pushed through the already assembled hook.

The last step of the final assembly before trolley assembly is the branding. The brand plates are modular, so no matter which brand hoist is being assembled, the process is same for all the brand plates. The cover set for the hoists consist of two end caps and a front cover plate. During the branding process, cable entries are also added for motor control and power supply. The motor side end cap is different from the brake side end cap and different size parts are used between the end cap sub-assemblies. The end caps are fitted with a sealing around the inner edge and a retainer, which prevents the end cap from falling when adjusting the electronics retroactively.

The end caps are screwed to the sides of the hoist by four screws. The front cover is attached by sliding it through a c-rail, which is screwed to the front of the hoist. The front cover and cable entries for pendant and power supply need to be attached before the other end cap is screwed on frame. The cover pieces also require brand specific stickers, which are placed by hand and the quality of the stickers is verified later in the factory acceptance testing (FAT). Finally, the hoist can be lifted to a pallet along with the optional pendant, where the confirmation of the final assembly is done. If the hoist requires a trolley, the confirmation is done after all parts as well as the trolley is brought to the same pallet. After the confirmation is done, a final sticker is added to the chain and the pallet is moved to FAT area.

As mentioned in the previous section, the trolley assembly can be considered as a separate assembly process in most cases and shipped while detached from the hoist. This is done due to possibility to save space during packing. The hoist and trolley are later joined together on-site. Exceptions exist for 3- and 4-fall hoists, where the trolley must be attached to the hoist before chaining.

Trolleys consist of a cross bar, two side plates, two tie bolts and rubber buffers. The number of side plates and tie bolts is four in 3- and 4-fall hoists and the cross bar is also much larger. The side plates are geared assemblies themselves, which have a rotating wheel attached. On-site, the trolley is moved along a beam using the wheels on the side plates. One of the wheels is controlled by a trolley travel motor, or if the trolley is a push trolley, no motor is required.

Motorized trolleys also often need a limit switch, which is attached to the motor before installing it to the trolley. The trolleys are assembled by attaching the cross bar to a jig, and the side plates are attached on both sides of the cross bar using the tie bolts. The correct width is adjusted using washers and the position is locked using tie bolt nuts and locking nuts. The travel motor side plate is placed on one side of the cross bar based on whether the hoist is a 1-fall or 2-fall hoist. For 3- and 4-fall hoists, the travel motor side is verified from a technical drawing. The final step of trolley assembly is to install the rubber buffers to both side plates. After the trolley is assembled, and the motor serial number is collected, the assembly can be placed on the pallet with the hoist.

FAT

Factory acceptance testing is the final inspection step before the hoists or bodies are packed and shipped to customers. The worker conducting the FAT follows a set of instructions. The instructions include the following steps:

1. Brand verification
2. *Trolley*
    i. Buffers
    ii. Stickers
    iii. Bolts and washers
    iv. Travel motor limit switch
    v. Condition
3. Hoist options and special requirements
4. Cable interfaces
5. Overall condition

6. Add chain lubricant
7. *Add towing arm and support arms*
8. Add hoist documents and certificates
9. Batch numbers and final confirmation

If any components are missing or defects are found during steps 1-5, a notification is made based on the significance on the defect and returned to the assembly cell to be fixed. The notifications are used later to review the production quality. After a hoist passes the first five steps, chain lubricant tube is packed with the hoist. Towing arm and support arms are also assembled and packed if the hoist has a trolley and a trolley limit switch. Also, the certificates are printed and added with hoist documents and packed with the hoist. The final step is to confirm the batch used for the chain and make the final confirmation of the FAT inspection completion. This ends the production process of the K-hoist, which is now ready to be packed for shipping.

3.5 Assembly area layout

In 2019, the production line in Hämeenlinna was constructed using the references and work instructions from Vernouillet factory. The designation for the Hämeenlinna factory is KHH and the factory site consists of three factory buildings: HH1, HH2 and a gear factory called KHT. The assembly area for K-hoist production is currently located at the HH2 factory building. The K-hoist assembly area occupies a small section of the HH2 building and the area acts as different from the rest of the factory, while also having a different storage strategy and routing from the other production lines in the factory. Therefore, it has been given its own designation, HH8 production line. Components and other materials can be directly ordered and delivered to HH8 production line buffer, when necessary. The HH8 production line operates as its own factory but shares the cafeteria and breakroom with HH2. Also, the supervisors and production planners of HH8 share the offices with HH2 personnel and the HH2 and HH8 have the same factory manager.

The HH8 assembly area layout is shown in the Figure 36 with the main processing areas for large frame size K-hoist production. The layout template and the more detailed layout about the specific working areas are included in Appendix A. The hoists go through five processing areas or work centers before they are transported out of the production line and into the shipping area. Storage shelves surround the main assembly areas and additional storage areas are located along the outer walls of the HH8. The first work center is the hoist body assembly area. Both small and large frame size hoist bodies are assembled there along with the rotor and limit switch sub-assemblies. From there, the hoist bodies are transported via the test beam to the tester in the second work center (area 2, Figure 36). The testing area contains racks for test hooks and chains for each frame size and power supply wiring for each of the electric provisions. The tester is a contained area, where the hoist is enclosed in the tester, while the operator uses the control board in front of the tester. This allows passage behind the worker doing the testing, while the hoists are transported via the test beam.

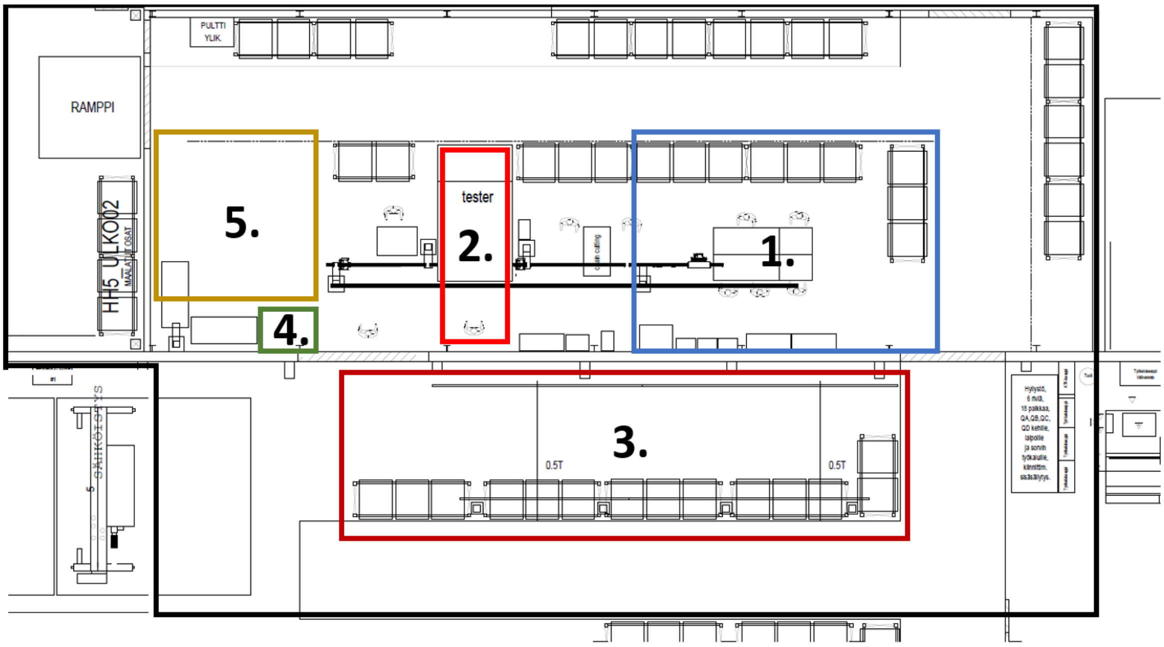


Figure 36: HH8 layout and main areas of the production process (modified)

Depending on whether the hoist is configured for customer orders or part of a factory body set, it is moved either to final assembly (area 3, Figure 36) or straight to FAT (area 4, Figure 36). The configured hoists are set on a pallet under the end of the test beam and await the worker from final assembly area to retrieve them using a pump jack. However, the factory bodies are moved either by the worker conducting the testing or by the FAT personnel on the floor at the final packing area, where they are inspected and packed for shipping.

As explained in the chapter 3.4, the final assembly is conducted on the configured hoists in order of chaining, hook assembly, order specific options, branding as well as trolley assembly if the hoist requires one. All the listed processes are conducted in the area 3. The area has three workstations as well as additional desks, workstation lifts and jigs. The chaining is done on the left, while the brand plates can be assembled in the middle and the trolleys are assembled on the right side of the final assembly area. After all steps of the final assembly are done, the hoist along with the trolley are placed back to the pallet and transported to the FAT area for inspection.

The FAT area has a computer, a desk for hoist documents, a shelf for chain lubricants and other sub-assemblies. The hoists are transported to the FAT area in a marked spot on the floor, where the hoists are inspected. After the inspection and FAT process is done, a green card is placed on top of the hoist signaling that the hoist is ready for packing and can be moved to the final packing station (area 5, Figure 36). The packing process is outsourced and not conducted by Konecranes employees.

Figure 37 shows the production line layout with storage bin locations as well as work centers used in SAP warehouse management. The buffer storages used for the K-hoist components are marked in yellow. The production line is also divided into two supply areas: SUPPLY 108 and SUPPLY 109. The SUPPLY 108 signifies the supply area and assembly area for small frame size hoists and components, and SUPPLY 109 is reserved for large frame size hoist materials and assembly. However, same components can be maintained in both supply areas, and they can sometimes have individual restock strategy or control cycle based on the supply area. For example, a bushing used in the hoist body assembly of both, the large and small frame size hoist, could be restocked to buffer of SUPPLY 109 based on current storage level and re-order point, whereas the same bushings in SUPPLY 108, could only be picked and ordered, when they are needed. This is practical when the consumption of the bushing is significantly greater for large frame size hoists in SUPPLY 109.

Due to the stepwise production ramp-up of the small frame size NECH product, the production of the small frame size hoists in Hämeenlinna is estimated to be completed early 2022 To improve the current state of the production material flow and focus it more on large frame size hoist assembly, changes to the control cycle and replenishment values of the components in both supply areas should be made. The reduction of small hoist components in the buffer leaves more space for large hoist components. This would ensure that production could be continued longer even in case of small material shortages.

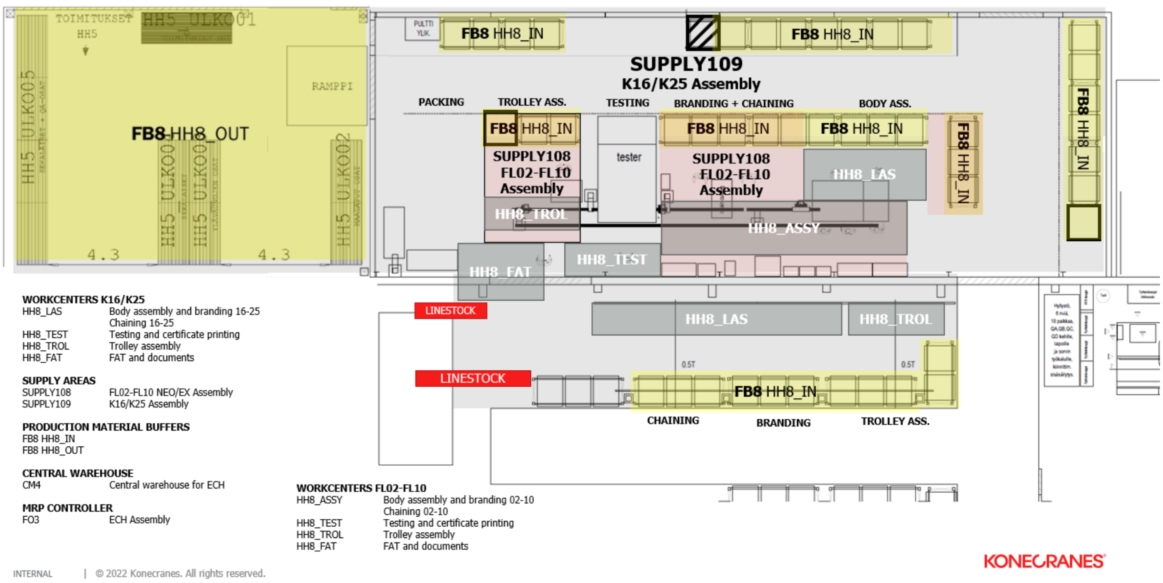


Figure 37: SAP warehouse management map with workcenters and storage IDs (modified)

4 MATERIAL FLOW IMPROVEMENT FOR ECH PRODUCTION

During the thesis contract period, the Hämeenlinna HH8 production line was under development in terms of layout design and material flow improvement. The improvement process consisted of material mapping, updates to the material control cycle and replenishment information, layout planning based on future demand, and buffer material storage relocation for more efficient material flow and capacity utilization. The author participated in the project, which provided a case example of how production improvement was conducted for a production line involving ECH production. The case itself was not affected by this thesis. However, the results and methods used during the project will provide references for the material flow improvement investigation of this thesis.

In this chapter, material flow improvement for ECH production is established by first determining the areas of material flow improvement based on findings from literature and visits to the Hämeenlinna HH8 production line. Second, we elaborate the findings and improvements made during the 3-month introduction and production development period regarding the HH8. Finally, an optimized material flow model and an improved assembly area layout for general ECH production is investigated. This is done by utilizing the Gould & Colwill framework for material flow assessment in manufacturing, findings from HH8 visit and KPI data from the current state of ECH production in Hämeenlinna.

4.1 Areas of improvement

To determine the areas of material flow improvement, it is beneficial to establish the ideal state of production, which would not contain any non-value-added time. An ideal production process would involve a pull-type production principle, and all materials would be picked for orders. Therefore, there would not be a need for material transportation within a production line, and the required components would already be picked and ready at the location, where they are needed. The material flow in and out of the production line as well as during the assembly process would be a straight one-piece or one-set flow, while providing flexibility for configurable product assembly. While the ideal state of production is desirable, real-life constraints in production processes and practices lead to compromises in facility and material flow design. However, we can use the ideal state of production to determine the goals for material flow improvement in different parts of the facility and process design.

This chapter introduces the potential areas of improvement and development suggestions based on the Gemba study of the ECH during the summer period. To determine the areas of material flow improvement specifically for ECH production, the details from the current production process must be accounted for. In ECH production, physical material flow is initiated after the MRP run. The run engages production planning and procurement of materials. The main factors affecting the material flow of ECH production can be determined by reviewing the production process steps which involve physical material flow. The parts of the ECH product and production process that dictate physical material flow are product structure, assembly order, material storage and replenishment policies, layout structure and transportation and logistics principles.

4.1.1 Product structure

While seemingly a less directly influencing factor, product structure in terms of product configuration, product type, material category and component modularity all affect how an assembly process is conducted and how much material movement is involved in the assembly process. Mass produced products offer little configurability. Therefore, their assembly or manufacturing processes consist of optimized material movement through production, but products lack variation. ECH production is more flexible due to the cellular production line layout. Product structure principles such as modularity and Design for Assembly (DFA) increase the level of customizability while maintaining large production quantities. Modularity is more commonly present in the components manufactured in a cellular production line. Product structure modularity can be applied by having components or sub-assemblies, which have interchangeable parts, but are attached together using standardized or similar fixtures and fastening systems. Therefore, modularity reduces the need for different set-ups and materials can be retrieved for the assembly process from same locations as other modular materials. In addition to modularity, the size, type of material, and weight of components determine whether tools, machinery and safety pre-cautions are needed for transportation and material handling.

In the case of the ECH product, the product structure is already quite modular. For example, the cover plates use similar fixturing between brands and the hoist body is assembled mostly from the same components between standard hoists and special variants. Often the special hoist variants require an additional component to be added to the structure (double-brake or rain cover), but sometimes they also require replacement parts for the more standard components (different chain guide for limit switches). The product structure supports material flow the best when the number of required components is minimized, and when they are distributed nearby the assembly area. This is because fewer materials required for the assembly means less movement and fewer components to retrieve during assembly. However, this would decrease the customizability of the product, which would also decrease the number of variant selections. This trade-off is solved by deciding the variant catalogue based on demand and product design capabilities. The demand for a specific variant type that requires unique materials must be higher than the costs of maintaining the possibility to produce such a variant. During this material flow analysis, the product structure cannot be changed so the effects of product structure change are not included in the investigation of the improved material flow for K-hoist production.

4.1.2 Assembly order

The assembly order of the K-hoists dictates the movement of materials within the assembly line. When designing an assembly layout, the assembly order of the manufactured product is one of the key influencing factors for workstation placement. The number of parallel workstations and shape of the assembly line is decided depending on the production demand and production principles.

Assembly order dictates the necessary assembly steps that need to be completed before other assembly steps can be started. This “critical assembly order” is useful to be understood, since by providing the most efficient means for the material storing and transport principles around these steps, bottlenecking of the assembly process can be decreased. In the case of ECH production, the assembly process of a K-hoist consists of multiple steps and the product is assembled from a selection of different hoist modules. For the standard K-hoist assembly, the critical assembly process is formed from the SAP workstations in the following order:

1. Hoist body assembly
2. Testing
3. Chaining
4. Branding
5. Trolley assembly
6. FAT

The critical assembly order is mostly apparent when inspecting the processes needed for K-hoist assembly (Figure 38). The hoist body assembly is the first step, and it needs to be done before the hoist body can be tested on the tester. The hoist body assembly includes two sub-assemblies for rotors and micro/limit switches. The assembly of these sub-assemblies can be started at the same time as rest of the hoist body, but they need to be attached before installing the rest of the electric motor and cubicle. However, the sub-assemblies are usually assembled at the time they are needed since one assembler oversees assembling a single hoist or a set of hoists. One area of improvement for ECH assembly material flow would be to establish the sub-assembly process in parallel to hoist body assembly as well as picking of either the components needed for the sub-assemblies or picking of the sub-assemblies themselves.

After testing, the hoist body is moved to chaining, where the chain, chain bucket, chain stop as well as the hook are attached to the body. During chaining, the hoist needs to be operated using either the pendant of the hoist or a test pendant, which needs to be removed before the brand cover plates are inserted. Therefore, branding comes after chaining. The brand cover plates themselves can be prepared at any point of the assembly process, but they can only be inserted after the chaining is complete. The trolley assembly is started at the same time as the chaining during final assembly, and for fixed suspension hoists, which do not include a trolley, the trolley assembly is obviously not part of the assembly process. In standard hoists, the trolley is shipped separated from the hoist body but is later attached to the hoist at the site of the customer. Therefore, the assembly process is not dependent on when the trolley is assembled. However, it needs to be inspected with the hoist body in FAT before packing.

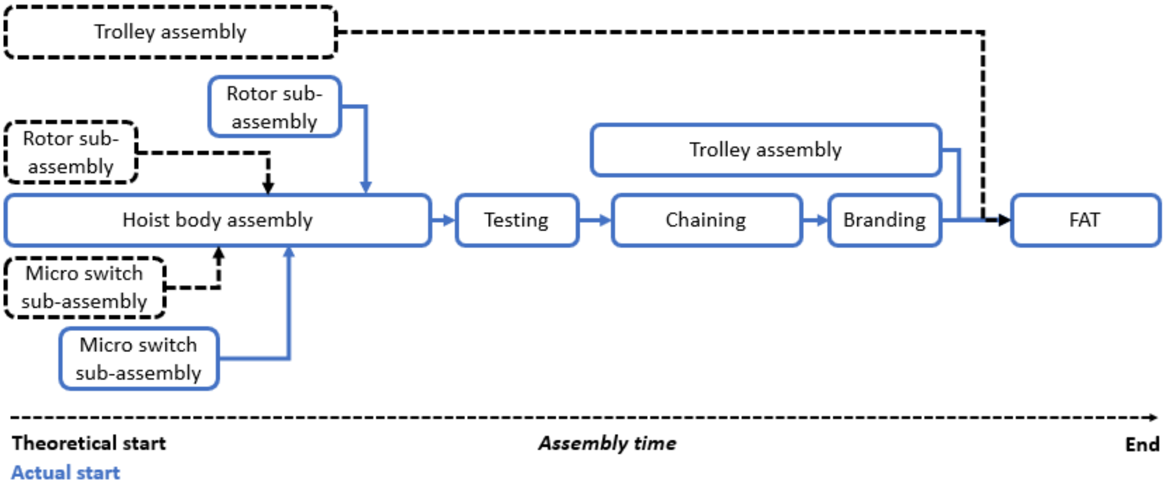


Figure 38: Standard K-hoist assembly order

The main difference in the assembly order of special K-hoists (Figure 39), such as 3-fall and 4-fall hoists, is the requirement for the trolley before chaining. Chaining is done to special hoists while they are attached to the trolley and shipped while attached to each other. This requirement increases the throughput time of the assembly process since the trolley assembly cannot be done in parallel to rest of the final assembly. However, the trolley could be assembled and prepared for both standard and special hoist types in parallel to hoist body assembly. For this parallel assembly to be practical, the assembly times of all modules need to be optimized so that buffering of Work-in-process (WIP) does not occur, and information of assembly step state and production order contents needs to be more transparent and visible between assembly steps and personnel.

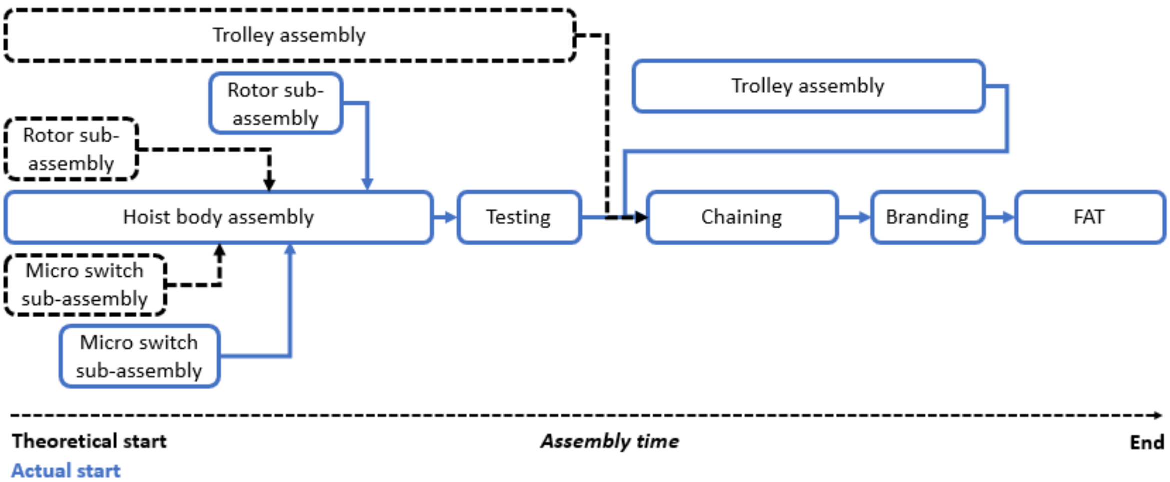


Figure 39: Special K-hoist assembly order

The improvements for ECH production found from analyzing the assembly order include conducting rotor and micro switch sub-assemblies in parallel or in advance to hoist body assembly as well as starting the trolley assembly at the same time as the hoist body assembly starts. However, in practice, to have the possibility to start the assembly in final assembly and hoist body assembly, communication and visibility between the workstations is needed.

4.1.3 Material storages & material replenishment

As discussed in chapter 2.2.3., multiple options exist for factories to manage material storing and transportation in and out of the assembly area. The storing method used as well as material replenishment principles influence the production process and material flow efficiency. For a configurable product with multiple variations and modules such as the ECH, the storing method must ensure visibility and accessibility in both the assembly process and material picking. Typical material storing methods for factory environments include large pallet storage shelves and storage areas, material supermarkets and picking stations, in-line buffers and conveyors, automated storage systems and storage shelves, cabinets for working safety gear, and small compartments for miscellaneous materials.

When considering the material flow in factories, the physical material flow starts when materials are shipped from suppliers to the factory site. Most often materials are shipped on pallets with pallet collars or cardboard boxes. Material handling in factories starts when internally manufactured components and picked materials from a central warehouse or supplier's inventory are received at the factory site. If the materials are received directly at the factory location, they are brought to the reception area via transport trucks and vehicles, and the contents are unloaded for inspection. Replenishment materials shipped from the central warehouse are unloaded and moved directly to the correct supply area bin in the assembly area since they have been already received at the central warehouse. Smaller components need to be moved from a pallet into suitable containers to be able to be stored on buffer shelves which means that not all materials can be dispatched directly to production lines. After the contents are verified, they are moved to the factory buffer storage area of the corresponding production line. This storage area usually consists of multiple pallet shelves (Figure 40) but can also be an automated storage system (Figure 41) where pallets are stored and delivered for picking automatically.

Figure 40: Pallet shelf [37]

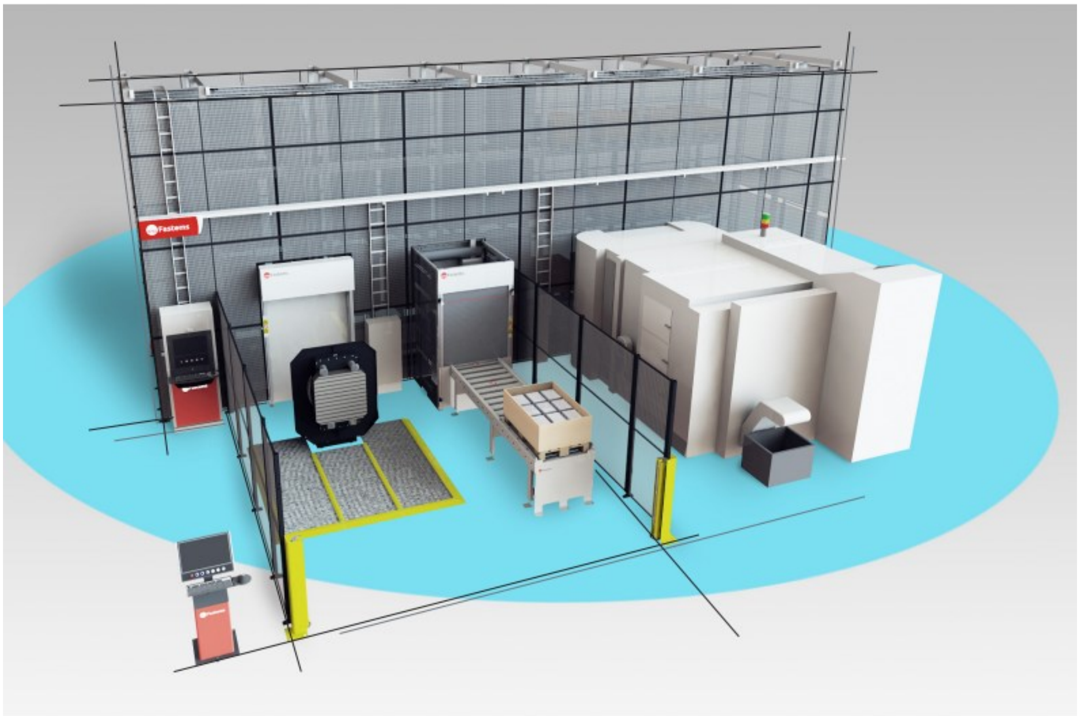


Figure 41: Automated storage system (Fastems, FMS) [36]

Order specific materials are picked by forklift drivers directly from material reception area and brought to the assembly area when needed. In the KHH factory, the MTS and PTS materials needed for further processing during the assembly process are delivered to the assembly area via forklifts, pallet jacks or picked by hand and delivered straight to the assembly workstation buffers. PTO and MTO components generally do not have buffer storages designated for them, instead, they are delivered next to the working area in the assembly cell after the production order, for which they are reserved, is released into production. Buffer storages for K-hoist production are reserved for components only, and not for Work-in-process (WIP), because the production process does not directly account for WIP build-up. During the factory body set assembly process, the finished hoists are placed on the test beam before testing. Because testing can be done to only one hoist at a time and testing process cycle time is smaller than in final assembly, WIP occurs before and after the testing process.

Buffer storage shelves used in K-hoist production at HH8 are displayed below in Figure 42 and Figure 43. The standard pallet shelves can have additional shelf spaces which allow personnel to pull the pallet towards them for easier material retrieval. Both storage shelf types are used in proximity of the assembly stations as well as around the general production area, from where the materials are picked when needed. Other smaller movable shelf types exist for small components, such as chain guide and micro switch components, and linestock materials, such as stator cover screws and cubicle screws. Other types of storage besides the component buffers are for example the safety equipment cabinets (Figure 44) and dedicated areas for pallet and empty container stacks. Production waste is managed in the HH8 by providing waste containers in each workstation and weekly emptying process conducted by the production line personnel.

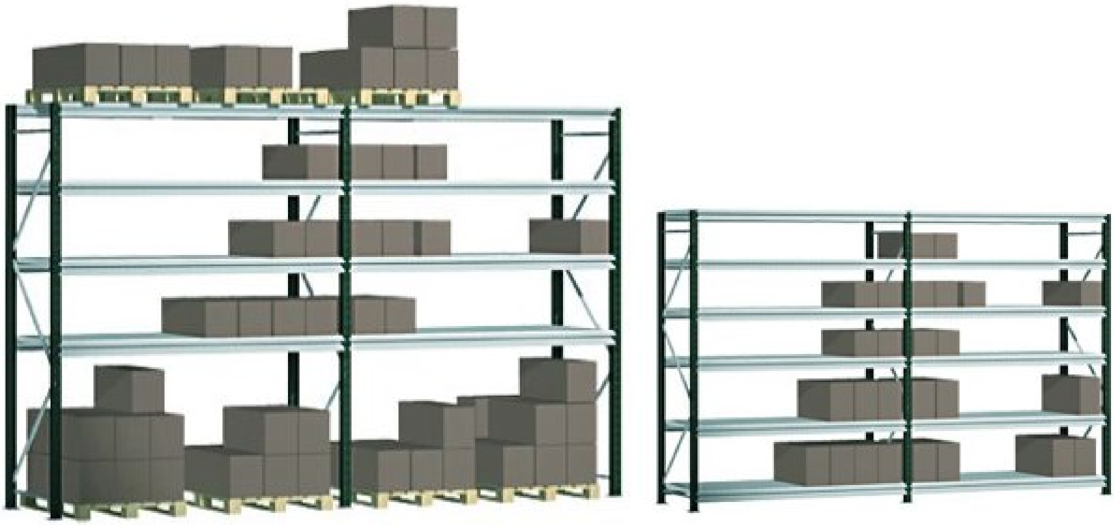


Figure 42: Typical production buffer material storage shelves [37]

Figure 43: Linestock storage shelf [37]

Figure 44: Cabinet for safety equipment [37]

While accounting for the different storing methods available in KHH, we can determine that the choice of storage type used for materials depends heavily on the employed production principle e.g., pull type production and JIT. When determining the potential improvements in factory material flow for ECH components, the goal is to simplify the material movement and retrieval from the storage locations and shelves. This is done by streamlining and reducing the number of locations where materials are stored before they are used and choosing storage shelf types that enhances and eases the picking process. Therefore, to support optimal material flow, the materials would need to be directly consumed in the production process after reception without going through any buffer storages. In practice, this is challenging to achieve because of the inconsistency of actual material delivery times. Also, for the production process to be initiated as soon as possible, all the materials needed in assembly must already be at the production line buffer.

Additional challenge for the K-hoist material storing is the configurable product structure. Because any customer can order any configuration of the product, the production facility must contain at least one of each material listed in the entire factory specific ECH superBOM or be prepared to order all required materials in short delivery times to provide competitive lead times and maintain customer satisfaction. The factory specific ECH superBOM is a BOM, which includes all possible materials that could be selected in K-hoist configurations assembled in Hämeenlinna.

Buffers increase production flexibility and competitiveness, which make them necessary in practice. Therefore, the material flow optimization should be about determining the size, number, type, and layout of the storages in the production process, defining the methods and practices used for material picking and handling as well as selecting the stored material quantity and replenishment values, and storing method used e.g., pallet or container. Other improvements could be in enhancing the material management system to gain more accurate information about stock levels and material locations.

When considering the storage and material replenishment improvements for KHH, it is important to differentiate the main reasons for non-value-added time during material storing and handling. The main areas where materials are handled are the material reception area, main storage area, in-line buffer storage area and shipping storage area. The focus for improving material flow in factories, such as the KHH, should be in enhancing the material movement between these main material handling areas by developing suitable storing solutions and logistic principles.

If we focus on the material reception and delivery to the main storage area, several practices can be utilized. Depending on which main storing method is used, manual pallet storage, automated storing system or a supermarket, the materials are received and dispatched to correct locations differently and can require additional handling steps. As we have previously established, the unnecessary material movement is reduced when the number of material storage locations is reduced. However, buffers are necessary for the flexibility of the production process and the main storage area cannot always be maintained close to the assembly area since, the main storage area can contain materials used in other production lines as well.

For KHH and ECH production in general, having specific personnel to handle material picking from the main storage area or supermarket would reduce the unnecessary movement during the assembly process. The heavy components, such as gearboxes and motor components could still be maintained in small buffers near the workstations since they cannot be maintained in automated storages, such as AGILON, Pater noster or Kasten TORNADO and their transportation to workstations would increase the picking duration and create other challenges since they do not fit in the same container with the other hoist body assembly materials.

Safety stocks and material replenishment practices affect the total quantity of materials maintained in the factory storage areas. To improve material flow by reducing the time materials are stagnant in production line buffers, the replenishment quantities need to be adjusted based on the current demand, production late and scheduled production volume. The replenishment values can be changed for individual materials in ERP system by adjusting MRP and warehouse management information. In addition to the replenished quantity, it is important to determine how materials should be placed in the containers and boxes, which are stored in either the production line buffers or the main storage area. The available space should be optimized based on the size of the components and replenishment quantity.

Similarly, the picking process could be improved by implementing more accurate procedures to have the ability to find all necessary materials for orders without previous experience. Currently, the materials are picked when they are needed from production line buffers by the assemblers using the production order as a picking list. This is not ideal, since the production order is generated from the KHH ECH superBOM and the materials are not listed specifically picking or assembly in mind. The possibilities for improvement would be to have and additional transfer order (TO) for the picked parts or using a software solution to manipulate the component list in the PO so that both the locations of the components are visible and the order in which they are needed is correct. This would also allow changes to be made to the product structure without the need to educate personnel about new storage locations, since they would be listed in the PO as well. In the timeframe of this thesis, this investigation is excluded but it would be essential to find a suitable system solution when implementing a picking process step for hoist body assembly. However, enhancing the storage for better accessibility and visibility would reduce risks for picking errors and make the process of retrieving materials from the shelves quicker. Also, reducing the buffer quantity in the assembly area, optimizing safety stocks and replenishment values based on demand and introducing a picking process, which could be done in parallel to hoist body assembly would reduce the production throughput time and reduce inventory holding costs.

4.1.4 Layout

The ECH production line in Hämeenlinna is a single line cellular layout. This means that the assembly layout is designed to increase production performance while maintaining flexibility in material flow and assembly practices. The hoist body assembly is conducted on a single workbench, which allows simultaneous assembly of multiple hoists. However, the rotor and microswitch sub-assemblies are conducted on separate workbenches at the cell, since the benches contain the required equipment and linestock set-ups. Testing is the following workstation from where the hoist bodies are moved either to final assembly or directly to FAT. Final assembly cell contains three workstations, which are stationed in a linear orientation. FAT inspection, while stationed next to packing workstation, can be conducted on hoists that are waiting to be moved on to the packing area.

When considering improvements of the current layout regarding material flow, we must consider the guidelines for effective production layout discussed in chapter 2.2.6. While accounting for these guidelines in the HH8 assembly area, potential areas of improvement can be found in the material flow pattern and production accessibility and visibility. Currently, the available working space has limited the positioning of the workstations in the assembly area, so that picking process is not supported in the hoist body assembly and final assembly is separated by a wall from the other production area (Figure 45). Due to the ramp-down of small frame ECH products, the possibility has arisen to implement final assembly directly after testing. The available space could be utilized to streamline the material flow by dedicating the space after hoist body assembly to hook sub-assembly (3b) and the space after tester to chaining and trolley assembly (3b). With this change and introducing a dedicated picking process to the hoist body assembly, travel distance, visibility, and flow of components in the assembly line could be improved.

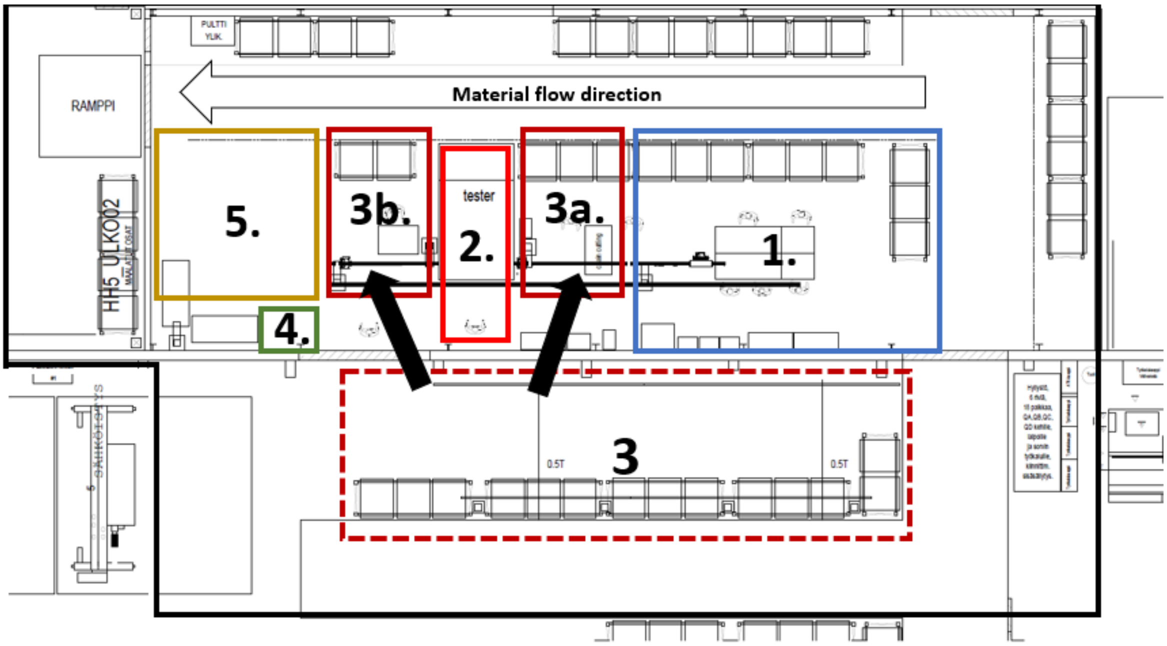


Figure 45: Final assembly relocation at HH8

While having the capability to assemble multiple products simultaneously is suitable for factory body set assembly, one-piece flow would be preferred in standard CTO hoist assembly. One-piece flow is the process of completing a manufacturing or assembly task on one product at a time and moving the product to the next step in as specific cycle-time. This practice would reduce the duration, which components are stored in buffers as well as production lead time. The production process can also adjust better to fluctuating markets and demand when utilizing one-piece flow. However, in practice, hoist body assembly is sometimes more efficient when producing a small number of hoists simultaneously. For example, factory bodies are always ordered in sets of four. Therefore, it reduces assembly cycle time if the assembly steps and picking of components can be made for all the hoists in the set at the same time.

When considering the assembly area shape, the assembly area layout does not allow space for a U-shaped line without major changes. The location of the tester is fixed, which dictates the layout significantly. Forcing the U-shaped line to curve to the current final assembly area by introducing FAT and packing at the same area would result in longer shipping distances out of the assembly area. Therefore, the linear production line shape is more suitable for HH8. Also, the wall dividing the two main assembly spaces would still limit visibility and would not lead to the desired quality improvements. Further improvements for the straight layout could be achieved if the packing process could be moved outside of the ECH assembly area. This would leave more room to include all final assembly process steps to the same side of the floor area, which would support the assembly of all ECH product types better.

4.1.5 Material transportation & logistics

In addition to product structure, assembly order, storing capabilities and practices as well as layout, improvements can also be made on the movement of materials within the factory. For determining what possibilities exist for transportation and logistics improvement, it is beneficial to analyze what materials are currently being moved and by what means.

Regarding ECH production, materials are shipped via trucks and vans and all materials can be shipped either on pallets or cardboard boxes. Since components are ordered mostly from EMEA and APAC regions, two distinct pallet sizes are used in each region respectively. While the European standard pallet size is smaller, the storage areas for the pallets are designed to support other pallet types as well. Depending on the size of the component and desired storing method, the materials can be transported directly to the factory storage area and to the buffer area without taking the components out of the shipped pallet. The pallets are usually outfitted with a pallet collar (Figure 46) to prevent materials from falling out during shipping, which makes the pallets to be suitable storage contains as well.

Figure 46: Pallet with collar [37]

Figure 47: Pallet Jack [37]

Figure 48: Stacker forklift [37]

The pallets are moved with either pallet jacks (Figure 47) or with forklifts. Since the materials for ECH components can be stored in standard sized pallets and the weight or size does not require specified equipment for transportation, they can be moved with smaller stacker forklifts (Figure 48). However, if the materials are small enough, they can be taken out of the pallets and moved to smaller plastic containers (Figure 49), which require less space to store. Typically, the forklift driver stacks the components on to the containers before bringing them to the assembly area material buffers.

Figure 49: Plastic containers used in ECH component storing [44]

Other equipment used in material movement in the assembly area include trolleys for additional working space as well as the trolley used in moving specific racks during the testing process. The hoist racks are fixtures for the hoists which are used to attach and move the hoists along the test beam. The racks are manually lifted to the test beam from one trolley located between the tester and the hoist assembly area. The racks are collected on another trolley at the other end of the test beam after the hoists are lifted out from the test beam. The hoists are placed on pallets and moved to the final assembly area via pump jacks. After the trolley at the end of the test beam is full of racks, it is manually moved and switched with the one at the other end. Any other materials are moved manually without any equipment, such as components needed in the assembly processes and safety equipment. However, exceptions include PTO materials, which are delivered in identifiable plastic containers directly to the assembly area by forklift personnel and the assembled hoist bodies, which are always moved via in-line chain hoists, which are mounted near all workstations.

Finding improvements for the material transportation and logistics planning revolves around the idea of reducing unnecessary movement of personnel or components in the assembly area. Additional improvements can be achieved by optimizing material replenishment in the buffers, dispatch of hoists and waste out of the assembly area. Starting from the material unloading at the reception area of the factory, the goal would be to ensure that the materials are delivered to the factory storage area as soon as possible. Changes could also be made to the logistic practices by introducing a picking process from a separate storage, which would be directly replenished instead of the factory storages. This would replace the current storage space and replenishment principle by reducing the need for in-line buffers for hoist body assembly. However, while picking process is a preferred change to the hoist body material retrieval, chaining during final assembly and trolley assembly would still need most materials to be stored near the assembly area to ensure flexibility in the assembly process.

If a picking process would be introduced, the materials would not need to be gathered from around the different assembly areas. Instead, they would be directly brought to the assembly area via forklifts and the materials could be picked into individual containers based on orders. While the materials themselves would need to be picked from a separate picking area, they could be picked simultaneously as the hoist bodies are assembled for previous orders, thus eliminating the picking time at the start and during the assembly process.

Chain hoists are always needed in the hoist body assembly as well as in final assembly to lift the hoist bodies and move them either to the test beam or to workstations and on pallets for final inspection. However, to reduce unnecessary movement, the workstations should be placed so that the hoist bodies can directly be lifted and moved to the next station without restrictions. In the case of HH8 assembly area layout, by moving the chaining process directly after the tester would allow the hoist bodies to be chained directly on the test beam removing the additional movement step of placing them on pallets. However, a separate workstation would be needed for chaining special hoists since the hoist bodies would need to be attached to the trolley before chaining. The implementation of the improvement suggestions discussed in this chapter, such as efficient use of equipment, is analyzed further in chapter 4.3.

4.2 Material flow development for ECH production in Hämeenlinna

In summer 2021, the author participated in a small production development project concerning the Hämeenlinna KHH ECH production line. Since the ECH production in Hämeenlinna was under ramp-down, opportunity arose to adjust the material flow, layout and material replenishment and control cycles to increase productivity and production efficiency while reducing unnecessary labor.

In this chapter, we will briefly discuss the reasons for changes and steps taken during the project as well as methods used for material mapping. The results of the project related to material replenishment and material flow will be also shown and later used in comparison with the investigated material flow specifically for ECH products, which would be designed without the spatial requirements of KHH.

4.2.1 Project in brief

The productivity improvement planning was scheduled for weeks 26-29 in the summer of 2021 and the implementation of the changes was done when the production of the standard smaller frame sizes could be stopped in late 2021. The planning consisted of four steps, each targeted for one week respectively. The tasks included material mapping, control cycle and replenishment information updating, creating proposals for layout redesign, and creating a preliminary plan for following through and implementing the suggested changes. The project was participated by the author, a development engineer conducting the ramp-down process of small K-hoists and a production supervisor at the HH8 assembly area.

The first task was to identify all materials that are maintained for ECH production in Hämeenlinna. This material mapping resulted in a list containing all materials used in small, large and both frame sizes as well as in other hoist types not directly in the scope of Hämeenlinna such as Stagemaker hoists. The materials were divided into categories based on whether they are produced in-house or procured elsewhere. The materials were also given specification for their use in different hoist types: NEO, EX-proof, or body set. NEO hoists are small frame inverter hoists, which offer increased lifting speeds and EX-proof hoists are special hoists designed for challenging environments, that require assurance that the hoists do not generate heat or sparks. EX-proof hoists are available in all frame sizes. In addition to these specifications, it was also beneficial to note whether the materials were used in other Konecranes products. Also, the control cycle, replenishment values, average consumption as well as how many of the specific material is used in one hoist assembly were important information to collect. The author was responsible for collecting the category, control cycle information and replenishment values from SAP as well as the usage information regarding the materials use in specific special hoist types.

The ramp-down of the ECH production line would be conducted in phases and the first phase would be to stop the production of the standard small frame hoists and later the special small frame products. Therefore, it was necessary for the project to identify the materials, which would be needed in all hoist types, and which would only be needed for the special hoist types. This was conducted by the author by collecting usage information from three data sheets spanning two previous years of production. The data sheets were provided by the development engineer and the information for the sheets was gained from SAP. By cross-referencing the materials in the usage lists, the author was able to gather a list containing all small frame materials and to divide them based on whether they are used in one or many of the FL02, FL05 or FL10 EX-proof or NEO hoist types. This information was used to individually determine whether the materials should be continued to be maintained in HH8 buffer or central warehouse based on expected demand for the product types. This improvement proposal was expanded to also include suggestions for updated replenishment values and method of storing the materials i.e., pallet or box container.

The suggested storing method for the materials was determined by visiting the production line and taking pictures of the current shelf space available and storing containers used. The author was responsible for visiting the production line and determining the available shelf space as well as quantity of existing materials stored in the buffers in terms of shelf space used out of the total available shelf space. The information was later examined by all participants and the decisions for the suggested materials were also done by joint efforts.

The author also expanded the analysis specifically for large frame materials. This new "ECH item catalogue" was a list of over 400 materials used in either large or both small and large hoists. The list also included information about the hoist module the material was part of as well as the type of material it was for the module i.e., primary, secondary, fastener, fixing part, lubricant, sealing or electrical component. The average consumption data was generated for the materials from the past 12 months. Since the large ECH production was still in the production scope of the HH8, the suggestions for the control cycle and replenishment values could prove beneficial in reducing inventory holding costs and improving material flow. The demand of large ECH products would remain consistent unlike the smaller frame sizes, which meant that improving the control cycle and replenishment of the large ECH materials would require analysis based on past consumption data.

Comparing the consumption, control cycle and replenishment of the materials regarding all other gathered information already collected for the materials, the author was able to identify errors in the current master information maintained in SAP for some of the large ECH materials. These errors were fixed with warehouse management team at KHH, and the list was then used to divide materials into three levels of priority. The PRIO 1 materials are fast movers and essential for every large hoist assembly, which is why they would need to be contained in buffers next to the assembly area to ensure flexibility in starting the assembly process as soon as the production orders are released to the assembly area. PRIO 3 materials are PTO category materials and rarely used special hoist components which require picking from central warehouse. PRIO 2 materials are not as common as PRIO 1 materials but do not require picking from central warehouse and could be contained in the factory storage area.

The third step of the production improvement project was designing an improved layout for the HH8 assembly area. The layout improvement was conducted in three parts. The first part was to establish the project participants, current state of production, technical limitations for the layout, problems or issues found in the current layout design, goals for the layout improvement and critical assembly order for ECH production. The second part included creation of the actual layout proposals as well as comparison of the created layouts. The final part was to present the ideas for supervising personnel and to decide upon one layout and plan the actions to implement the changes into the HH8 assembly area. This was done along with presenting the results of the entire project during the last week of the project.

During the first part of the layout redesign, the current state of the assembly area and storage space was determined by the author. As discussed previously in chapter 3.5., the layout supports assembly of both large and small frame size hoists. One of the main issues in the current layout were the number of small frame components kept in the assembly area buffers while the demand was decreasing due to production ramp-down. The current layout was initially designed for the assembly of smaller frame sizes, which meant that the final assembly for the large chain hoists were established later and in a separated section of the HH8 area. The layout redesign would allow the participants to improve the picking process by analyzing the picking need and replenishment values for components that would continue to be used in the assembly after the initial ramp-down wave. The physical restrictions for the assembly area included the wall between main assembly area and final assembly area, the tester as well as the packing area. While the packing could in practice be transferred elsewhere in the layout, it already is in the desired location in terms of smooth product dispatch. The other restrictions, such as the location of the tester are fixed and cannot be changed.

The goals for the layout redesign included utilizing the open shelf space left because of small frame ramp-down, easing material storing in the assembly area and increasing personnel comfort and working capability, streamlining material flows, finding ways to prevent material shortages, and increasing productivity. The author established the available buffer shelf space in HH8 (Figure 50), which was used to determine what materials should be relocated in the layout proposals.

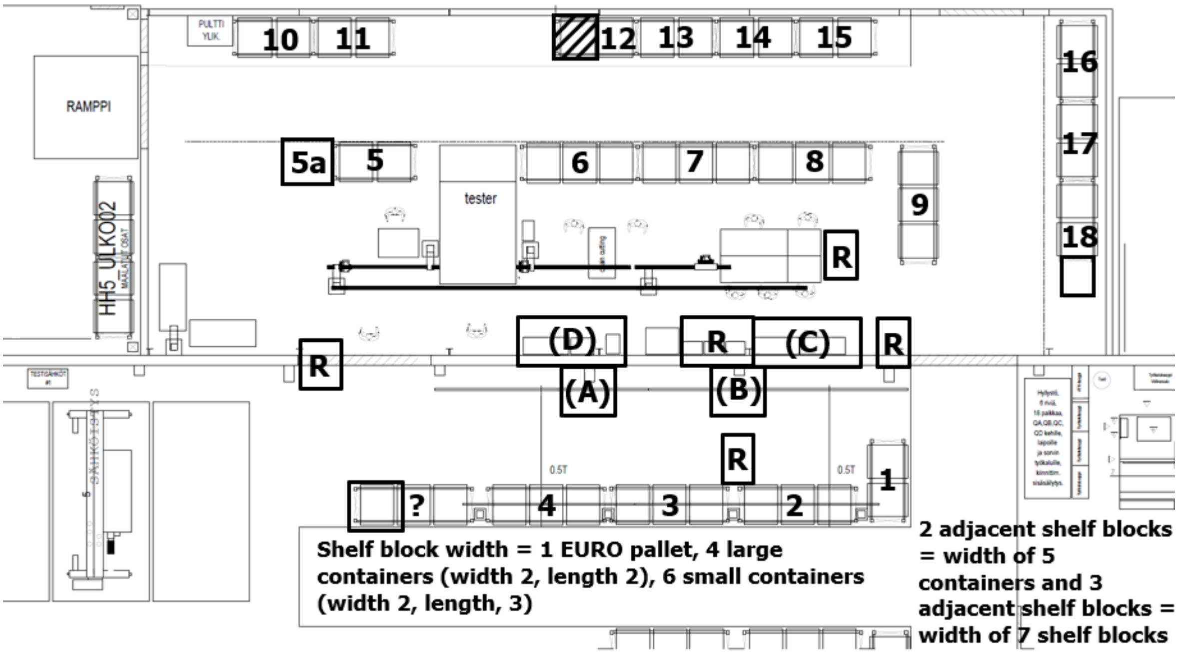


Figure 50: Available buffer shelf blocks reserved for ECH production in HH8

The layout proposals were created by the author together with the HH8 production supervisor. The second part of creating the layout proposals led to five layout proposals and an extra layout which incorporated more significant changes than the other official proposals. The proposals can be seen from Figure 51 to Figure 59. The process flow direction of the layouts is marked with red arrows and red numbered workstations.

The first (Figure 51, Figure 52) and third (Figure 54, Figure 55) proposals include both the layout with highlighted changes and a layout with SAP identifications for the workstations. The routing for the assembly process involves movement from one workstation to the next. The second layout (Figure 53) is like the first layout but with changes to routing, hence only the drawing with SAP workcenter identification.

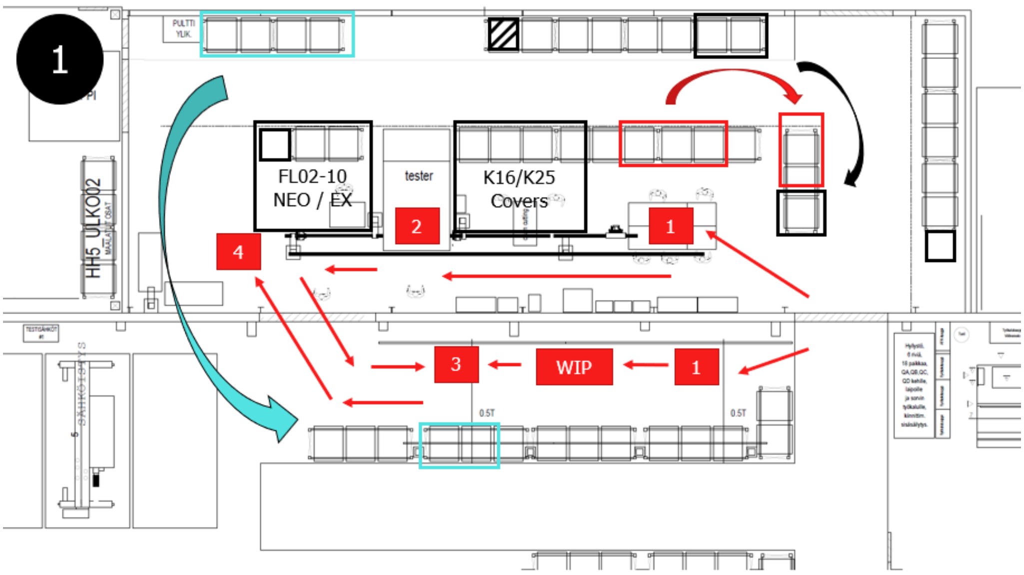


Figure 51: HH8 Layout proposal #1

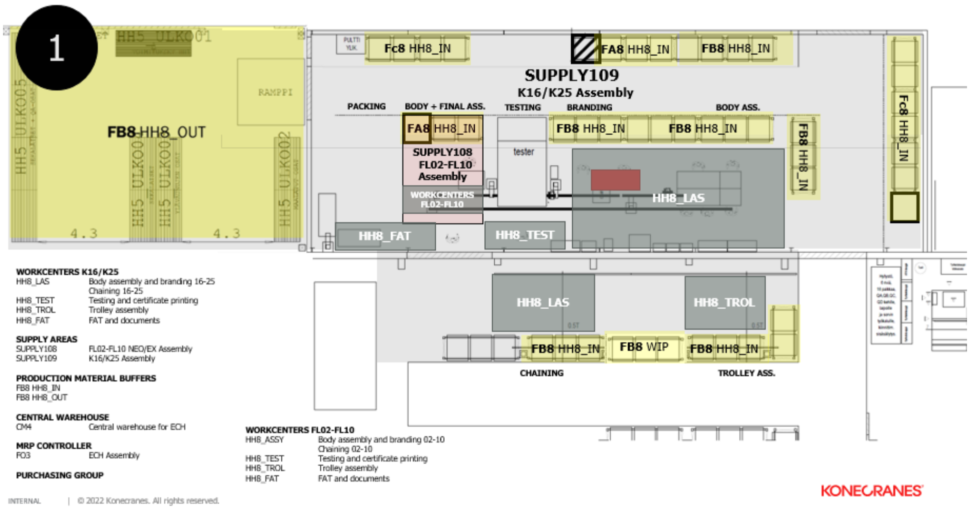


Figure 52: HH8 Layout proposal #1 with SAP identification

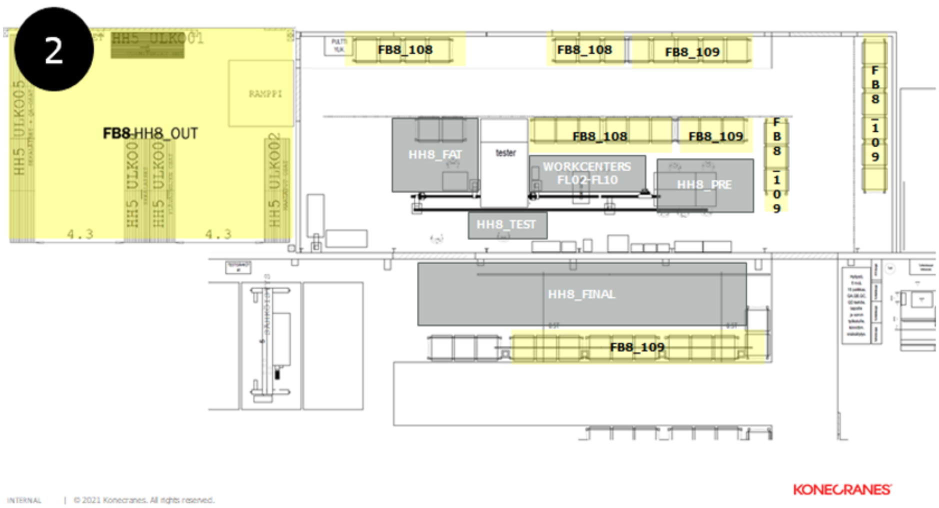


Figure 53: HH8 Layout proposal #2 with SAP identification

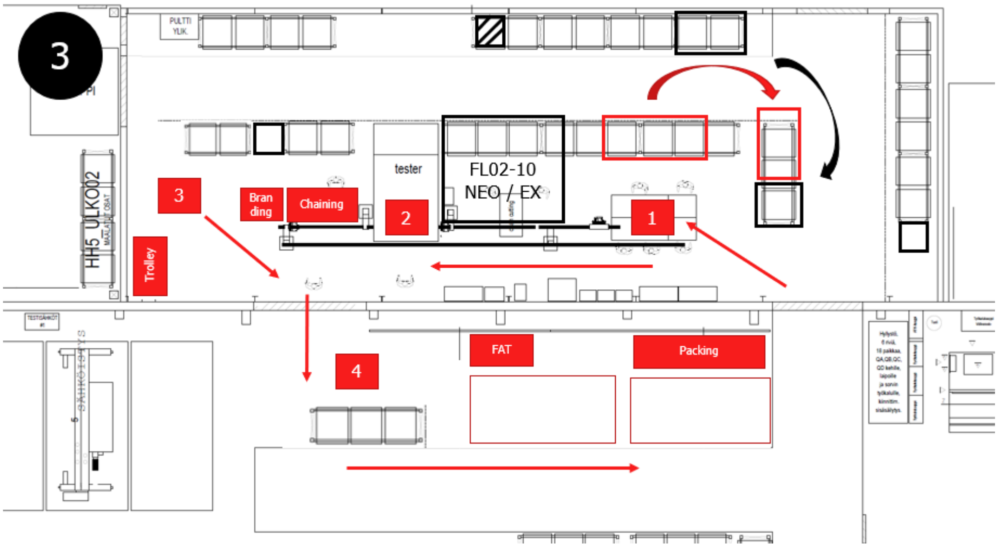


Figure 54: HH8 Layout proposal #3

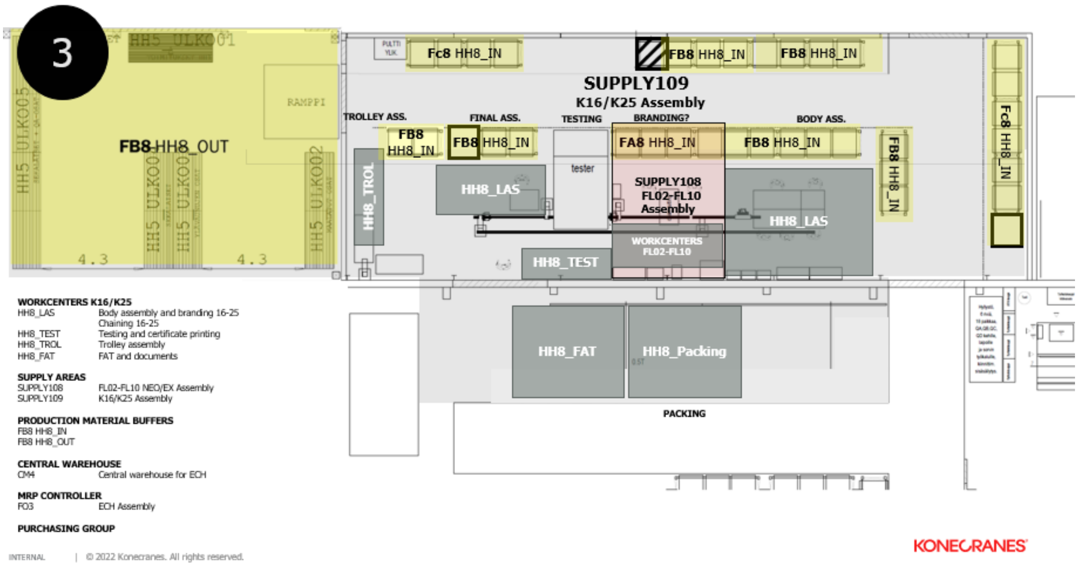


Figure 55: HH8 Layout proposal #3 with SAP identification

The fourth layout is divided into 4a (Figure 56) and 4b (Figure 57) layouts, which showcase the proposed changes before and after the ramp-down is conducted for the smaller frame sizes.

Figure 56: HH8 Layout proposal #4a

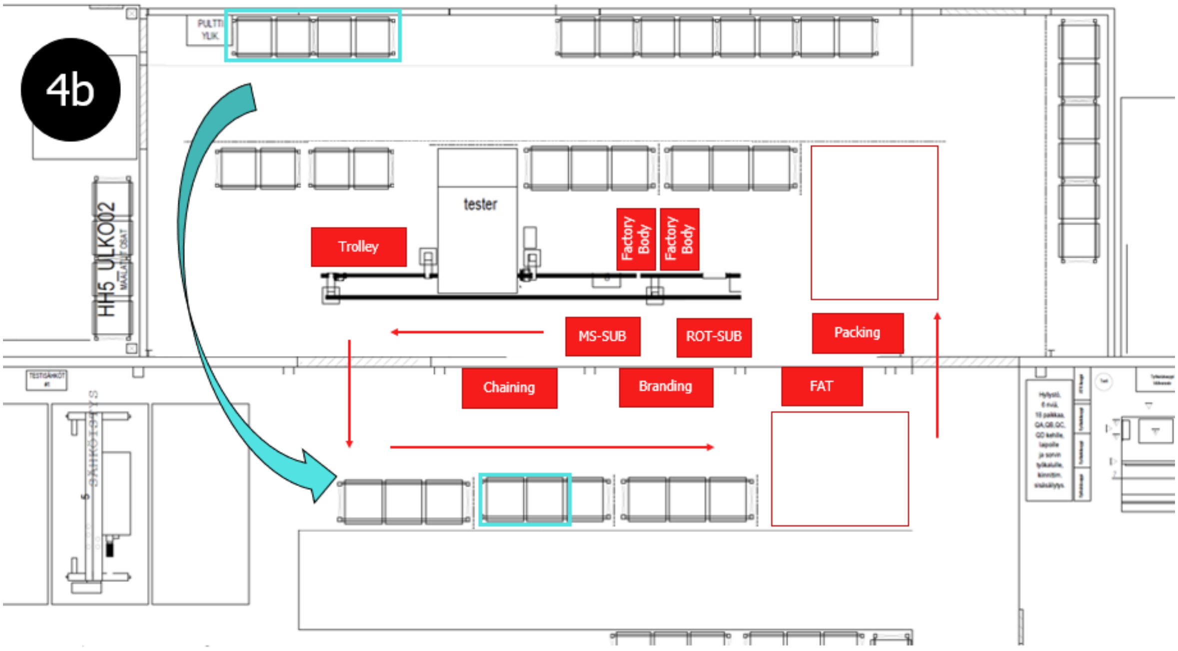


Figure 57: HH8 Layout proposal #4b

The fifth (Figure 58) and the final extra layout (Figure 59) have an inverted material flow direction and the extra layout completely removes the final assembly area by integrating it right after the tester in the same floor area as the other process steps.

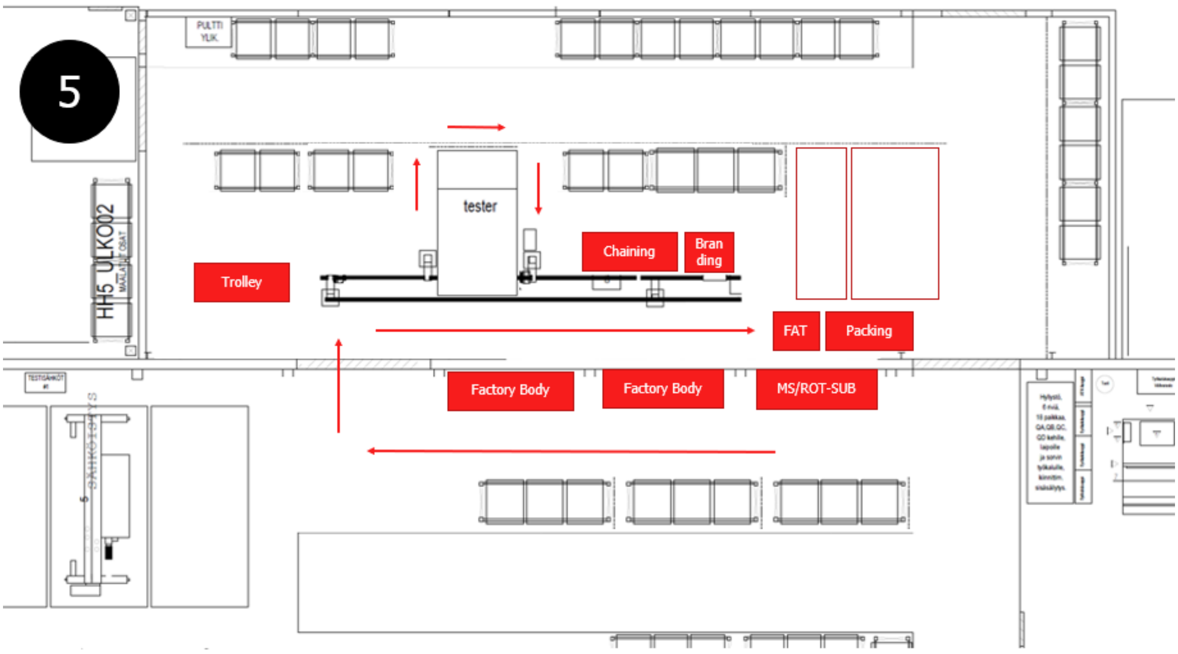


Figure 58: HH8 Layout proposal #5

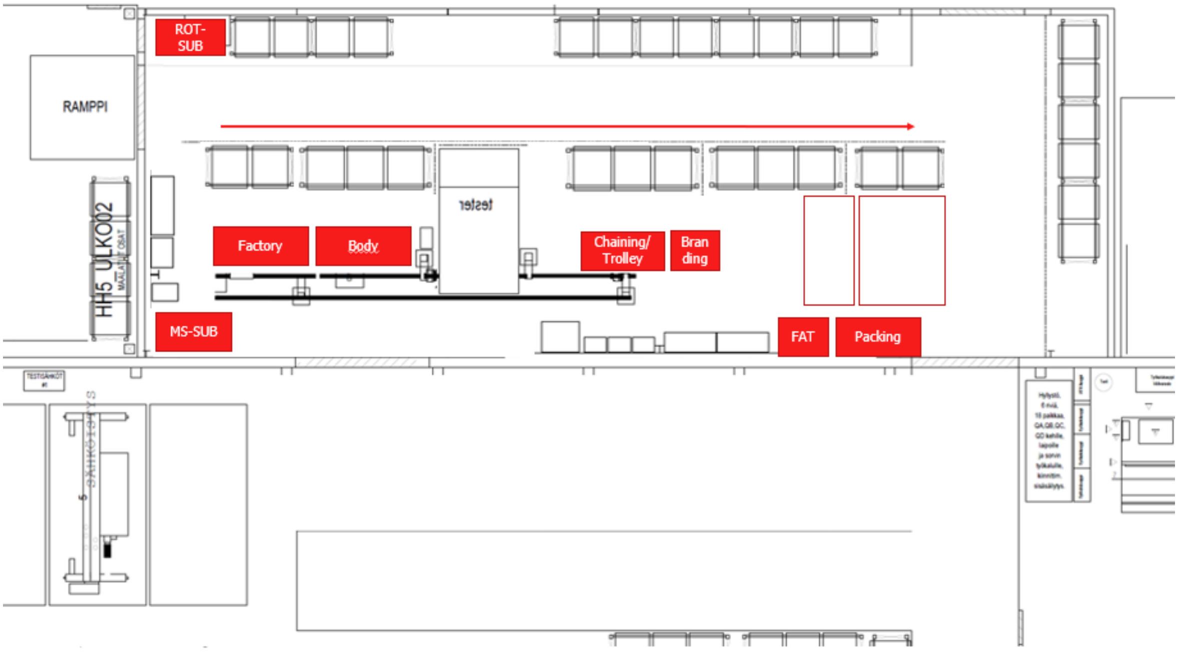


Figure 59: HH8 extra Layout proposal

4.2.2 Results

The layouts offered good ideas on what changes would be beneficial and how they would be implemented but choosing just one layout proved to not be the result of the third part of the layout redesign endeavour. Instead, the resulting changes would be a combination of the best design elements from the created layouts. The storage location changes including pendants, rotors and gearboxes highlighted by curved arrows in Figure 51 were an obvious improvement and easy to implement since the change would directly reduce picking and worker travel distance during assembly process. Another suggestion that would be implemented was the temporary location for small frame NEO and EX-proof assembly shown in proposal 2. The location in the assembly cell was previously underutilized and now the available space was used more efficiently. The area would later be used as another large hoist body assembly workstation after the NEO and EX-proof variants of the smaller frame hoist production is ended.

Other changes included the trolley assembly location shown in layout 4b, which could now be conducted in the area directly after the tester, where the travel motors could be more easily tested before trolley assembly. The FAT process also was expanded so that hoist documents, towing arm and support arm components would be located closer to the inspection area. The final layout and routing resemble mostly the one seen in Figure 60.

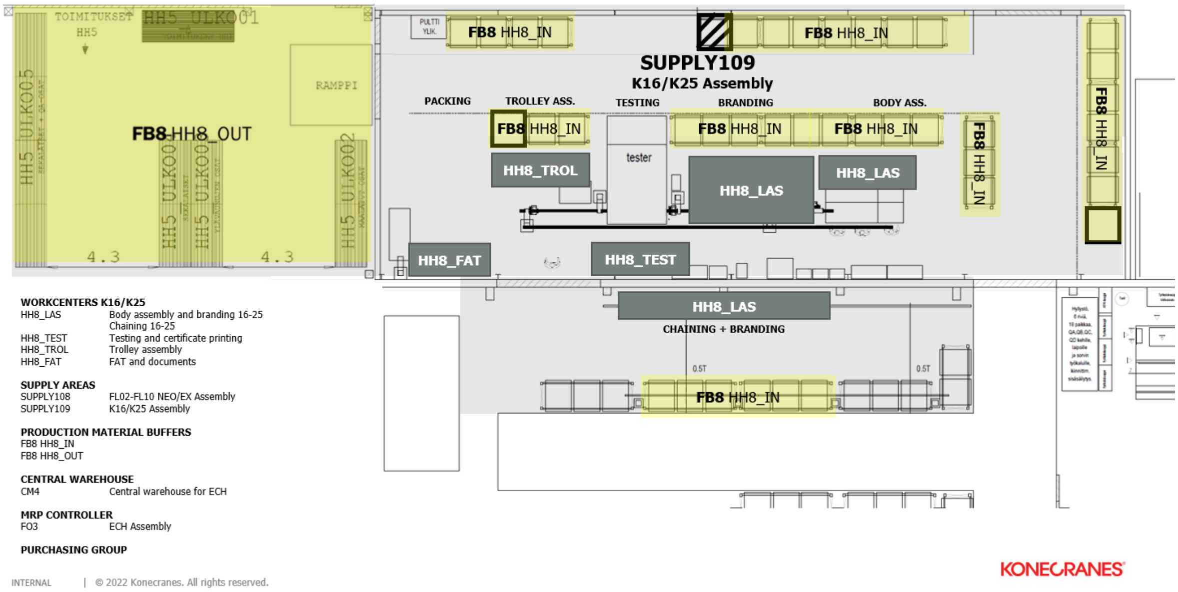


Figure 60: HH8 Final assembly area layout and routing

In addition to the layout redesign, the previously established changes for the small frame component SAP material master information were also made. With these changes the quantity of small frame hoist materials could be reduced in the buffers based on demand estimates until the production was eventually ended and focused fully on large ECH production. The number of some of the fast moving and common large ECH components could then be increased in the buffers to prevent material shortages. After this initial concept was established in HH8, plans for additional changes were also suggested for the layout after the production of small frame hoists would end. One of the main goals would be to completely transfer the final assembly workstations to the same floor space as the other process steps. However, the planning of these changes was not developed further since it was established that the packing process would still be at the assembly area. There was no confirmation at the time that the packing could be moved elsewhere.

All in all, the project proved beneficial in terms of increasing knowledge on material mapping and available storage space. It also resulted in SAP material master and layout changes that streamlined the production process, decreased process cycle time by providing shorter material picking distances for certain components and helped to decrease storage levels of smaller frame components systematically.

Notable for the HH8 development was that in early 2022, the discussed goal for the final assembly location could be reached when it was confirmed that the packing process could be moved to the HH2 packing area. The changes were then implemented shortly after the decision was made. However, in the comparison of the results and material flow improvement methods later in chapter 5, we will refer to the resulting layout and changes made during the HH8 improvement project in summer 2021.

4.3 Investigating blank paper material flow for ECH production

In addition to elaborating the material flow development of ECH production in Hämeenlinna, main goal for this thesis is to investigate a blank paper material flow for ECH production. In this case, the blank paper approach refers to ECH material flow planning, while not being restricted by similar constraints as the production line in Hämeenlinna. In practice, this gives an opportunity or a "clean slate" to investigate an optimized production line layout, storages, replenishment and logistic strategies, control cycle and transportation specifically for large ECH production. By conducting this investigation, we can determine which steps of the production process have the greatest influence on the material flow, and what production line layout supports the production material flow of large ECH components the most when product mix and required production output is known. The results of this investigation can be used to evaluate the current material flows in other Konecranes ECH production lines and determine whether improvement is needed. The results also help in designing production lines and material flow for other similar Konecranes products.

In the following sections we will discuss the restrictions for the blank paper approach, the formulation of the layout and material flow using frameworks from literature and existing research, and finally, the functionality and practicalities of the resulting layouts and material flows are elaborated.

4.3.1 Restrictions

Instead of focusing on spatial restrictions, the blank paper approach allows investigating an optimized production line material flow while only being restricted by annual production volume and product mix. This opens the possibility to design a production line that would be more suitable to reach the production volume with less resources spent on material flow related tasks and processes. Two scenarios are investigated, where the main difference between the scenarios is the annual production volume forecast. In addition to the basic restrictions mentioned before, we decided to also account for a 20% growth in the annual production volume for both scenarios. The production volume goals for each product type in both scenarios are listed in the Table 6 and Table 7 below. With these restrictions and the current knowledge about the structure and performance of an ECH production line, we can start to develop the blank paper approach for the ECH production line material flow.

Table 6: Scenario #1 (similar demand as for HH8)

Product type	Annual volume	Annual volume with ~20 % growth
K16/K25 CTO Products	47 % of total demand	20 % volume increase
K16/K25 Bodies	47 % of total demand	20 % volume increase
K16/K25 Specials	6-7 % of total demand	20 % volume increase

Table 7: Scenario #2 (increased total demand)

Product type	Annual volume	Annual volume with ~20 % growth
K16/K25 CTO Products	54 % of total demand	20 % volume increase
K16/K25 Bodies	38 % of total demand	20 % volume increase
K16/K25 Specials	8 % of total demand	20 % volume increase

As a result of this investigation, we will also determine a more suitable worker shift system for the production line, the layout and storage location in the production line as well as the internal logistics and transportation of materials into the production line. The production will be conducted in either 1-, 1,5-, or 2-shift workdays depending on the investigation results. A VSM is made for the current and future states for the ECH production and used to assess the process steps for improvement potential. The final material flow assessment will be made using layout drawings for the material picking area and the assembly area. These drawings as well as KPI evaluation will be used to determine the improvements made in the material flow design when compared to the current state of ECH production in Hämeenlinna later in chapter 5. The components used in this investigation are included in the ECH item catalogue.

4.3.2 Structure of the investigation

Following the framework for material flow assessment by Gould et al. [18], we can approach the investigation of an optimized material flow for ECH production by establishing the five phases of the framework. The first phase and consideration of the material flow improvement is to define the production system scope including production system boundaries, functions as well as product mix. The second phase is where the materials are determined for the material flow assessment as well as the relations of different production processes in terms of material movement and handling. The third phase is about determining the performance metrics used to analyze the material flow performance. In the fourth phase, the areas of improvement regarding material flow efficiency are addressed and an improved model for the material flow is created using selected methods. The final interpretation phase is not addressed individually. Instead, it means that all other phases should contain continuous iteration to find the best results possible. The goal of this investigation is to:

1. Plan an improved material flow to the assembly area and during the assembly process leading to the packing and shipping
2. Design an improved layout for ECH assembly area which includes the improvement suggestions from chapter 4.1.

4.3.3 Phase 1 – Defining the scope

The investigation of an optimized material flow is done for the two scenarios, where one of the two has an increased annual demand. This gives a broader approach in designing the layout structure to benefit both the material flow and efficient assembly process. Usually, the assembly area design is limited by spatial requirements or time and cost restrictions. However, in this blank paper approach, the goal is to determine an optimized material flow for ECH production in general. Therefore, these restrictions are not present.

Before determining the assembly area layout, we need to determine the number of “assembly lines” required. To do this, we can use the information available from the current assembly process in Hämeenlinna. KPIs such as cycle time, throughput time and production capacity as well as asset utilization are needed to determine whether the demand goals of the two scenarios can be reached by one assembly line. Table 8 represents the list of cycle times of each workcenter collected from Konecranes SAP for each product type. These cycle times are summed to get the throughput times.

Table 8: Cycle times and throughput times for the different hoist types (values retrieved from SAP, actual values not included due to confidentiality)

Throughput times				
Workcenter	**Control key**	**Description**	**Labor**	**Unit**
TROLLEY				
HH8_LAS	CNF req	Body assembly and branding 16-25	...	HR
HH8_LAS		Chaining 16-25	...	HR
HH8_TEST		Testing and certificate printing	...	HR
HH8_TROL		Trolley assembly	...	HR
HH8_FAT		FAT and documents	...	HR
Throughput time	(Labor SUM)	HR		
FIXED				
HH8_LAS	CNF req	Body assembly and branding 16-25	...	HR
HH8_LAS		Chaining 16-25	...	HR
HH8_TEST		Testing and certificate printing	...	HR
HH8_FAT		FAT and documents	...	HR
Throughput time	(Labor SUM)	HR		
BODY				
HH8_LAS	CNF req	Body assembly and branding 16-25	...	HR
HH8_TEST		Testing and certificate printing	...	HR
HH8_FAT		FAT and documents	...	HR
Throughput time	(Labor SUM)	HR		
3-fall				
HH8_LAS	CNF req	Body assembly and branding 16-25	...	HR
HH8_LAS		Chaining 16-25	...	HR
HH8_TEST		Testing and certificate printing	...	HR
HH8_FAT		FAT and documents	...	HR
Throughput time	(Labor SUM)	HR		
4-fall				
HH8_LAS	CNF req	Body assembly and branding 16-25	...	HR
HH8_LAS		Chaining 16-25	...	HR
HH8_TEST		Testing and certificate printing	...	HR
HH8_FAT		FAT and documents	...	HR
Throughput time	(Labor SUM)	HR		

As established in chapter 3.4, the assembly process for the K-hoist is done in a cellular assembly layout and in five steps: Hoist body assembly, testing, final assembly, FAT, and packing. These processes require their own workstations, and in Konecranes SAP, a separate workstation exists also for trolley assembly, which is done during hoist final assembly. In 2021, the average 1-2 shift industry workers' workdays included 216 workdays (rounded up) and the working hours per week were 36,6 hours for office employees and 40 for factory workers [24].

By collecting the cycle times per workcenter from SAP and summing them to get the throughput times for each product type, we can estimate the required hourly capacity to produce products based on annual demand volume. The cycle times were collected for the different product types; CTO hoists (trolly and fixed suspension variants), body sets and special hoists (3- and 4-fall hoists) and the total annual time for the entire demand was calculated by adding the required throughput times of all product types in the scope with the demands for the two scenarios. The hourly capacity requirements for the scenarios are calculated in Table 9 using the throughput times (TPT) from Table 8.

Table 9: Capacity requirements for the blank paper scenarios

Product mix	Production volume		Time requirements	
Scenario	Annual volume	(20% growth)	Annual time	(20% growth)
Scenario 1	**PC**	**PC**	**HR**	**HR**
K16/K25 CTO	Demand, Table 6	20% increase		20% increase
Trolley	(CTO / 2)	...	Trolley TPT*Trolley	...
Fixed	(CTO / 2)	...	Fixed TPT*Fixed	...
K16/K25 Bodies	Demand, Table 6	...	Body TPT*Body	...
K16/K25 Specials	Demand, Table 6	...		...
3-fall	(Specials / 2)	...	3-fall TPT*3-fall	...
4-fall	(Specials / 2)	...	4-fall TPT*4-fall	...
TOTAL	Demand, Table 6	20 % increase	**(SUM = capacity)**	20 % increase
Scenario	Annual volume	(20% growth)	Annual time	(20% growth)
Scenario 2	**PC**	**PC**	**HR**	**HR**
K16/K25 CTO	Demand, Table 7	20% increase		20% increase
Trolley	(CTO / 2)	...	Trolley TPT*Trolley	...
Fixed	(CTO / 2)	...	Fixed TPT*Fixed	...
K16/K25 Bodies	Demand, Table 7	...	Body TPT*Body	...
K16/K25 Specials	Demand, Table 7	...		...
3-fall	(Specials / 2)	...	3-fall TPT*3-fall	...
4-fall	(Specials / 2)	...	4-fall TPT*4-fall	...
TOTAL	Demand, Table 7	20 % increase	**(SUM = capacity)**	20 % increase

The asset utilization is estimated at 85%, which does not represent the actual rate of the KHH factory but is an achievable goal for the assembly process and can be used as a basis for the capacity requirement calculations. The annual active labor time of a single worker is 1191 hours (Table 10). If we divide the annual required production time for a specific product variant (capacity) calculated in Table 9 with the annual active labor / year of Table 10, we get the required personnel for the two scenarios.

Table 10: Worker capacity and personnel requirements for the scenarios

Worker capacity		
1 Person		
Parameter		Unit
Labor/year		
	216	D
Labor/week		
	40	HR
Labor/day		
	8	HR
Lunch		
	0,5	HR
Pause x2		
	0,167	HR
Active labor/day		
	7,167	HR
Asset utilization		
	0,85	100 %
Active labor/year		
	1315,8	HR
Active labor/week		
	30,458	HR

Personnel requirements		
Scenario	Personnel	(20% growth)
SCENARIO 1		
Personnel	7,15	8,62
(Rounded)	8	9
SCENARIO 2		
Personnel	11,00	13,40
(Rounded)	12	14

The resulting personnel requirements are summarized for both scenarios:

- Scenario 1 personnel requirements (20% demand growth) = 8 (9)
- Scenario 2 personnel requirements (20% demand growth) = 12 (14)

Based on these results, the estimated demand for scenario 1 can be achieved with a 1-shift schedule and with 8-9 personnel production line. The K-hoist assembly line in Hämeenlinna can be operated with 6-7 personnel, excluding packing personnel and a forklift driver. Also, the demand estimates of the large chain hoist production for HH8 are roughly comparable for scenario 1 and can also be reached with 1-shift schedule. Therefore, the results from the calculations are feasible and comparable to the capacity requirements in HH8. In summer 2021, the HH8 production scope included small frame hoists and the practical personnel requirement was 12 workers and a 2-shift schedule. When comparing to that production capability, the results from scenario 2 are more comparable. The capacity requirements for the scenario 2 dictate that the production line would be operated best with 12-14 personnel in a 1-shift schedule or with 6-7 personnel in a 2-shift schedule if the total demand would be increased from the scenario 1 demand.

For the blank paper investigation, it was chosen that two improved assembly area layouts and material flow designs would be made and used to make the recommendation for ECH production material flow. This would allow the author to determine what ECH production material flow would look like for a single production line and a 2-line assembly area layout. Some tasks of the 2-line assembly area could be shared for the two production lines, which would reduce the required number of personnel in the assembly area. In chapter 4.3.6, we establish the layout designs, with the 1-line layout serving as the investigated solution for scenario 1 and the 2-line layout for scenario 2.

4.3.4 Phase 2 – Defining the materials and flow relations

The product mix, consisting of K16/K25 CTO hoists, hoist bodies and special hoists (3-fall and 4-fall hoists), limits the number of materials reserved in the production cycle. During the production development period in Hämeenlinna, an ECH item catalogue was generated for large ECH product materials. The list contains category, material type, consumption, warehouse management, replenishment, and usage information for all large K-hoist components. The total number of different components for large K-hoist manufacturing summarized from the ECH item catalogue is 415 different components.

These materials form the basis of the material flow investigation. The principles of material storing, handling, and transportation included in the production process are the focus of the material flow improvement. In addition to these materials, the assembly process requires “secondary” materials, which are not listed in the table above. These include paper versions of the production orders, worker equipment and protective gear, lighting, documentation, and scanning equipment as well as tools and other materials. These secondary materials are not included in the material flow investigation since they are maintained specifically for different factory environments and practices.

The relations between the production processes and materials can be identified by analyzing the ECH production workflow (Figure 61). Since, the investigation is restricted to physical material flows of the factory, where the assembly of the hoists is conducted, the material flow is initiated by the procurement and manufacturing of critical components. Almost all materials used in K-hoist assembly are ordered to a central warehouse before moving the items to the assembly line or factory storage area. The only exceptions include linestock materials, which are directly replenished by suppliers based on storage level, MTS and MTO components, such as gearboxes, which are manufactured at the factory site and transferred to factory storage area or production line buffer directly, and components with high level of urgency, which can be ordered from suppliers directly to the factory address.

Workflow for Standard hoists (Stock)						
	Lead time 2-3 Weeks (due to backlog + CTO pendant delivery time 1-2 weeks)					
	Day 1	Day 2	Day 3	Day 4 ... 19	Day 5 ... 20 (1 Day)	Day 6 ... 21
Order Management	Order received					
Production Engneering		BOM creation				
MRP			MRP run			
Material management				Material & CTO pendant Procurement		
Central warehouse				PTO picking		
Production Planning				Production order release		
Production					Assembly & Packing	
Delivery					Shipping	

Figure 61: ECH production workflow in Hämeenlinna

Depending on the factory in question, the central warehouse can be located either near the manufacturing facility or further away from the production site. The central warehouse might be operated by an external service provider, which regulates the service by charging for the material intake and shipping. The choice of using an external service provider depends on the trade-off between service costs and establishing sufficient investments for infrastructure, knowledge needed for connecting company ERP with warehouse management, and workforce to maintain warehouse logistics and supply chain operations. The central warehouse providing services to the Hämeenlinna factory has a one-day delivery time set for component picking and transport tasks to the manufacturing facility. Therefore, the production planner must wait one day before the production orders can be released to the assembly line because after the MRP run, the procurement and delivery of the materials from the central warehouse takes at least one day. When the production system has been already established, the assembly of the standard hoist bodies can be started right after the production orders are created, since the required materials are found at the assembly line buffer. For the blank paper model of the ECH production material flow, we can assume the one-day delivery time from the central warehouse.

One of the steps of the investigation is to compare different forms of storage methods which could be used for material storing within the factory site. Regarding the material storage and internal material transport principles, different options can be chosen either based on cost-centric perspective or production practicality perspective. Cost centricity prefers to limit the materials maintained in production line buffers since they bind purchasing and transportation costs to factory storages without insurance that the materials would be consumed for orders, and they limit the space for the assembly processes. Therefore, the cost-centric perspective to material flow would be to maintain materials in a central warehouse or external picking area (supermarket), from where the materials would be picked and transported directly to the assembly area. The assembly area would not contain any PTS or MTS materials, instead they would be picked from the same picking area. Picking is useful for materials that are more difficult to store in a standard buffer area and the costs from ordering these materials from the central warehouse would be lower than the amount needed for adjusting the buffer area for increased storage capability. Alternative for this would be to maintain all the materials that need picking in a factory-site supermarket. This would also remove the picking fees resulting from ordering of picked parts all the way from the central warehouse.

The only components allowed in the assembly area itself would be the linestock materials as well as other small consumable items. Despite the cost advantages of picking and supermarket material storing principles, in practice it would offer little possibilities for assembly process flexibility and worker well-being. If errors would occur during picking, for example if wrong materials would be transported to the assembly line, the problems would not be quickly solved since materials would be needed to be returned, and the correct materials would need to be picked and transported from the picking area back to the assembly line. To prevent such occurrences, the personnel charged for the picking would need to be competent and they would need knowledge about the assembly process, product structure and variants, and production order contents. With thorough picking personnel knowledge and experience most of the potential picking related issues can be avoided.

On the contrary, production practicality perspective would prefer most or all materials to be maintained within the assembly line to improve production flexibility and ability adjust to production volume changes. Material shortages would be more easily visible for all assembly workers, which would give the production planner current data about the material quantities more quickly when compared to "picking only" perspective. This approach would also allow the production to initiate right after the production order would be created and printed in the production line since there would not be picking involved. Materials would be positioned in buffer storage shelves in and near the assembly area, which would allow the assembly process to start as soon as production orders are received and the assembly process would also be better prepared to component failures and assembly errors, which might occur during assembly. However, the floor space needed and bound costs from the material management in the factory would be significant and therefore, less desirable in the production cost point of view. Large buffers can also create additional problems. New personnel would need more time to learn where all materials are located and when more materials are scattered around the production line, more travelling to retrieve components is required during the assembly process.

Different material storing methods exist for ECH production. For example, in Hämeenlinna, most of the ECH components have a dedicated buffer storage and the more rarely used or needed PTO & CTO components are picked from the central warehouse. The other example is from the Wetter factory in Germany, where almost all components are picked from a separate picking area in the factory site and the components are transported to the assembly area only when they are needed. Both approaches have their advantages and disadvantages, but they are designed with different production perspectives and different goals in mind. The production line in Hämeenlinna was set up quickly to support the European demand for ECH products and the most important factor at the time was to establish the production capability with the best production performance possible with the factory area restrictions in mind. Later, when the production was ongoing, advancements were made to improve the production practicality and reduce production costs, while knowing that the production line would eventually face production ramp-down. The factory in Wetter was designed from the cost reduction perspective from the start. However, the practicality and productivity of the production process has room for improvement. Therefore, by applying elements from both material storing examples, we can establish a more optimized material handling and material flow principles for ECH production in general.

In addition to the storage principles used in the factory, the shelf and storage options also influence material flow. The ECH materials are stored in multiple different shelf types. The ease of retrieving and replenishing storages is critical in reducing non-value-added time of the production process. As discussed earlier in chapter 4.1.3., one improvement for the ECH production material flow would consider the storing and transportation principles from the factory material reception to the production line. While picking itself is an effective method to reduce buffer quantity, fully committing to material picking would compromise the manual process flexibility. Therefore, the suggested improvement for the ECH production material flow would be to adopt a hybrid material flow of milk run and production line buffer. However, choosing the storing method for the components needs to be elaborated.

Klenk et al. [31] and Mácsay et al. [32] emphasize the effectiveness of milk run practices in taking an approach to internal material transportation while implementing Lean practices of Just-in-Time production and reduction of lead time. For the ECH production, a couple of milk run concepts are viable: manual supermarket, automated supermarket, manual picking, and fully automated solutions. To select the most suitable alternative, we can evaluate the concepts based on the storage use, flexibility, picking lead time and technological requirements. The evaluation and selection of the picking strategy is done in phase 4 of the blank paper investigation. Typical examples of an automated storage system could be integrated can be seen in Figure 62 and Figure 63, which showcase the Kasten TORNADO automated storage system. It is an alternative method for storing materials close to the assembly area while reducing the overall storage space for components [35]. The storage systems contain revolving shelves, which can store small to medium sized components and linestock materials while allowing the materials to be picked and ordered remotely [35]. The materials can also be picked manually and transported to the assembly area or picking area via a conveyor [35].

Figure 62: Kasten TORNADO automated storage system (1) [35]

Figure 63: Kasten Tornado automated storage system (2) [35]

4.3.5 Phase 3 – Establishing the performance metrics

The performance metrics used to evaluate the performance of the investigated material flow include the traditionally used KPIs:

- Lead time (end-to-end)
- Throughput time (production order release to packing)
- Process step cycle time
- Capacity
- Asset utilization
- Work-in-process
- Product mix
- Buffer vs picked qty
- Production volume
- Flow intensity (travel distance / travel qty for each production cycle)
- Transportation & handling & searching time

Other beneficial KPIs include production late (tardiness) and scrap rate but are not included in this investigation since they would require information from practical testing of the proposed production process. While the effectiveness of flow rate in determining bottlenecks in production material flow is also discussed, it requires accurate data about WIP in production. For ECH production, the WIP quantity is difficult to measure since, it varies heavily based on product mix, material sufficiency and capacity used for hoist body assembly and final assembly, which are not always constant. Also, the production process does not generally produce WIP similarly to mass production. Therefore, most if not all the occurring WIP is unplanned. The KPIs listed above are used in the comparison and evaluation of the investigated layouts and material flows with the current state and HH8 improvement project results in chapter 5.

4.3.6 Phase 4 – Formulating the improved models

Developing the improved material flow model requires the consideration of the current state and the five areas of improvement of ECH production. In this phase, we start the formulation of improvement by first using VSM to identify the bottlenecks of the current process and to create a future state map, including the desired improvements. The second step is to conduct an evaluation and selection of a desired picking process, which is then scaled for the two investigated blank paper scenarios. Finally, layouts of the assembly area and internal logistics are established for the ECH production showcasing the material flow pattern and relations between workstations and how material movement is conducted with different product variations.

The workflow for standard hoists was established earlier in phase 2, which can be used in formulating the VSM for blank paper ECH production. We can use the workflow of Hämeenlinna as a baseline for the blank paper VSM since, the processes conducted for large ECH manufacturing would be the same as they are in Hämeenlinna except gearbox manufacturing, which would be supplied by an internal supplier. The resulting current state VSM can be seen in Figure 64. The VSM was formulated using the common symbols discussed in chapter 2.3.1. From the map, we can see that much of the production lead time is focused on the material supply to central warehouse, specifically the pendant supply. While regular hoist components such as PTS and MTS components can be delivered to the central warehouse in less than a week, the pendant supply is the main contributing factor to the non-value-added time in the total production lead time (not including K-hoist shipping time to customers). However, the material flow from suppliers to central warehouse is not the focus of improvement in this thesis. Instead, we can focus on finding improvements in the factory operations and material movement in internal logistic processes.

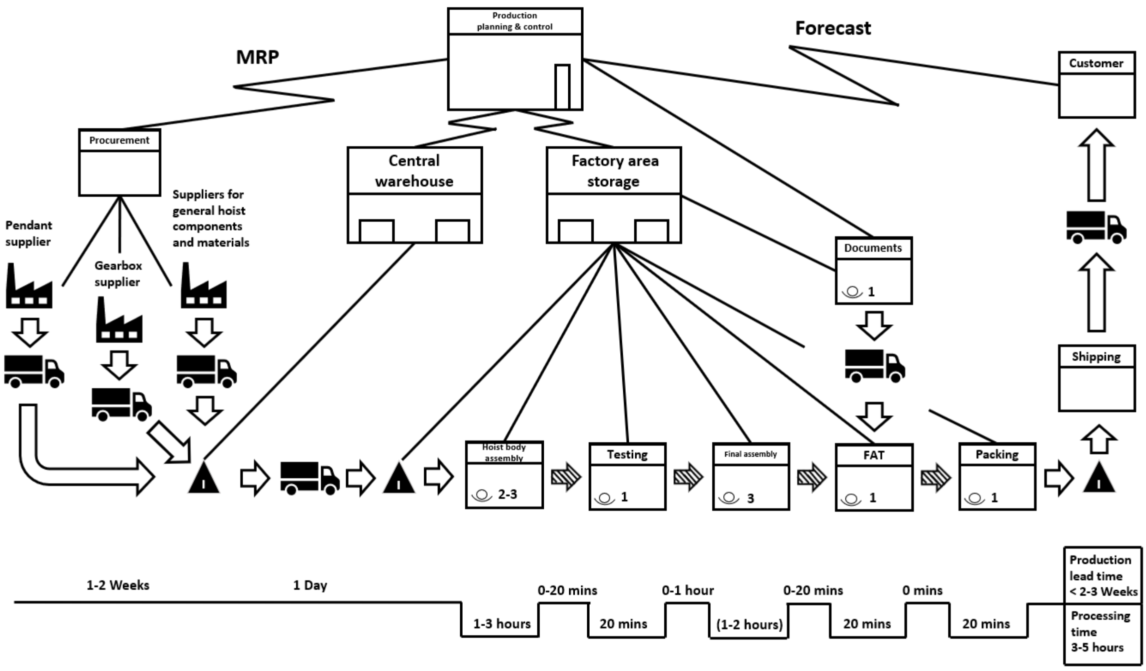


Figure 64: ECH production current state VSM

For any production process, it is important to optimize the material supply from suppliers and subcontractors. While ordering materials directly to the factory where the products are manufactured results into the most streamlined material flow, it is not practical if a factory manufactures multiple different products, production lines and requires significant storage space for all internal production processes. Improving material flow from the factory warehouse to the assembly area as well as reducing the potential WIP occurring between the assembly steps proves to be an efficient method to reduce non-value-added time. In chapter 4.1. we established that the main areas of material flow improvement for large ECH manufacturing could be solved by doing the following changes:

1. Conducting the rotor and micro switch sub-assemblies in parallel or in advance to the hoist body assembly
2. Starting the trolley assembly at the same time as hoist body assembly
3. Enhancing the storage shelves and assembly area for better visibility and accessibility
4. Reducing buffer storages in hoist body assembly and replacing them by a separate picking process
5. Adjusting safety stock, replenishment and control cycle values for materials maintained for the assembly process
6. Layout changes regarding workcenter placement and guidelines for efficient layout design
7. Optimizing the use of existing equipment to reduce unnecessary movement

With these changes in mind, we can adjust the VSM to create a future state map, which incorporates these changes. In Figure 65 the future state VSM is displayed and the effects from the changes suggested can be seen in green. The effect of these changes impacts mostly the initial material picking for hoist body assembly by reducing the overall processing time. Because picking as well as sub-assemblies can be done in parallel to the hoist assembly, the overall processing time can be reduced. The other layout changes and practical changes impact personnel efficiency and reduce the occurrence of unplanned WIP, thus reducing most of the non-value-added time in between the assembly steps.

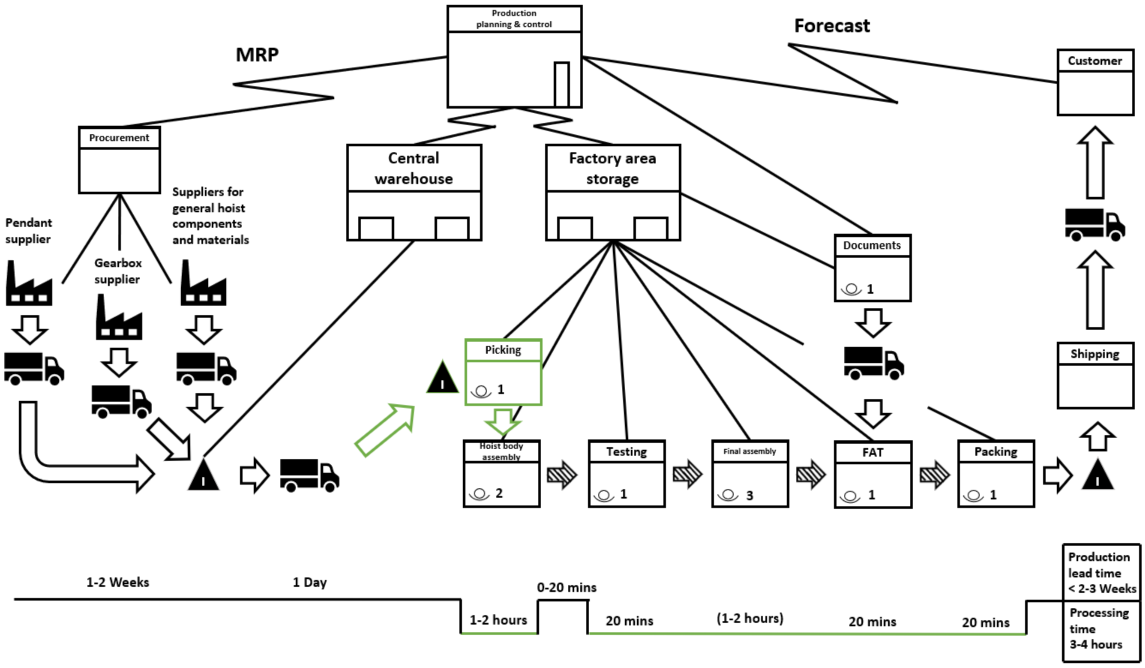


Figure 65: ECH production future state VSM

Now that the bottlenecks and improvements have been identified for the production process, the next step would be to investigate and determine the most suitable picking milk run practice and material storing method for large ECH hoist body assembly components. Before selecting the material picking practice for the blank paper investigation, we should establish the materials that would be included in the picking process. As previously mentioned in chapter 4.1.3, the gearboxes and heavier components should still be maintained in assembly line buffers. When determining exactly what components could be picked from a separate internal storage picking area, we can create a table which visualizes the components that are acceptable for internal picking process and for the hoist body process step specifically.

The hoist modules and components listed in Table 11 show the ECH materials that are feasible and not feasible to be stored in an AGILON automated storage system. If an automated storage system would be implemented for the picking process, AGILON would provide a suitable candidate since it is already employed for example in wire rope hoist material storing in other Konecranes factories. While a manual picking storage allows a better capacity for storing even larger materials and components, the feasible materials for AGILON provide a selection of hoist module components that are within AGILON storing specifications and which do not restrict production flexibility if they would be stored outside of the assembly area. Based on the future state map, we determined that that the picking process should mainly be beneficial for ECH assembly in the hoist body assembly process. With this in mind, we can select components from Table 11 that should still be maintained in buffers even though they would be feasible for AGILON or storing in an outside picking area. The components that would be picked are blank and the ones stored in buffers are marked red.

Table 11: ECH components feasible for AGILON storing and for picking

Feasible for AGILON				Not feasible	
Axles & tie bolts	Chain guides	Hook assembly & parts	Sprockets	Travel motors	Suspension parts
Bearings	Extensions	Pendants	Grease & lubricant	Counter-weights	Chains
Brakes and brake hubs	Chain stops	Cross bars (light)	Fans	Cross bars (heavy)	Assembled trolleys
Buffers	Linestock	Push trolley parts	Fixing plates	Gear-boxes (MTS)	Radios
Cable inter-faces	Cover plates	Control boards and power supply	Sealings	Rotors	Stators
Electrical wires & plugs	Suspension hooks	Micro switches and components	Gearboxes (MTO)	Trolley side plates	
Chain bags	Cubicles	Hook assemblies	Stickers		

Even if some components, such as linestock, stickers and bearings could be picked for orders, they take up so little space from the assembly area that they could still be stored at the assembly area. Also, since rotors are stored at the assembly area, the bearings and linestock needed for the sub-assembly should be also nearby. Linestock replenishment is also more beneficial to be made by the working personnel at the workstation, since they identify better when the materials are running low and the location for the linestock storage should therefore be close to the assembly area workstations.

The selected picked materials do not require a large picking storage area and all materials could directly be replenished to the picking area storage without a separate material reception. Therefore, the materials would be supplied from the central warehouse directly to the picking area without storing the materials anywhere in between the storages. In the case of Hämeenlinna, if picking would be implemented, also MTO gearboxes could be stored in the picking area since they are manufactured for orders at an adjacent gear factory. However, for the blank paper approach we consider the MTO and MTS gearbox supply as any other supplier and they would circulate to the assembly area through the central warehouse. If this blank paper production process would be established and employed in practice, similar to the ECH item catalogue created for the production development project at Hämeenlinna, prioritizing certain materials should be made based on the consumption and demand history. This would ensure that the most common materials for picking are readily available and closer to the start of the picking route.

For the blank paper material flow investigation, the second goal was to create layouts for the two different production scenarios, which incorporate proposed improvements for the issues affecting productivity and material flow efficiency. When designing the methods how the picking process could be integrated to the ECH production, the chosen method was to design and compare picking areas with different storage principles. The picking areas were designed based on the milk run process concepts presented in chapter 2.2.3. and the designed picking areas for ECH production can be seen in Figure 66, Figure 67 and Figure 68.

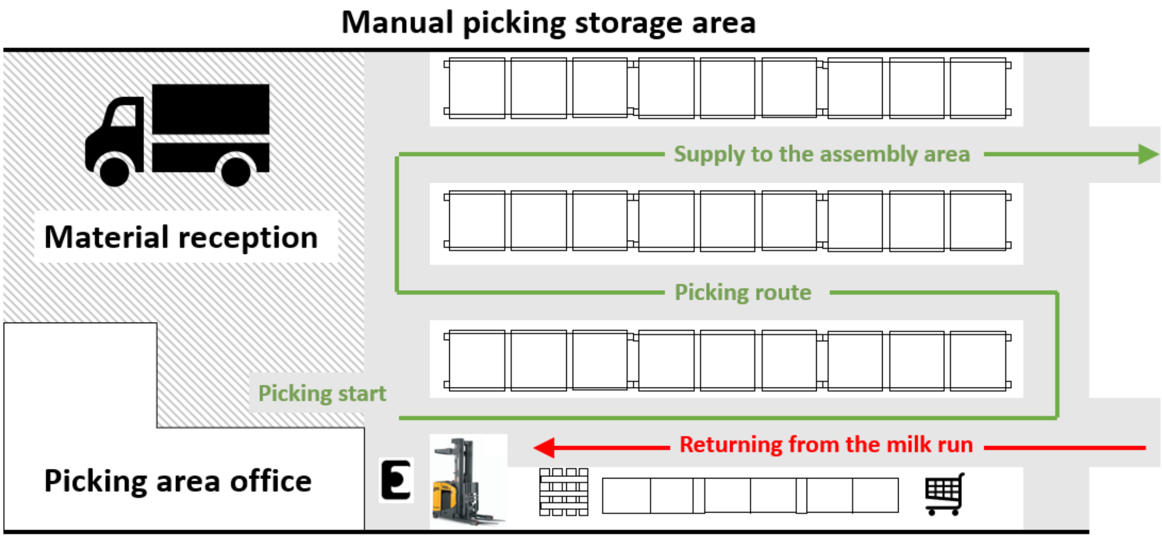


Figure 66: Manual picking storage area concept

The manual picking process in Figure 66, starts from the picking area office, where the production orders and hoist stickers are printed and brought to the picking area. From there, the picking personnel takes a stacker forklift and the required number of containers as there are hoists in the orders printed and places them on a pallet. The worker then takes the forklift and moves the pallet on a serpentine picking route as seen in the figure to retrieve all necessary components for the orders. The worker steps out of the forklift to retrieve the materials from the shelves. After the components are picked, the worker delivers the components to the ECH production line supply area. While having the picking area next to the assembly area would provide the fastest milk run time, in regular factories the facility layout must also support other production lines and the picking areas and assembly areas are not always next to each other. Therefore, we examine the possibilities for the picking process as separated from the ECH assembly area.

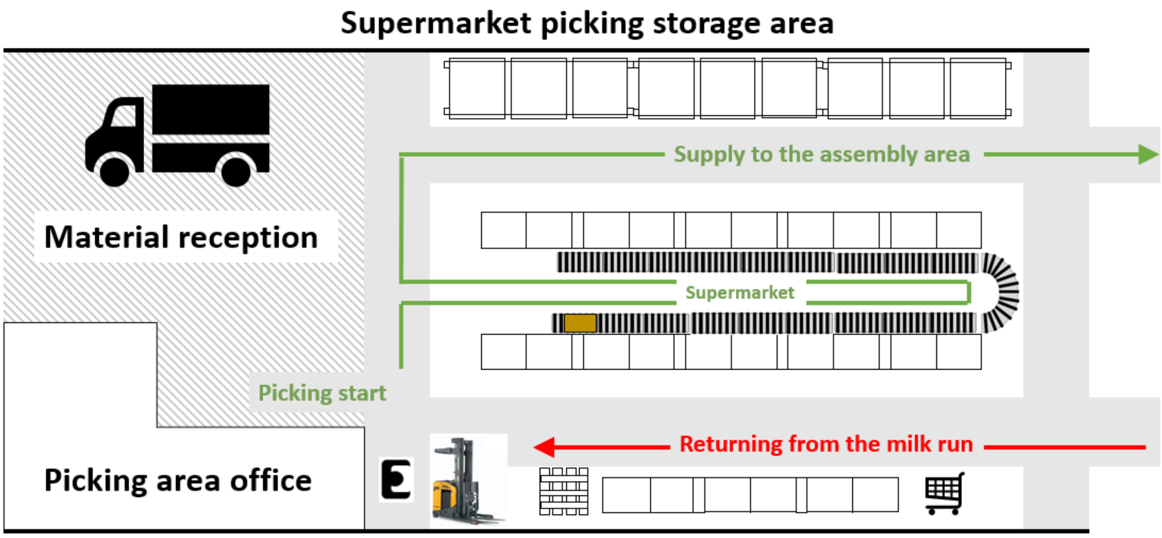


Figure 67: Supermarket picking storage area concept

The supermarket picking area layout (Figure 67) differs from the manual picking process by having a unique storage shelf arrangement. In the proposed layout, the supermarket consists of two stackable shelves opposite to each other and a roller table for moving the material containers along the supermarket. The picking process starts similarly to manual picking process. However, the worker does not take the forklift straight away. Instead, they take containers from the equipment storage space (bottom of the figure) and circulates the supermarket while manually picking the materials from the shelves along the way. The shelves are arranged so that the materials are all in reach by hand and can easily be replenished from the back side. After the materials are picked from the supermarket, the containers are placed on a pallet and delivered to the production line supply area buffer. As with all the picking processes, the production order and stickers are left in the corresponding material container, so that the assemblers at the production line know what type of hoist the materials belong to.

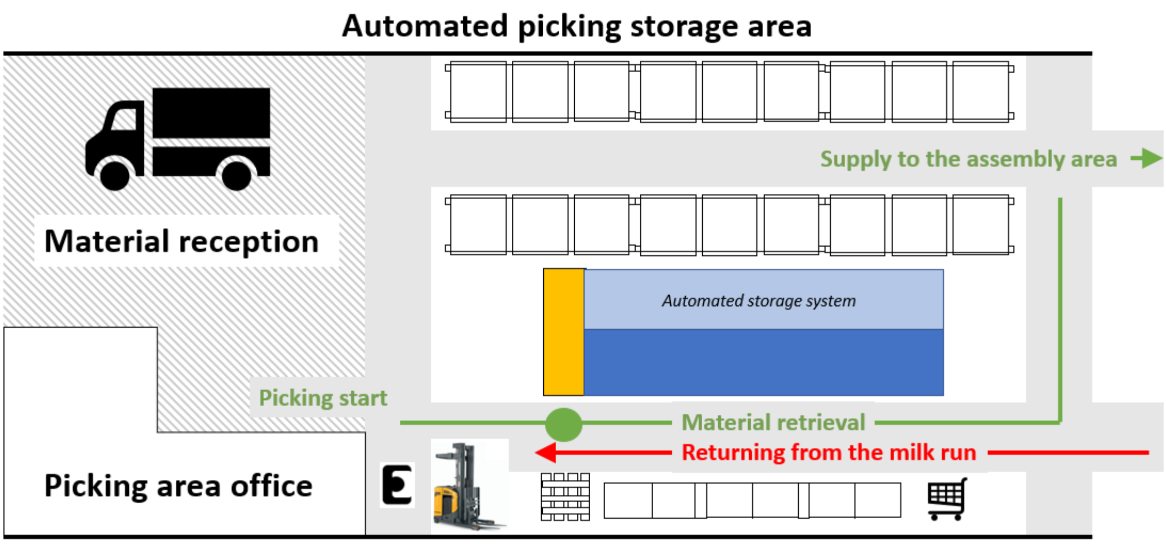


Figure 68: Automated picking storage area concept

The final investigated picking area concept involves an automated storage, from where the materials are picked. Different automated solutions exist for material storing but we can assume that the storage would be operated either like AGILON (Figure 69) or Kasten TORNADO automated storage system. The AGILON is operated by walking to the AGILON console and ordering the desired components individually. The components are stored in individual containers as seen in chapter 4.1.5. The containers are received from the hatch below the console. Retrieving each material takes around 30 seconds which makes the picking process last longer than other process concepts. However, with Kasten TORNADO, multiple components can be picked from one single revolving shelf. If most of the materials that need picking are stored on the same shelf, the picking time is reduced significantly. After the materials are picked, they are placed on containers and delivered on a pallet via forklift to the assembly area similar to the other picking concepts. Notable is the reduced picking travel distance due to "goods-to-man" principle, where the materials are brought to the worker instead of the "man-to-goods" practice of the other concepts. However, the automated solution results potentially in increased picking time if the materials need to be delivered to the worker individually.

Figure 69: AGILON automated storage system [22]

We can compare the picking concepts by using criteria for efficient picking while giving the criteria a weight based on its significance to material flow. The level of importance for each criteria is chosen by the impact it has towards the total picking time as well as the resource and capacity (personnel) requirement to complete the picking task. For example, the significance of picking travel time is greater than basic time, since collecting the equipment needed for the picking process rarely lasts longer than traveling along the actual picking route. Table 12 represents the evaluation of the picking concepts. The evaluation of the concepts is graded on a scale of 1-3, where 1 is the lowest score, e.g., picking time is the longest, and 3 is the highest, where the concept is the most optimal for the criteria. These scores are then multiplied with the level of importance for the criteria and added together to get the final grade for the concept.

Table 12: Evaluation of the picking concepts based on picking efficiency criteria [12, p. 246-253, Appendix B, 5]

Criteria	Importance 1-5	Manual concept	Supermarket concept	Automated concept
Basic time	2	1	2	3
Travel time	5	1	2	3
Grab time	5	2	3	1
Dead time	4	1	2	3
Picking accuracy	5	1	2	3
Picking output - pc/min	3	2	3	1
Ease of replenishment	5	3	2	1
Travel distance	3	1	2	3
Capacity required	5	3	3	3
Storage space required	1	1	2	3
Equipment required	2	2	2	2
Competence required	4	2	3	1
Result		78	105	96

If we focus on the overall picking time of each concept, we can see that while the automated concept provides the shortest time for all other picking processes, it has the potential for the longest grab time, which is not ideal. Automated solution also provides the best picking accuracy since the operator inputs the required material identification to the console and the storage system delivers the correct materials without risks of choosing wrong materials. However, picking output and ease of replenishment are the main drawbacks with the automated concept. The most average and all-around best alternative in this evaluation was the supermarket concept, which gives the highest grade for the evaluation. The supermarket offers the fastest grab time, as well as picking output with the least competence requirements. It is faster than fully manual picking process because the materials are oriented for better accessibility. The manual process has the best storage replenishment possibility since received pallets can be stored as is and only one person can manage both the picking process as well as material replenishment. However, these advantages did not make the process more favorable as in supermarket picking concept.

To formulate the assembly area layout for the blank paper approach, we can use the findings from the areas of improvement regarding layout, capacity requirement calculations and buffer storage design as well as the practical experience from the introductory period. The layouts are presented in the following section for each scenario.

Scenario #1

As established earlier in phase 1, the personnel required for the demand in scenario 1 can be achieved with 8-9 assemblers in a 1-shift schedule. The resulting layout is best operated by 7 assemblers, a packing worker, and a picking worker/ forklift driver and with two additional sub-assemblers when the demand would increase. The layout was created with taking reference of the HH8 assembly area, while making it more streamlined and changing the workstations to minimize travel distances and possibility for WIP build-up. The layout drawing can be seen in Figure 70.

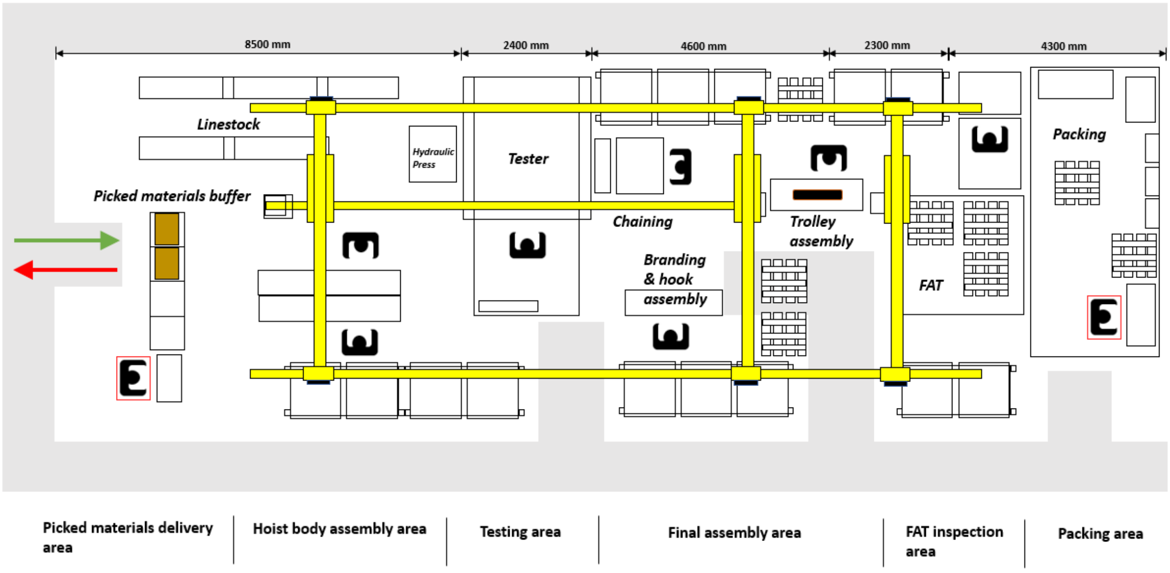


Figure 70: Blank paper scenario #1 assembly area layout

Going over the layout, starting from the left side, picked material buffer and linestock replenishment buffers are located close to side where the materials would be supplied to the production line supply area. The green and red arrows depict the material flow from the picking area to the assembly area. The picking personnel places the picked components on containers on the shelves of the buffer. From the buffer, the hoist body assemblers can retrieve the materials and start the first step of the actual ECH assembly. The in-line storages at the hoist body assembly area are reserved for gearboxes, motor components, test hooks and suspension parts. Other materials were brought to the cell via picking. The hoist body assembly is conducted similarly to the assembly process at HH8, where the workstation consists of a single double-sided table, which can be used separately. Two workers occupy the workstation but when demand increases, an additional person helps by doing the subassemblies in parallel to rest of the assembly steps and another worker can assist the final assembly process by picking materials from the in-line buffers to all final assembly workstations this assisting personnel can also communicate between the hoist body and final assembly process steps to inform the trolley assembly worker when to start and which trolley variant to assemble. This allows the trolley assembly to be conducted in parallel to hoist body assembly.

When the hoist bodies are ready, they are placed on the test beam going through the tester. Testing process is conducted for individual hoists at a time as is done in HH8. After testing the hoists are moved directly to chaining, which is located close to the other end of the test beam. This ensures that the chaining can be started immediately when the bodies are received from testing. The chain, chain stop, chain buckets as well as pendants are stored near the chaining workstation. The worker conducting the branding and hook assembly, must maintain communication between the worker conducting the chaining to know when the hook can be attached to the hoist. The brand plates can be assembled during chaining and the components for the hook can be retrieved right after the chaining is started. Trolley assembly can be started early if communication is maintained between the hoist body assembly and the trolley assembly workstations. When the hoist is completed, it as well as the trolley are placed on a pallet in front of the branding workstation using the two overhead cranes. They are then manually moved to the FAT workstation using a pallet jack. The FAT workstation is visualized using coloured tape on the floor to signify the area where hoists are to be inspected. The workstation can be equipped with a roller table, where the pallets are lifted for inspection to allow better visibility for the worker conducting FAT.

After FAT has been made and the documents and lubricants and towing arms are added with the hoist, they are available for packing and marked correspondingly. The packing personnel can then see what hoists are ready and they can move the hoists to the packing area and forward to the shipping area outside the production line.

The following drawings represent how the material flow changes in the assembly area for each of the product types planned for the scenario including factory body sets, CTO hoist and special hoists. The blue arrows represent the material flow through the assembly process and the green arrows represent material retrieval from in-line buffers and workstations. Figure 71 depicts the assembly process for factory body sets, Figure 72 depicts the standard CTO hoist assembly process and Figure 73 shows the differences when assembling special ECH products.

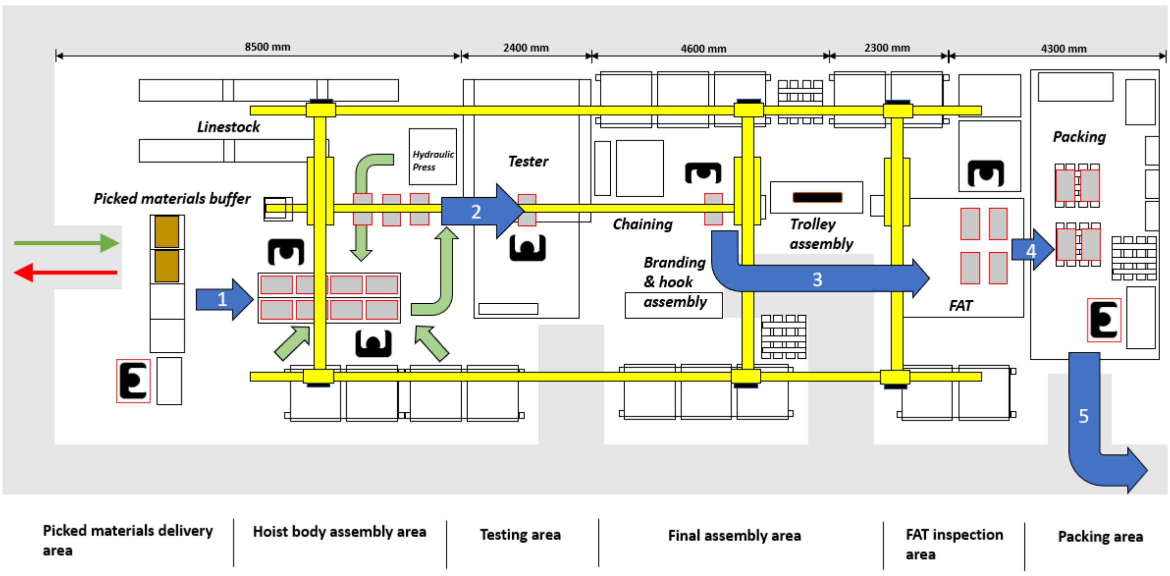


Figure 71: Blank paper scenario #1 assembly area layout (Factory body set)

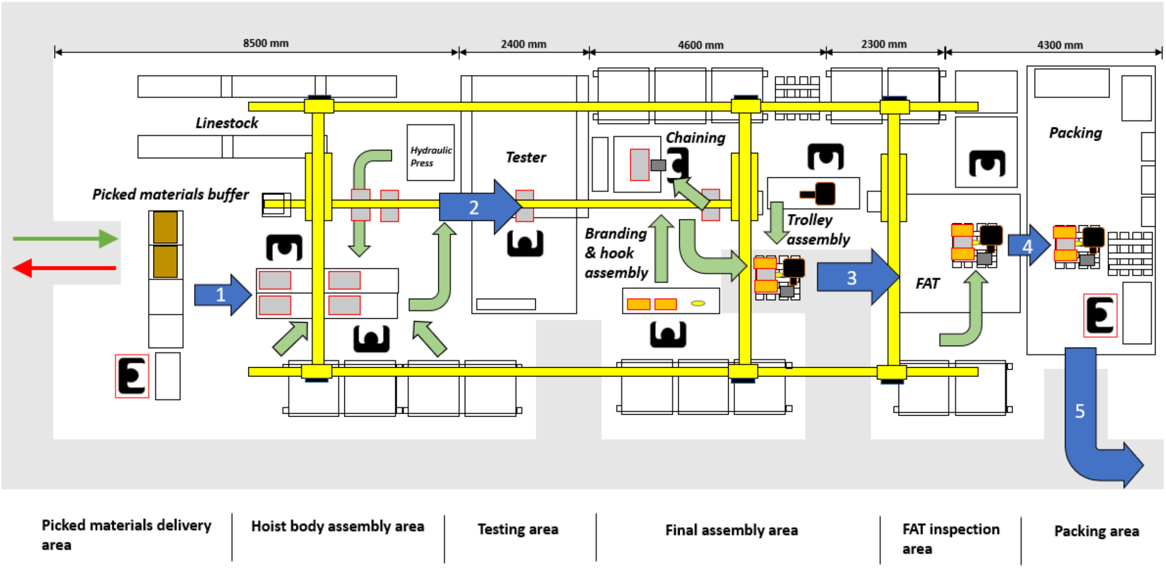


Figure 72: Blank paper scenario #1 assembly area layout (CTO hoists)

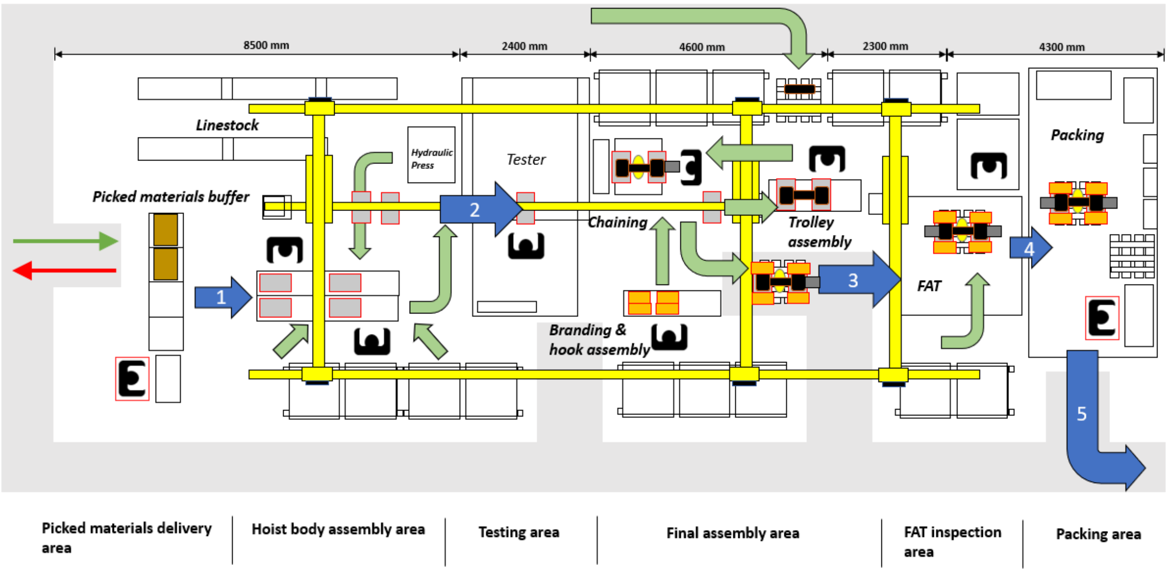


Figure 73: Blank paper scenario #1 assembly area layout (Special hoists)

The main differences between the processes are with the final assembly. The factory bodies are moved directly to the FAT workstation after testing. CTO hoists are moved from the test beam directly to the chaining workstation while in special hoist assembly, two hoist bodies need to be moved to the trolley assembly station after the trolley is finished. They are then attached to the trolley and moved to the chaining station. After chaining and branding, the hoists are moved onwards similarly to CTO hoist assembly.

In addition to the layout drawings, a separate layout was made, which shows the workcenter SAP identification needed for routing (Figure 74). This drawing provides identification for the layout supply area, workstations, and buffer storages. The figure also shows the linear material flow direction in the assembly area. However, the naming of the workstations should be revised if the routing of this layout would be implemented in a factory since it might be more useful to further differentiate the cycle times for different steps in the final assembly. The identification BPS1 in the figure stands for blank paper scenario 1.

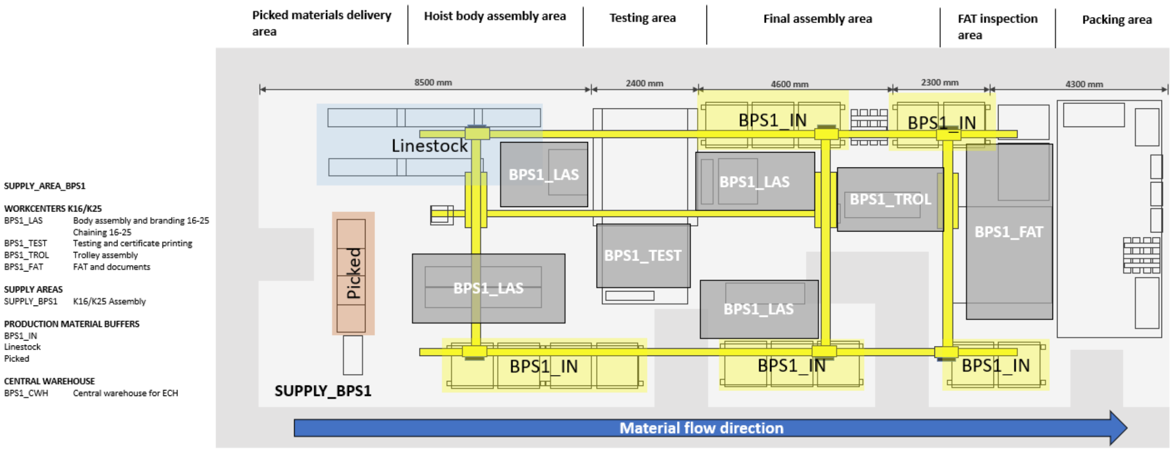


Figure 74: Blank paper scenario #1 assembly area layout with SAP identification

Scenario #2

While the demand of the scenario 2 could be achieved with a 2-shift schedule using the layout for scenario 1, the choice in this investigation was to determine what advantages and disadvantages would a 2-line assembly area with a 1-shift schedule have for ECH production material flow. Increasing the number of production lines would require more personnel but it would also increase the overall production volume to achieve the demand goal. The goal was again to make the layout more streamlined and to minimize travel distances and possibility for WIP build-up. The designed layout for the scenario 2 (Figure 75) is best operated with 13-14 personnel while also requiring a packing worker and a picking personnel / forklift driver. The 14th worker would act as a sub-assembler and a communication link between the production process steps similarly to scenario 1.

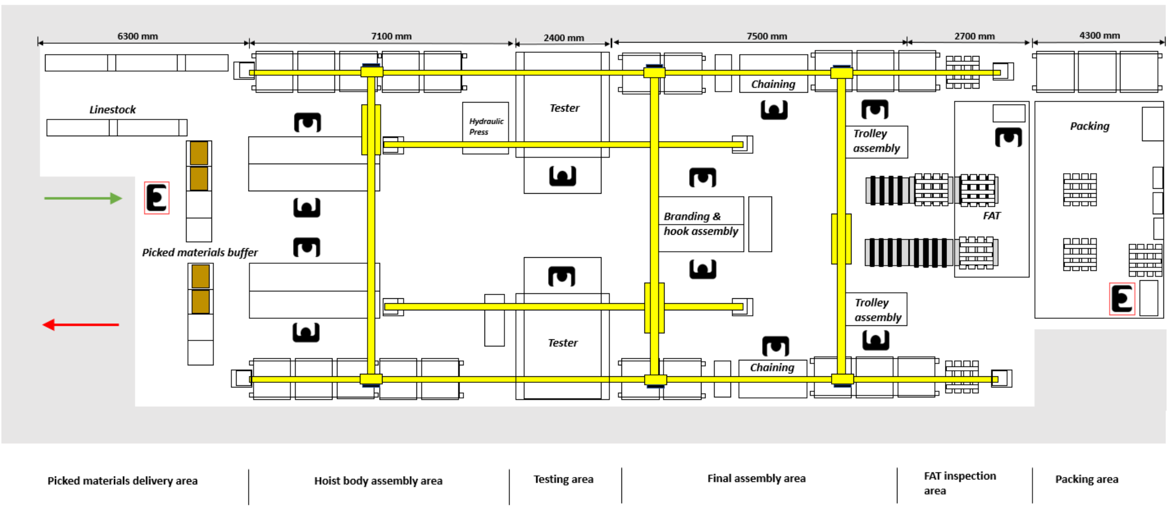


Figure 75: Blank paper scenario #2 assembly area layout

The layout structure starts similarly to the layout design of scenario 1 but having two production lines and two sets of workstations as a result. The main differences are in the final assembly and FAT workstations. The branding and hook assembly is conducted on a similar two-sided table as there is in the hoist assembly workstation. Also, chaining area is located in between the trolley assembly and branding to account for special hoist assembly as well as the standard hoist assembly processes. The layouts presented in the following figures (Figure 76, Figure 77 and Figure 78) visualize the material movement and process flow within the assembly area for each product type specifically. It must also be understood that while the drawings show the assembly process of one product type in all process steps, different product types can be assembled simultaneously in the assembly area. If the layout would be iterated further, it could be argued that by increasing the number of chaining stations and trolley assembly stations, an increase to production output could be achieved instead of applying an entire second production line. However, the two parallel lines offer a more streamlined material flow through the assembly area while having an additional tester in case of equipment failure as well as the capacity to produce enough products based on the increased demand estimate.

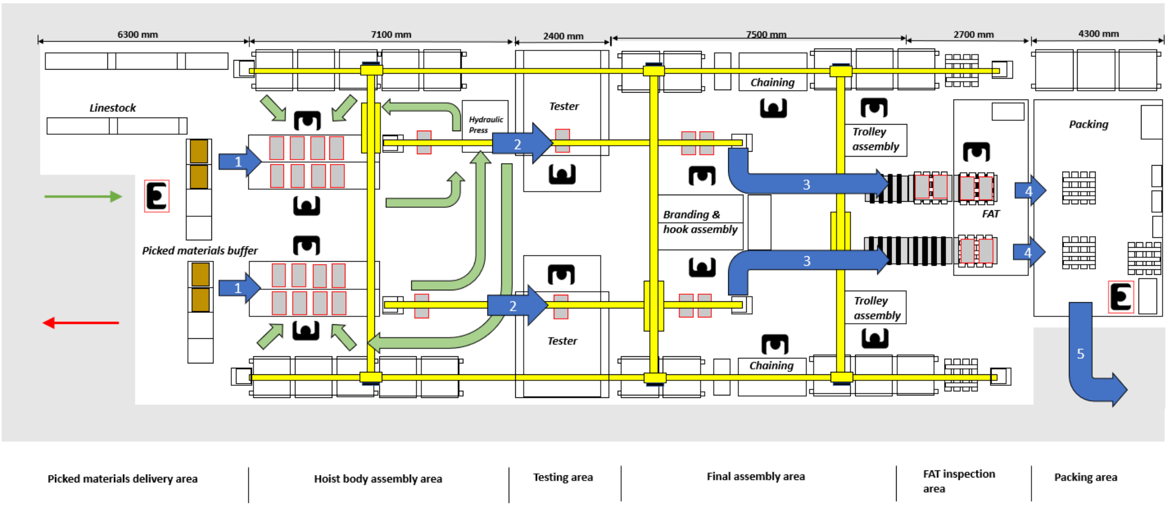


Figure 76: Blank paper scenario #2 assembly area layout (Factory body set)

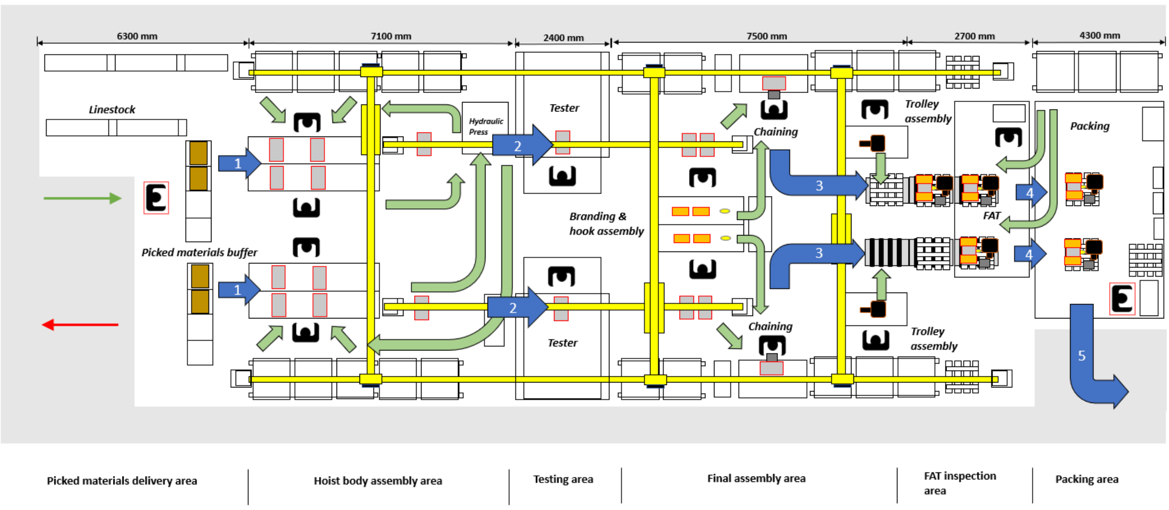


Figure 77: Blank paper scenario #2 assembly area layout (CTO hoists)

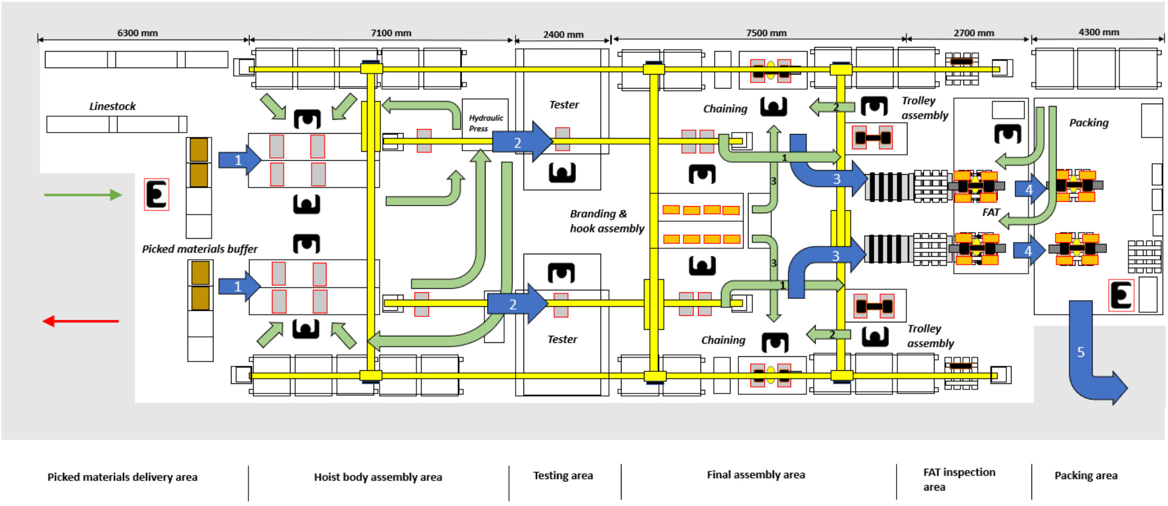


Figure 78: Blank paper scenario #2 assembly area layout (Special hoists)

The same critical assembly order remains for scenario 2 as well as for other ECH assembly processes. Therefore, standard hoists are moved straight to chaining after testing and in the case of special hoists, they need to be attached to the trolley first. Another difference of this assembly area layout to the one in scenario 1 is how the assembled hoists are moved to FAT area and how FAT is conducted. In the drawings, two roller tables exist between the final assembly and FAT areas. The hoists are placed directly on empty pallets, which are placed on the roller tables beforehand. The pallets are then pushed to the FAT area, where they can easily be inspected by one assigned personnel for the two lines. From the FAT area, the hoists are moved to the packing area by packing personnel using a pump jack or a forklift.

Another layout drawing was also made for the scenario 2 similarly to the one in scenario 1, which shows the SAP workcenter placement and identification. This drawing is useful if the layout would be established in an actual factory and the routing for the layout would need to be set up. The layout can be seen below in Figure 79. When a 2-line assembly area would be established in practice, the workstations should be named for the lines individually. Because the workcenters maintained in SAP contain information about the assigned personnel quantity and the process cycle time, it would be more beneficial to identify and separate the lines from each other. In this case the naming is used to visualize the workstations, where assembly is being made.

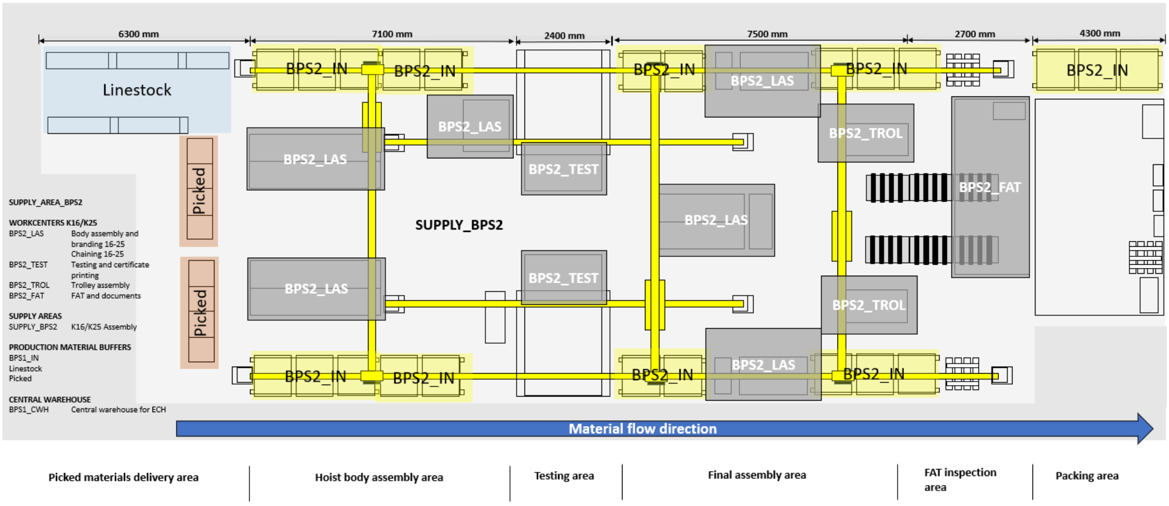


Figure 79: Blank paper scenario #2 assembly area layout with SAP identification

The investigated material flow for the blank paper scenarios resulted in two layouts, which include an improved design to reduce potential WIP build-up. In addition to these layouts, the choice of including a supermarket picking process for the hoist body assembly components streamlined the material flow in the assembly area, and the changes in layout workcenter design have a potential for increasing production efficiency and material flow by reducing unnecessary steps and waiting. The effectiveness of the material flow in these layouts as well as the methods used for this improvement are compared with the current state of production in HH8 and with the results from the HH8 improvement project in the following chapter.

5 MATERIAL FLOW COMPARISON AND RESULTS

In the previous chapter, the ECH production process was analysed by elaborating the potential areas of improvement for material flow. Two approaches were discussed for ECH production material flow improvement. The two approaches included the production improvement project for the HH8 production line and the blank paper material flow investigation for developing improved material flow and layout designs for ECH production in general. The differentiating factor for the HH8 improvement project was that both the spatial requirements of the assembly area and on-going ramp-down created restrictions for the planning and impacted the methods as well as the results for the improvement. In the blank paper investigation approach, the only restrictions were the estimated demand and product mix. The approach also utilized previous investigation of the areas of improvement together with the findings and frameworks from literature review.

In this chapter, we will focus on comparing the two approaches with the current state of ECH production to determine how the productivity and material flow was increased and how the utilization of literature impacted the results for designing material flow for ECH production. First, we will compare the methods used in both improvement approaches, second, we will compare the layout and material flow designs resulting from the two approaches to the current state. After the comparison, the results are discussed, and the concepts are evaluated to compile a final recommendation for large ECH material flow improvement. Lastly, the limitations of the thesis and further research opportunities are discussed.

5.1 Comparison of the used methods

The goal of the blank paper investigation was to use a systematic approach to find improvements for ECH production material flow. The investigation relied on frameworks from literature, such as the Gould and Colwill framework for material flow assessment, to advance the improvement in systematic phases. The other methods included capacity requirement calculations, used in determining the required assembly personnel for the estimated demand. Referencing the research conducted on material picking practices and existing technologies for material storing were used in evaluating a suitable picking process for ECH production. The knowledge of the current state production process at Hämeenlinna and well as Lean tools, such as Gemba (factory visit and hands-on experience in this case) and value stream mapping were used to determine the areas of improvement and potential bottlenecks in the current production process. While focusing on the internal factory material flow, layout proposals for the two scenarios in the blank paper material flow investigation were created, which visualized both the designed improvements for the production process as well as material flow during the assembly process with actual locations and flow directions.

The approach for the HH8 improvement project was quite different. From the start the project was on a much tighter schedule since the production process was under production ramp-down. The focus was to provide plans for control cycle and replenishment values specifically for the materials in immediate influence of the ramp-down. The methods used in determining the updated values as well as the production line improvement included material mapping based on material consumption information from SAP, visiting the production line and documenting the assembly area for analysis of the available storage space and formulating several layout proposals to design the assembly area to better answer the estimated demand and workflow. The use of these methods resulted in updated material master information as well as practical changes to the assembly line.

In a factory environment, it is essential to have thorough understanding of the product and the actual processes used in the making of the product before planning an improvement project. Without visiting the assembly area in practice and seeing the potential issues in person, it would be challenging to find issues directly affecting material flow, and to determine practical solutions for the issues. Therefore, both improvement approaches involved the participants to visit the actual factory location the assembly area. However, when comparing these two improvement processes, the main differences were the approach for finding the areas of improvement, restrictions for the improvement as well as the goal.

While both approaches revolved around the concept of material flow improvement, the HH8 project was directly designed to improve productivity and the local production process at Hämeenlinna. The goal not only included assembly process and central warehouse picking process material flow improvement by updating the control cycle and replenishment values, but also relocation of buffer storages and workcenters to increase production efficiency. However, the blank paper approach was not restricted by an improvement endeavour of a certain location. While focusing on the internal factory material flow, the approach required information about the current state of ECH production, which was provided by analyzing the production principles of HH8 production line. But instead of finding improvements for the HH8 assembly area under similar time constraints and practicalities, the approach allowed more open-ended planning of how the production material flow of how the large ECH products could specifically be improved. This resulted in the use of more standardized and literature-based material flow improvement methods and a complete re-design of what an improved assembly and picking area layouts and material flow for the production could look like.

The advantages of the methods used in the HH8 project included the use of actual consumption data to create a comprehensive suggestion for the updated control cycle and replenishment values as well as the storing methods for the components. These changes could then be directly implemented to both aid the systematic reduction of small ECH components from the buffers, and better utilization of storage space to continue to produce large ECH products. The layout improvement also included iteration by providing multiple alternatives, from which the best layout properties could be chosen in terms of practicality and ease of application. However, practicalities, such as adjustment time of workers for major changes and time constraints of designing the layouts affected the quality of the layouts themselves. For the blank paper approach, layout design was not as strongly involved in the scope as material flow design, but it proved more effective to visualize the material flow during the assembly process as well as the picking process using detailed layout drawings. Therefore, further iteration of the layouts by providing alternative assembly area designs for the 1-line and 2-line layouts were not included in this case.

However, iteration of the layout concepts could be a focus for further improvement projects on the topic.

5.2 Comparison of the layouts and material flows

The ECH production facility at Hämeenlinna is an important hoist manufacturing facility not only for CTO hoist production but also for hoist body production and supply to the ECH factory in China. The unique aspect of the HH8 is the ability to manufacture the hoist bodies from raw materials and gearboxes, which are manufactured at KHT, an adjacent gear factory to the HH2 factory, where the HH8 is located. However, since the hoist body assembly process and testing are included in the ECH production assembly area, it creates challenges and issues for the overall material flow of the ECH production.

The main issues for the current state layout (Figure 80) are the material flow pattern, flow directions of the incoming material supply, material picking times from buffers, visibility and communication between hoist body and final assembly, and the quantity of buffer storages, which increases material holding costs. Also, material storing was previously not optimized for large ECH production but after the HH8 improvement project, this issue was addressed.

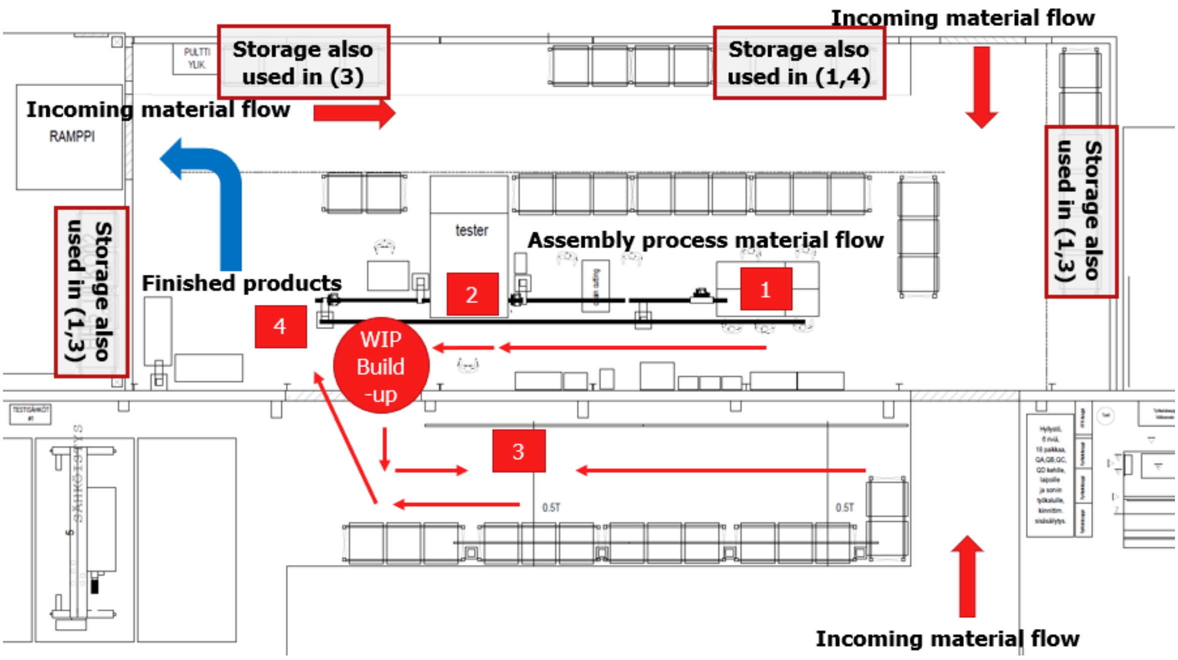


Figure 80: HH8 current state material flow directions

From the Figure 80, we can see that not only does the location of the final assembly (3) create WIP build-up, but also the distances, from where the workers must sometimes retrieve components are significant and increase the process duration. The HH8 project was made to directly improve the existing process flow under constraints of time, assembly area space and ongoing ramp-down process. However, with the suggested changes as well as the update of control cycle and replenishment information, the stored material quantity in the buffers was optimized, and planned workstation changes were made as the demand for the small ECH products was reduced in HH8.

Figure 81 shows the resulting material flow of the HH8 improvement project, which was planned and implemented in late summer, 2021. From the figure, we can see that the incoming material flow directions were not affected by the improvement but the available space in the assembly area was better utilized as well as the number of buffers reserved for ECH production were reduced. These changes reduced the duration required for material retrieval from buffers and allowed the trolley assembly to be moved closer to the FAT area since in most cases the trolley assembly is not dependent on other assembly process steps. Trolley assembly is still made in the final assembly area for special hoists, which require the trolley to be attached before chaining. When compared to the current state HH8 assembly area layout and material flow, the improvement in this case optimized the storing of materials as well as the available working space during the ramp-down and reduced some unnecessarily long material retrieval distances. With these changes, the resulting layout and material flow was improved to better support working conditions and large ECH production going forward.

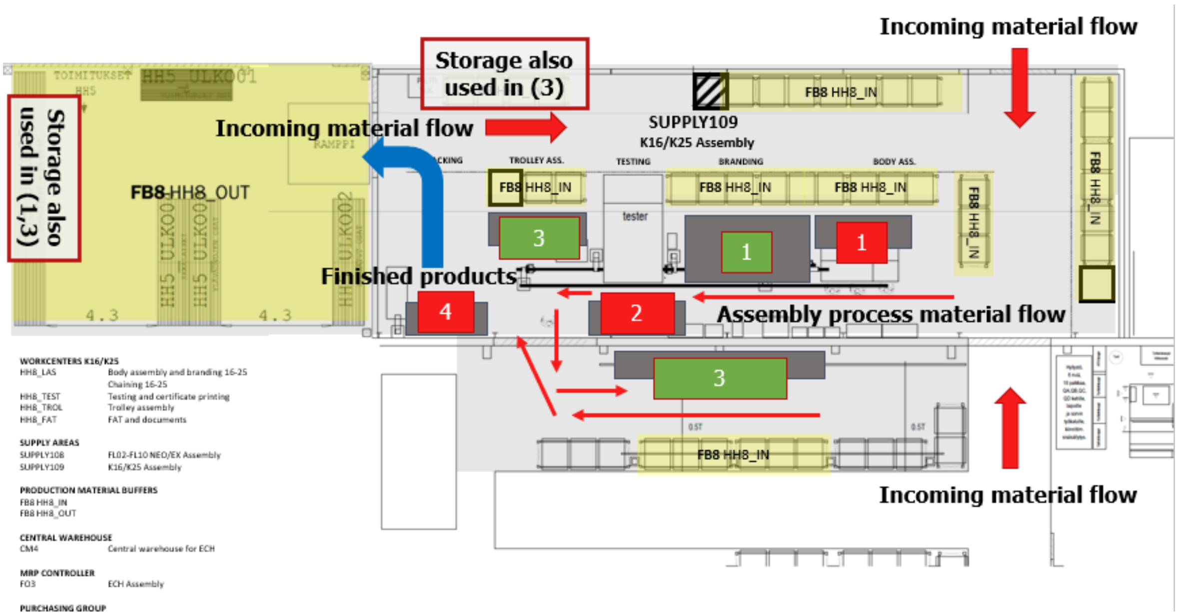


Figure 81: HH8 improved material flow

However, not all aspects of the production material flow could be improved during this project. While the project proved to be beneficial for improving the assembly process, the changes did not affect much the overall lead time of the order-to-delivery process. All materials used in the assembly process steps are still shipped and delivered to the buffers and workers must manually pick the required components whenever they are needed. Also, it would be challenging to bring both final assembly and trolley assembly to the same side with the tester due to spatial limitations without removing the packing area. Further improvements for the layout would be to incorporate picking process for the assembly steps, which would reduce the need for buffers and allow all assembly steps to have sufficient space in the same side of the floor area as the tester. Picking process would streamline the incoming material flow further and it could also reduce the hoist body assembly throughput time.

In the blank paper approach, the concepts for the HH8 areas of improvement were addressed along with some concepts that were not possible for the HH8 improvement project due to previously mentioned restrictions. As a result, the investigation provided a suggestion for the picking process along with improved assembly area designs to support efficient material flow of large ECH production. In the Figure 82, the chosen layout design and the material flow for ECH component picking area is shown. The storage spaces are refilled manually based on material replenished information maintained in SAP. The roller table and the U-shaped design allows materials to be picked by hand and placed in containers, and with experienced picking personnel the duration of the picking process can be reduced even further. The handpicked materials are then transported to the assembly area with a forklift. The design includes storage space for more materials that were reserved for picking in this investigation, but the available space could also be utilized for extended picking process, where components would also be picked for final assembly of the ECH. We will later discuss in chapter 5.4 the reasons why in this investigation, the picking process was only included for the hoist assembly.

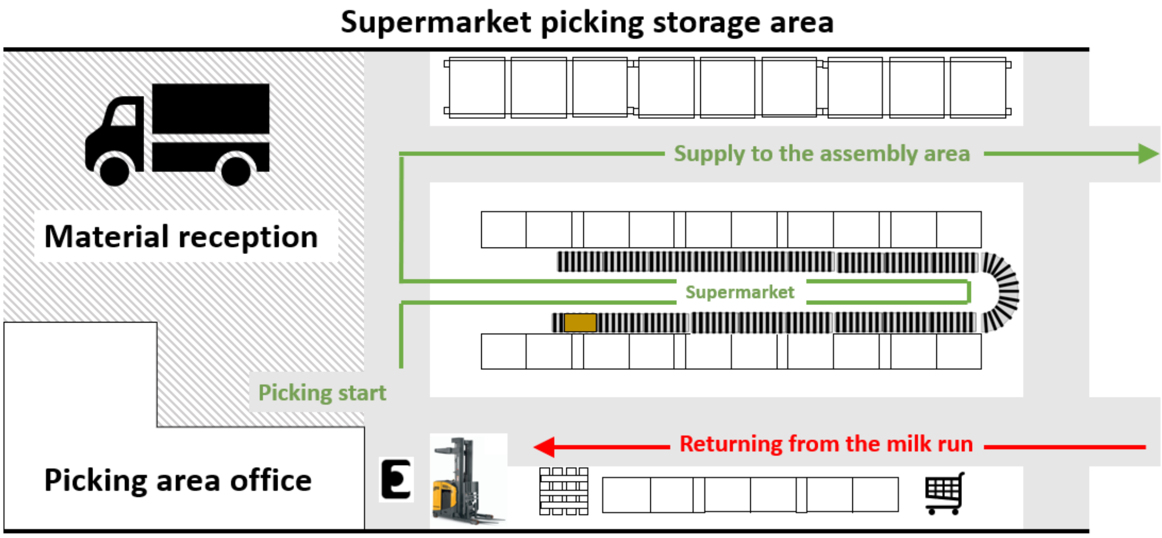


Figure 82: Supermarket picking storage area for ECH components

The resulting material flows of the two scenarios of the blank paper investigation were implemented the picking process for the hoist body assembly. The assembly area layouts for the two scenarios were designed using the HH8 layout as a basis, while addressing the areas of material flow improvement and Gemba from HH8 production line. The resulting material flows for the two scenarios can be seen in Figure 83 and Figure 84.

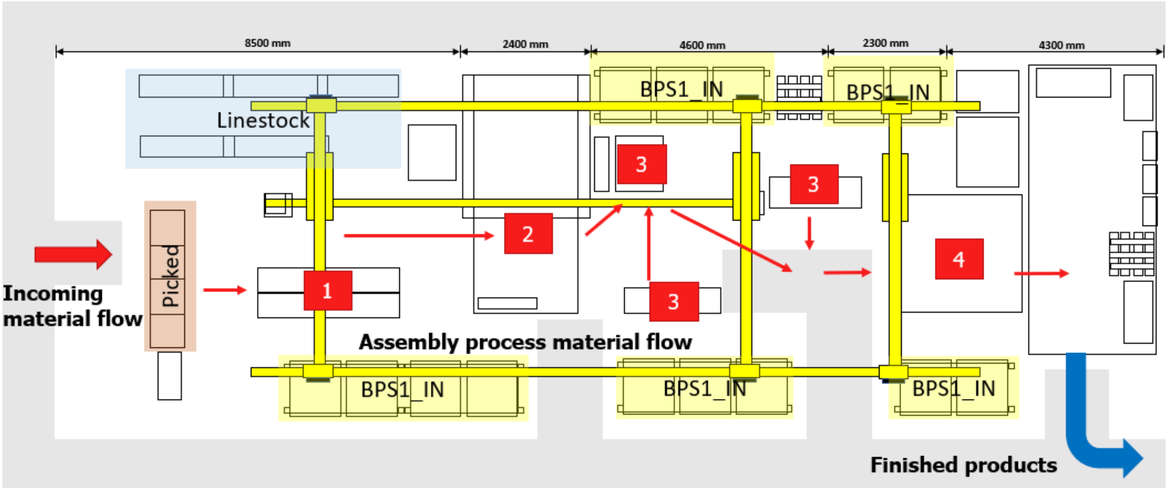


Figure 83: Scenario #1 assembly process material flow

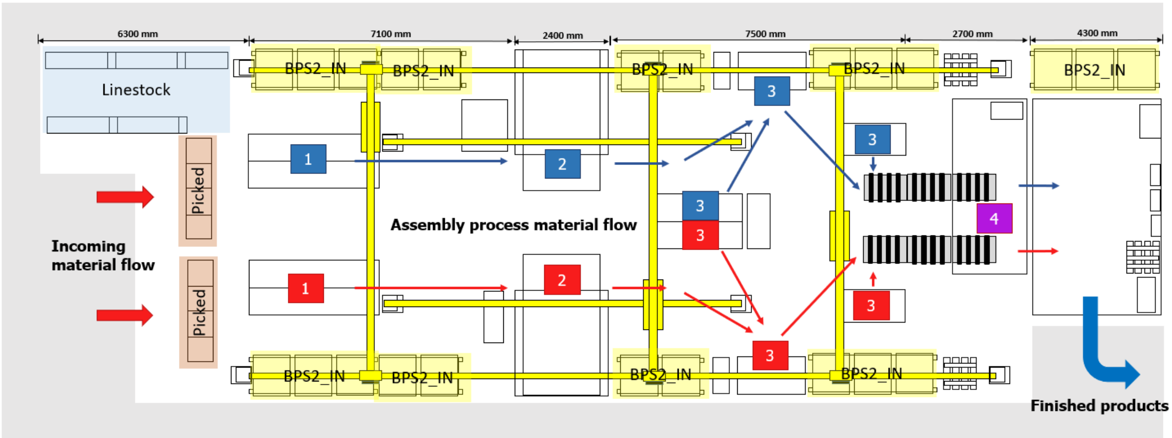


Figure 84: Scenario #2 assembly process material flow

The same principle for the material flow pattern and workcenter locations exists in both scenarios. However, scenario 2 mirrors the assembly process flow into two separate production lines, which are connected with a combined FAT production process step. The workstation placement in final assembly process step is designed to be more suitable for the assembly of different product types available for the ECH in both scenarios. While the figures display the material flow of the standard CTO hoist assembly, the body assembly and special hoist assembly do not require additional assembly spaces or entirely different practices to complete. Material movement is also be minimized by placing all the processes close to each other and not in a direct line, since the critical assembly order is not fixed between the different product types.

For the comparison of the resulting layouts and material flows with the current state HH8, we can use criteria for material flow performance evaluation derived from literature [22 p. 242, 34, 38]. The general information about the supply principles, spatial requirements, assembly area capacity and movement in the assembly area are compared in Table 13.

Table 13: The general information of the compared layouts and material flows

	Current state	Improved HH8	Scenario #1	Scenario #2
Storing and supply principle	Majority of materials are stored in assembly area buffers with replenishment directly from CWH. PTO materials are picked from CWH and delivered directly to assembly area and not stored in buffers.	Quantities of materials stored in buffers is optimized based on demand. Majority is still stored in buffers and PTO picking from CWH is similar to current state.	Picking process from a factory supermarket is introduced to most materials required for hoist body assembly. The materials needed in other process steps are stored in buffers. Picked PTO materials from CWH are supplied directly to the assembly area.	Picking process from a factory supermarket is introduced to most materials required for hoist body assembly. The materials needed in other process steps are stored in buffers. Picked PTO materials from CWH are supplied directly to the assembly area. Access to two lines increases the number of materials stored in buffers.
Layout size	243 m^2	243 (212) m^2	186 m^2	282 m^2
Work-stations	6	7	6	11
Personnel required	6-7 (1-shift)	7-9 (1-shift)	7-9 (1-shift)	13-14 (1-shift)
Demand for large ECH products	100 %	100 %	≈100 %	Increased
Movement of materials and personnel	Manual material retrieval required for each assembly step conducted by assemblers and WIP hoists are moved using inline hoists, pallet jacks or by hand. Long travel distances between buffers increases cycle times and unnecessary movement.	Workcenter placement is revised, and buffer locations are updated to reduce travel distances, but the material flow pattern requires the use of similar equipment as in the current state.	Workcenter placement is revised, and buffer locations are updated to reduce travel distances in the assembly area, while increasing accessibility and good working conditions. The layout is designed to allow the products to be directly moved from testing to chaining using a hoist instead of a pallet jack.	Workcenter placement is revised, and buffer locations are updated to reduce travel distances in the assembly area, while increasing accessibility and good working conditions. The layout is designed to allow the products to be directly moved from testing to chaining using a hoist instead of a pallet jack. The layout also introduces roller tables for moving the hoists on pallets from final assembly area to testing and eliminates the need for pump jacks for all assembly process steps besides packing.

From the comparison, we can see that by optimizing the layout design and introducing picking process reduces both the need for buffers and the size requirement for the assembly area in the scenario 1. Similar advantages exist also for scenario 2 but increasing the number of workstations requires the overall assembly area to have a larger floor space to include the two production lines and the linestock buffer. The improved HH8 layout provided a more efficient buffer and workcenter placement compared to the current state, which reduced unnecessary movement but not in the same scale as was resulting from the blank paper approach. However, the possibility to conduct trolley assembly next to the tester in the improved HH8 layout reduces the layout requirement for standard hoists, but because all hoist types must be possible to be assembled, the assembly area layout size stays the same.

In addition to the general information, we can compare the layouts and material flows using commonly used KPIs in material flow assessment, discussed in chapters 2.2.5 and 4.3.5. Table 14 shows the comparison of the KPIs for the different layout and material flow designs.

Table 14: Comparison of the layouts and material flows using commonly used KPIs

	Current state	**Improved HH8**	**Scenario #1**	**Scenario #2**
Flow intensity (m/travel) [Appendix D, Appendix E, Appendix F]	-Hoist body assembly: 60 / 6 -Testing: 0 -Final assembly: 110 / 8 (140 / 9) -FAT: 30 / 3	-Hoist body assembly: 55 / 6 -Testing: 0 -Final assembly: 100 / 7 (140 /9) -FAT: 10 / 3	-Hoist body assembly: 25 / 4 -Testing: 0 -Final assembly: 20 / 6 -FAT: 8 / 2	-Hoist body assembly: 25 / 4 (35 / 4) -Testing: 0 -Final assembly: 20 / 6 -FAT: 10 / 2
Picking times (mins)	-Hoist body assembly: 5-20 -Testing: 0 -Final assembly: 10-20 -FAT: 5	-Hoist body assembly: 5-10 -Testing: 0 -Final assembly: 10-20 -FAT: 5	-Hoist body assembly: 2 -Testing: 0 -Final assembly: 10-20 -FAT: 5	-Hoist body assembly: 2 -Testing: 0 -Final assembly: 10-20 -FAT: 5
Cycle times	100%	Minor reductions to hoist body assembly, final assembly, and FAT.	Greater reductions to hoist body assembly, final assembly, and FAT due to picking process and improved workcenter placement.	Greater reductions to hoist body assembly, final assembly, and FAT due to picking process and improved workcenter placement.
Lead time (end-to-end)	2-3 Weeks	2-3 Weeks	2-3 Weeks	2-3 Weeks
Throughput time (estimate based on picking times and cycle times)	100%	90%	72,5%	72,5 (36,25) % (2 parallel production lines)
WIP quantity	0-1 / process step	0-1 / process step	0-1 / process step	0-1 / process step
WIP time (hours)	0 – 1	Reduced due to faster cycle times	Reduced due to faster cycle times	Reduced due to faster cycle times

Notable is that scrap rate and tardiness is not compared since the layout and material flow designs of the blank paper approach are not applied in practice and gathering the data of these KPIs is not the in the scope of the thesis. Flow intensity in this case is the travel distance per travels to different locations. This highlights the average distance for each travel during an assembly process step. The picking times are estimates based on the layout design, distances, and experience from the HH8. The improved HH8 layout moved some storage locations closer to the assembly area but the improvement suggestion for the scenarios introduced a picking process, which had a more significant impact on the picking time for the hoist body assembly.

For the cycle times, the implementation of the picking process in the blank paper scenarios reduces the hoist body assembly cycle time the most. Also, significant changes can be seen in final assembly and FAT process steps, which have been designed with better workflow and material flow in mind. The impact of these changes can be seen in the cycle time estimates of Table 14. The investigation resulted in layouts which have the potential to reduce the overall assembly throughput time further than in the improved HH8 production process. Scaling the layout with greater demand in mind, the 2-line layout investigated in scenario 2 provides flexibility for the assembly of multiple hoist types simultaneously. Other advantages of the 2-line layout include insurance that production is not seized in case of testing equipment failure by having double the workstations. Also, including two parallel production lines does mean that two hoists are assembled and inspected in roughly the same time as in scenario 1. Therefore, the hoists move through the entire assembly area twice as fast. However, disadvantages for the 2-line layout would mostly be the additional buffers required for the assembly area and the fact that same materials are stored in different buffers in adjacent sides. This would create challenges to manage the storages in ERP. One solution would be to maintain the storage bins for each production line individually. This would make the tracking of material quantities more accurate in the assembly area.

With the changes for the improved HH8 layout, the cycle times could also be reduced but not to the same extent as in the scenarios. However, with all the included changes, the end-to-end lead time is not affected significantly in none of the resulting layouts. As established in chapter 4.3.6, the assembly process itself is only a small part of the overall lead time. Improving the internal factory logistics impacts more the production quality, productivity, and assembly throughput time.

The average occurrence of WIP is difficult to estimate for the ECH production due to the configurable product structure and small practical differences in processing times. However, it is safe to assume that shorter cycle times for the final assembly process reduce WIP after testing, but they also risk more hoists to be waiting to be tested. If all product types are made in regular intervals, the production process does not generate WIP but if an increased number of special hoists are assembled, WIP might occur. The duration a hoist can stay as WIP is usually not more than one hour in the current state assembly process and the WIP time is reduced in the improved cases due to shorter final assembly cycle times.

5.3 Evaluation of the results and final recommendation

For compiling the final recommendation for large ECH production material flow improvement, the results from the comparison should be evaluated. We can create a SWOT analysis to analyze the investigated layouts and material flows. The SWOT analysis can be seen in Figure 85. It can be used then to summarize what was found to be the most influential improvements for ECH production material flow and what aspects about the production process or this investigation would still require further development. The limitations during the thesis and further research topic suggestions are discussed in chapter 5.4.

The strengths of the investigated layouts and material flows include firstly the straight material flow pattern. The layout is designed so that the final assembly process steps are no longer conducted in a separate space, which would hinder the workflow as well as information flow from the other processes. Secondly, visibility and accessibility would be increased in the designs for the buffers and workstations. Third, unnecessary movement would be reduced through optimized buffer placement and assembly area equipment usage for example by allowing hoists to be directly lifted from the test beam to chaining. Fourth, the suggested picking process would reduce the hoist body assembly lead time by allowing materials to be supplied directly to the assembly area while the other process steps are conducted. This would also reduce the quantity of buffer stored materials further reducing travelling distances during assembly. Fifth, the second tester in scenario 2 offers a solution in preventing production stoppages in case of testing equipment failure. Finally, the strengths of the resulting layouts and material flows include an improved workcenter placement by having a layout design that better supports the material flow during assembly of all hoist types.

The weaknesses of the designed material flow can still be found in the configurable product structure. While the choice of providing a customizable product is part of Konecranes business plan, it provides issues for material storing. The configurable structure requires that all combinations of the product must be manufacturable with short lead times. To make this possible, all materials maintained in the factory scope superBOM must be stored at the factory site or possible to be ordered and supplied in a few weeks. Updating the safety stock and replenishment data for the materials included in the production scope based on confirmed demands would alleviate this challenge in practice. Other weaknesses include the fact that this investigation did not consider material flows from suppliers, which based on the VSM, were the largest contributing factor for the order-to-delivery lead time. Lastly, the layouts were investigations and not tested in practice, which meant that picking time and cycle time KPIs for the scenarios were estimates and not derived from actual tests.

The opportunities for the investigated material flows include updating the assembly order by starting the sub-assemblies and trolley assembly as soon as the hoist assembly process step is started. This could be possible by increasing communication between the workcenters, but the practicality was not addressed further in this thesis. Other opportunities for the improved material flow would include implementing the picking process also for final assembly steps. This could be possible perhaps by expanding the milk run using a Kanban scheduling, but the practicality would require further investigation. Finally, while the ECH production material flow was investigated for both 1-line and 2-line assembly area, further iteration of the layouts could reveal additional improvement opportunities.

The threats of the planned improvements include the practical implementation of the picking process. While in practice, the picking process would reduce assembly process cycle times, the guidelines, use of TO, PO modification to support picking process, SAP integration, information flow and responsibilities would need to be planned further.

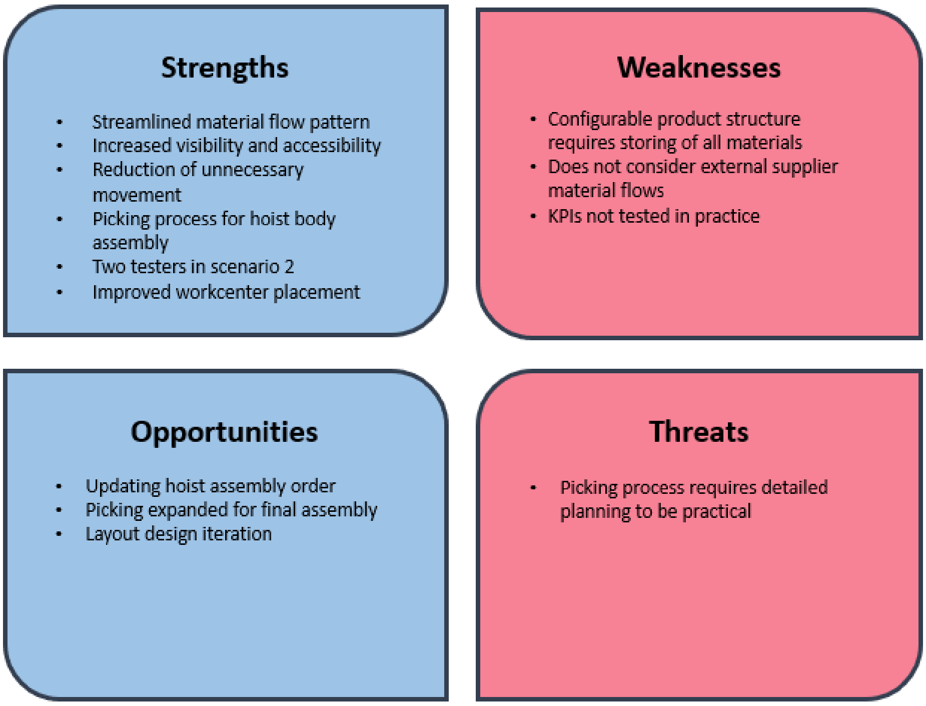


Figure 85: Blank paper material flow investigation SWOT analysis

When accounting for the SWOT analysis as well as the comparison of the results, this thesis recommends the five main improvements for ECH production material flow. These recommendations are listed below. The presented recommendations consist of findings from the blank paper investigation and the areas of improvement from HH8.

1. Starting the assembly of sub-assemblies and trolley simultaneously to hoist body assembly
2. Establishing an internal picking process for hoist body assembly materials involving a separate supermarket picking area
3. Adjusting safety stock and replenishment quantities for ECH materials based on demand estimates similar to ECH item catalogue used for HH8 improvement
4. Layout changes investigated for scenarios 1 and 2 including improved workcenter, buffer and assembly equipment placement to better support assembly of all large hoist types and to reduce unnecessary movement between workstations
5. 2-line layout for increased demand scenario to increase assembly stability

5.4 Limitations of the project and further research

While this thesis presents an improved material flow and layout design using systematic production development, not all aspects of material flow improvement were able to be included. Early on, it was decided that the material flow investigation would be focused on the internal logistics of the assembly facility and excluding the material flow from external suppliers. The choice was made due to limitations in schedule, accessibility and collaboration between factories and suppliers outside of Finland. However, the introduction to the Hämeenlinna factory allowed the author to target the issues found in the current assembly process regarding the large ECH production. With this limitation in mind, the material flow between the suppliers and the central warehouse could be researched further to find methods for reducing the order-to-delivery lead time more significantly.

Other limitations for the material flow improvement were the highly variable product mix, which has more variation in practice than with the product mix used in investigating the two scenarios. This made it difficult to use detailed KPI data in analyzing the overall performance of the current production material flow. Therefore, most of the areas of improvement were discovered through the Gemba visits, participating in the assembly process at HH8 and using VSM as well as knowledge gained from literature. There is also other aspects of the improved material flow and layout designs recommended by this thesis that would be suitable topic for further research. These aspects include the following:

- Planning of the picking process SAP integration and practicalities
- Developing picking process also for final assembly and how it would work with hoist body material picking
- Layout iteration and 3D-modelling
- Iteration of the workcenter design and routing
- Practical testing and implementation
- Referencing material flow improvement projects of other companies in the industry

While one of the recommended changes to the current ECH production would be to implement a picking process to the hoist body assembly, it would require more research and effort to determine the practicalities of maintaining information of the state of both the production orders, material locations and quantities as well as guidelines and tools needed for the process. Another additional research topic could be the possibility of implementing the picking process for final assembly as well and how the two picking processes could be managed in practice.

The layouts could be iterated further by providing alternative workstation placement and they could also be improved using a 3D-modelling software to better highlight how the assembly process material flow would look like in the improved environment. To not only estimate and deduct the effectiveness of the recommended designs, testing and practical implementation would be needed to determine the actual KPIs. Other means for determining the effectiveness of the designed material flow could also be found by interviewing other industrial equipment manufacturing companies which have previously conducted material flow improvement.

6 CONCLUSIONS

The purpose of this thesis was to investigate potential areas of improvement for ECH production material flow through a systematic development approach. The existing ECH assembly line at the Konecranes Hämeenlinna factory was used as a reference for the current state and Gemba analyses. The assembly line was visited for 3-months by the author during the thesis contract introductory period to gain hands-on experience of the assembly process and the product itself. The visit proved useful not only for finding potential issues in the material flow but also for a local development project concerning the production line improvement. The focus for the thesis was also decided during the visit. Since, the production line at Hämeenlinna was under production ramp-down for the small frame K-hoists, the choice was to focus on improving the material flow of large frame K-hoists. The investigation was also decided to be in a broader concept involving large ECH production in general rather than improving the existing HH8 assembly line. This, more open approach for material flow investigation allowed the author to be less restricted by physical constraints of the HH8 and rather develop an improved assembly area layout and material flow using literature and practical knowledge from HH8. However, to limit the scope, it was chosen that the material flow investigation would only consider physical material flow of internal factory processes.

The focus of literature research was to elaborate the terminology used in the investigation, finding the factors affecting production process material flow, means for improving material flow, determining logistic strategies for factories as well as finding examples of material flow improvement projects and how the material flows could be evaluated. Production development, layout design, factory logistics and facility planning were found to be the main themes from literature and this thesis.

Production process material flow, investigated in this thesis, is the handling and physical movement of raw materials, components, semi-finished goods, sub-assemblies, waste, and documents required or resulting from producing a product. This movement of materials is conducted by involved personnel via logistic processes. Factors affecting material flow include material category, storage type, storing method, replenishment strategy, internal material transport principles, process flow, information flow, production area layout, product structure and assembly order.

Material categorization affects how the materials are stored and whether they are produced for orders or to stock. If the materials are stored in buffers, they cause inventory holding costs, limit working space and require material retrieval during assembly processes. Selecting which components to store in buffers, which to be ordered directly from central warehouse and optimizing safety stock and replenishment values based on consumption forecasts is key for maintaining competitive advantage in changing markets. Internal storing methods for factories include either manual buffers, a separate storage area or an automated storage system. While manual storing methods offer a simple strategy for material retrieval, they often result in longer picking times, which can be addressed with supermarket or automated storing methods. The internal material transport principles of factories can be divided into supply and dispatch of materials in and out of the assembly area, and material handling during the assembly process. Materials can be transported using forklifts, by hand or by external equipment, such as hoists and pump jacks. The material transportation can be managed by transfer orders, by using Lean scheduling principles, such as JIT and Kanban, or by integrating the transportation to the process flow. Process flow is the movement from one supply chain process to the next in the order-to-delivery process. This movement is often monitored by seamlessly integrating it with information flow. The information of the state of each process step is documented using physical devices or sensors to gather data into company ERP information systems. Managing the information about process steps allows managers to keep track of the process flow and to better forecast lead times and resource requirements. The production area layout affects the productivity and production throughput time by dictating the workcenter and buffer placement, visibility and accessibility in the assembly area, and by a straight or U-shaped material flow pattern, which offer the most streamlined workflow in industrial equipment production.

From the Gemba visit to the HH8 production line, the author also discovered how the product structure and assembly order influences the material flow during the assembly process. The modularity of the product and DFA determine the number of different fixtures and set-ups required for manufacturing each product type. Increasing product structure modularity reduces travelling during the assembly process as well as processing times. The assembly order also influences material flow by determining which steps need to be made before others can be started. If some assembly processes can be started simultaneously and scheduled so that WIP does not occur, the production throughput time can be reduced. After the factors affecting material flow were compiled from the literature, it was also important to find frameworks and case examples of the means for material flow improvement. Lean tools, such as JIT, Kaizen, Gemba, Kanban, MRP, 5s and VSM can be used for production development as well as finding improvements for material flow. Kaizen continuous improvement frameworks such as PDCA, and the four steps of lean improvement process could be followed to conduct a systematic production material flow improvement project. The four steps are listed below.

1. Identify wastes
2. Determine root causes
3. Find solution
4. Test and implement the solution

Other production and material flow improvement concepts include Lean six sigma (LSS), which combines the quality improvement guidelines of Six sigma and the waste reduction philosophy of Lean. One of the LSS practices includes DMAIC quality management and improvement approach. Also, an alternative approach to Lean includes following the six material flow planning steps presented by Shenk et al.

1. Performance program coordination
2. Determination of functions
3. Dimensioning
4. Structuring
5. Design
6. Verification of functions using a model

Another framework, which was chosen to be used in the investigation of the material flows and layouts for ECH production in this thesis was the Gould et. al. 5-phase material flow assessment framework in manufacturing systems (MFAM framework). The framework was used for the systematic analysis and improvement of an existing material flow and production process.

The literature review was followed by establishing the current state product structure and the state of ECH production at Hämeenlinna in summer 2021 and compiling the areas of material flow improvement. The areas of improvement were divided into five topics, which were analysed for the possibility to be included in the improvement investigation or not within the scope of the thesis. The main areas of improvement discovered from visiting the HH8 assembly area included the product structure and assembly order discussed earlier, material storages and material replenishment practices, layout and material transportation and logistics.

The material flow improvement investigation was followed by a HH8 production development project, which the author participated. The goals for the project were to improve productivity under the ramp-down and the assembly area layout so that it better serves the production of large K-hoists going forward. The project was successful in increasing knowledge about the materials maintained for the assembly process and by updating the control cycle and replenishment values of the materials. Layout planning and iteration was also made, which resulted in improved buffer and workcenter placement. The changes altogether were beneficial for improving the productivity and assisting in the ramp-down process based on discussion with local production planners and supervisors.

With knowledge from the literature, introduction to the HH8 production line as well as participating in the HH8 development project, the author was able to start developing the systematic improvement planning for general ECH production material flow. For the material flow improvement planning, the approach was to investigate a material flow and an improved layout for two scenarios, where the second scenario had a larger demand estimate. The chosen method was to use the MFAM framework to establish the scope and structure for the investigation. VSM was used to determine the bottlenecks in the production process. The most influential improvement suggestion to the current process was to include an internal picking process for the hoist body assembly process step. This would allow picking and supply of components to the assembly area while other hoists could be assembled thus reducing hoist body assembly cycle time, need for in-line buffers and movement during the process step. For designing the picking process, a weighted comparison and evaluation of the factory environment logistic strategies were made. These logistic strategies included picking from a manual picking area, supermarket picking area or an automated storage system. The advantage of the automated storage is the goods-to-man picking principle, which eliminates most of the picking time when compared to the man-to-goods principle in the other two logistic strategies. However, from the comparison, it was found that picking process from a separate supermarket picking area would offer the best balance between short picking times, required competency and resources needed. The important concepts for implementing the picking process in practice would consist of further planning of details how the milk run from the picking area to the supply area would be conducted. However, the suggested picking strategy would consist of pull type production strategy for the picking, and push type strategy for the following assembly. In practice, this means that the picking initiates the pre-assembly process and when the materials are supplied to the assembly area, they are used to assemble the products in First in First out practice or by Kanban scheduling.

Other suggested changes resulted in an updated design for the workcenter placement in the final assembly and FAT process steps, which would be designed to support the assembly of all product types better. The placement of workcenters would also increase visibility in the assembly area, reduce the need for additional equipment in material handling and potentially reduce WIP occurrence. However, these results could not be verified using test data, since the designs were suggestions based on findings from literature and HH8.

Designing the layouts for the scenarios was made using the capacity requirement calculations for the two scenarios and by using the HH8 assembly area as a reference. The workcenter design, including minimal distances from buffers, utilization of space, visibility and accessibility and ergonomics were planned while accounting for the guidelines of effective layout design. The results from the investigation resulted in two layouts, with material flows visualized using actual workcenter positioning in the production of standard CTO hoists, hoist bodies and special hoists (3-fall and 4-fall hoists in this case). Both layouts incorporated the changes based on the found areas of improvement, and they also included the picking process for the hoist body assembly. These resulting material flows, and layouts were then compared with the layout and material flow results from the HH8 development project as well as the state of ECH production before the development project.

From the comparison it was determined that the recommended changes would provide a substantial improvement on the production throughput times, streamline the material flow pattern to increase productivity and to reduce unnecessary movement of materials and personnel during the assembly process. However, since the results were based on estimates, the actual impact in the cycle times and other KPIs could not be verified. The benefits of the recommended layouts and material flows were evaluated using a SWOT analysis, which dictated the final recommendations for ECH material flow improvement suggested by this thesis. These recommendations are summarized in chapter 5. The main topics for further material flow improvement include updating the ECH production cycle times, detailed planning of the picking process practicalities, possibility of picking process for final assembly and iteration of the suggested layout designs.

The approach for material flow improvement presented in this thesis, which focused on finding areas of improvement for producing a specific product instead of improving an existing production line was unique among most example cases found from literature. The choice of including the HH8 improvement project gave the evaluation of the impact that the recommended changes had towards the current state of ECH production a more practical comparison and tangible results, even though the KPIs could not be verified through testing.

REFERENCES

[1] Konecranes, "Konecranes in brief". [online]. Available: https://www.konecranes.com/about/konecranes-in-brief [Accessed Feb 23rd, 2022].

[2] Konecranes, "Business areas". [online]. Available: https://investors.konecranes.com/evolution-our-business-areas [Accessed Feb 3rd, 2022].

[3] Cargotec, "Cargotec and Konecranes to merge creating a global leader in sustainable material flow", Oct. 2020. [online]. Available: https://www.cargotec.com/en/nasdaq/stock-exchange-release-kalmar-hiab-macgregor/2020/cargotec-and-konecranes-to-merge-creating-a-global-leader-in-sustainable-material-flow/ [Accessed June 6th, 2021].

[4] Konecranes, "Equipment overview". [online]. Available: https://www.konecranes.com/equipment [Accessed June 6th, 2021].

[5] Konecranes, "Mergers & Acquisitions". [online]. Available: https://investors.konecranes.com/mergers-acquisitions [Accessed June 6th, 2021].

[6] Hugos M. Essentials of supply management. *John Wiley & Sons. Inc.* Hoboken, New Jersey, 2003. ISBN 0-471-23517-2.

[7] Somers T., Ragowsky A. Enterprise resource planning. *Journal of Management information Systems*, 2002. Vol. 19:1, pp. 11-15. DOI: 10.1080/07421222.2002.11045718.

[8] Akhtar J. Production planning and control with SAP ERP. 2nd ed. *Rheinwerk publishing Inc.* Boston, Massachusetts, 2016. ISBN 978-1-4932-1430-3.

[9] Wemmerlöv U. Assemble-to-order manufacturing: Implications for materials management. *Journal of Operations Management*. 1984. Vol. 4:4, pp. 347-368. DOI: 10.1016/0272-6963(84)90021-4.

[10] Seiler F. M., Greve E., Krause D. Development of a Configure-to-Order-Based Process for the Implementation of Modular Product Architectures: A Case Study. *Proceedings of the 22nd International Conference on Engineering Design (ICED19)*, Delft, The Netherlands, 2019. DOI:10.1017/dsi.2019.304.

[11] Ni G. Replenishment policy for a purchase-to-order seller: a tradeoff between ordering cost and delay cost. *International Journal of Production Research*, 2019. DOI: 10.1080/00207543.2019.1616846.

[12] Schenk M., Wirth S., Müller E. Factory planning manual – Situation-driven production facility planning. *Springer-Verlag,* Berlin Heidelberg, 2010. DOI: 10.1007/978-3-642-03635-4.

[13] Sulgan M., Sosedova J. Procurement of Materials and Components for Manufacturing Activity. *Communications - Scientific Letters of the University of Zilina*, 2014. Vol. 16:2, pp. 58-62. ISSN 2585-7878.

[14] Qu T. IoT-based real-time production logistics synchronization system under smart cloud manufacturing. *The International Journal of Advanced Manufacturing Technology,* 2015. DOI: 10.1007/s00170-015-7220-1.

[15] Elisa Industriq, "How to Optimize Material Flow with Data Analytics and Machine Learning?". [online]. Available: https://elisaindustriq.com/how-to-optimize-material-flow-with-data-analytics-and-machine-learning/ [Accessed June 6th, 2021].

[16] Gupta S., Jain S. K. A literature review of lean manufacturing. *International Journal of Management Science and Engineering Management*, 2013. Vol 8:4, pp. 241-249. DOI: 10.1080/17509653.2013.825074.

[17] Rahani A., Muhammad al-A. Production Flow Analysis through Value Stream Mapping: A Lean Manufacturing Process Case Study. *Procedia Engineering*, 2012. Vol.41, pp. 1727-1734. DOI: 10.1016/j.proeng.2012.07.375.

[18] Gould O. A material flow modelling tool for resource efficient production planning in multi-product manufacturing systems. *Procedia CIRP 41,* 2016. p. 21-26. DOI: 10.1016/j.procir.2015.12.139.

[19] Domingo R., Alvarez R., Melodía Peña M., Calvo R. Materials flow improvement in a lean assembly line: a case study. *Assembly Automation*. 2017. Vol. 27:2, pp. 141-147. DOI: 10.1108/01445150710733379.

[20] Dierkes S. Production and cost theory-based material flow cost accounting. *Journal of Cleaner Production*. 2019. Vol. 235, pp. 483-492. DOI: 10.1016/j.jclepro.2019.06.212.

[21] Wang C. An Empirical Study of the Machine Assembly Efficiency Improvement Based on Lean Six Sigma Technique. TEM Journal. 2019. Vol 8:2, pp. 471-476. DOI: 10.18421/TEM82-21.

[22] Konecranes. “Konecranes Brand Portal”. [online]. Available: brand.konecranes.com [Accessed November 11th, 2021].

[23] Konecranes. “Teamcenter”. [database]. Hyvinkää. (2021).

[24] Teknologiateollisuus. ”Työntekijöiden työaika 2019-2021”. Technology industry worker worktimes 2019-2021. Available: https://teknologiateollisuus.fi/sites/default/files/2020-01/Vuosity%C3%B6aika_2019-2021_2.pdf [Accessed November 11th, 2021].

[25] Siemens PLM. “Siemens Technomatix”. [online]. Available: https://www.plm.automation.siemens.com/global/en/products/tecnomatix/ [Accessed December 2nd, 2021].

[26] Siemens PLM. “Geographic-based Manufacturing Information Access”. [online]. Available: https://www.plm.automation.siemens.com/global/en/products/manufacturing-planning/geographic-based-manufacturing-information-access.html [Accessed December 2nd, 2021].

[27] Siemens PLM. “End-to-end simulation and virtual commissioning facilitate cost-effective and convenient implementation of complex and efficient automobile production facilities”. [online]. Available: https://www.plm.automation.siemens.com/global/en/our-story/customers/tms-technomatix/69190 [Accessed December 2nd, 2021].

[28] Siemens PLM. “Intosite for the digital factory”. [online]. Available: https://www.plm.automation.siemens.com/global/en/webinar/digital-factory/77696 [Accessed December 2nd, 2021].

[29] Siemens PLM. “Plant Simulation & Throughput Optimization”. [online]. Available: https://www.plm.automation.siemens.com/global/en/products/manufacturing-planning/plant-simulation-throughput-optimization.html [Accessed December 2nd, 2021].

[30] Cheng C., Miltenburg J., Motwani J. The Effect of Straight- and U-Shaped Lines on Quality. *IEEE Transactions on Engineering Management*, 2000. Vol. 47:3, pp. 321-334. DOI: 10.1109/17.865901.

[31] Klenk E., Galka S., Günthner W. A. Analysis of Parameters Influencing in-plant Milk Run Design for Production Supply. *International Material Handling Research Colloquium Proceedings*. Gardanne, France, 2013. Vol. 12, pp. 25-28. Available: https://www.mhi.org/downloads/learning/cicmhe/colloquium/2012/klenk.pdf [Accessed December 11th, 2021].

[32] Mácsay, V., Bányai T. Toyota production system in milkrun based in-plant supply. *Journal of Production Engineering*. 2017. Vol. 20:1, pp. 141-146. DOI: 10.24867/JPE-2017-01-141.

[33] Varisco M., Deuse J., Johnsson C., Nöhring F., Schiraldi M.M., Wöstmann R. From production planning flows to manufacturing operation management KPIs: linking ISO18828 & ISO22400 standards. *IFAC PapersOnLine*. 2018. Vol.51:11, pp.25-30. DOI: 10.1016/j.ifacol.2018.08.229.

[34] Liu C., Lin L., Chen M., Horng H. A New Performance Indicator of Material Flow for Production Systems. *Procedia Manufacturing*. 2017. Vol. 11, pp. 1774-1781. DOI: 10.1016/j.promfg.2017.07.311.

[35] Kasten. Products: "TORNADO automated storage system". [online]. Available: https://www.kasten.fi/Tuotteet/Varastoautomaatit/TORNADO-Varastoautomaatti/ [Accessed December 11th, 2021].

[36] Fastems. Brochure: "Take your Production Capacity to the Next Level". [online]. Available: FMSBusiness_Leaflet_A4_EN_WEB.pdf (fastems.com) [Accessed December 11th, 2021].

[37] Rastec. Storage solutions catalogue. [online]. Available: https://rastec.fi/Varastointi/ [Accessed December 11th, 2021].

[38] Manos T. Value stream mapping-an introduction. *Quality Progress*. Jun. 1st, 2006. Vol. 39, pp.64-69. Available: https://faculty.washington.edu/apurva/502/Readings/Lean/value-stream-mapping--an-introduction%20lean.pdf [Accessed January 6th, 2022].

[39] Tyagi S., Choudhary A., Cai X., Yang K. Value stream mapping to reduce the lead-time of a product development process. *International Journal of Production Economics*. 2015. Vol. 160, pp. 202-212. DOI: 10.1016/j.ijpe.2014.11.002.

[40] Zupan H., Herakovic N., Zerovnik J., Berlec T. Layout optimization of a production cell. *International Journal of Simulation modelling*. 2017. Vol. 16:4, pp. 603-616. DOI: 10.2507/IJSIMM16(4)4.396.

[41] Rufe, P. D. Fundamentals of Manufacturing (3rd Edition). *Society of Manufacturing Engineers (SME)*. Dearborn Michigan, USA. 2013. ISBN 978-0-87263-870-9.

[42] Cheng C. H., Miltenburg J. & Motwani J. The Effect of Straight- and U-Shaped Lines on Quality. *IEEE Transactions on Engineering Management*. 2000. Vol. 47:3, pp. 321-334. DOI: 10.1109/17.865901.

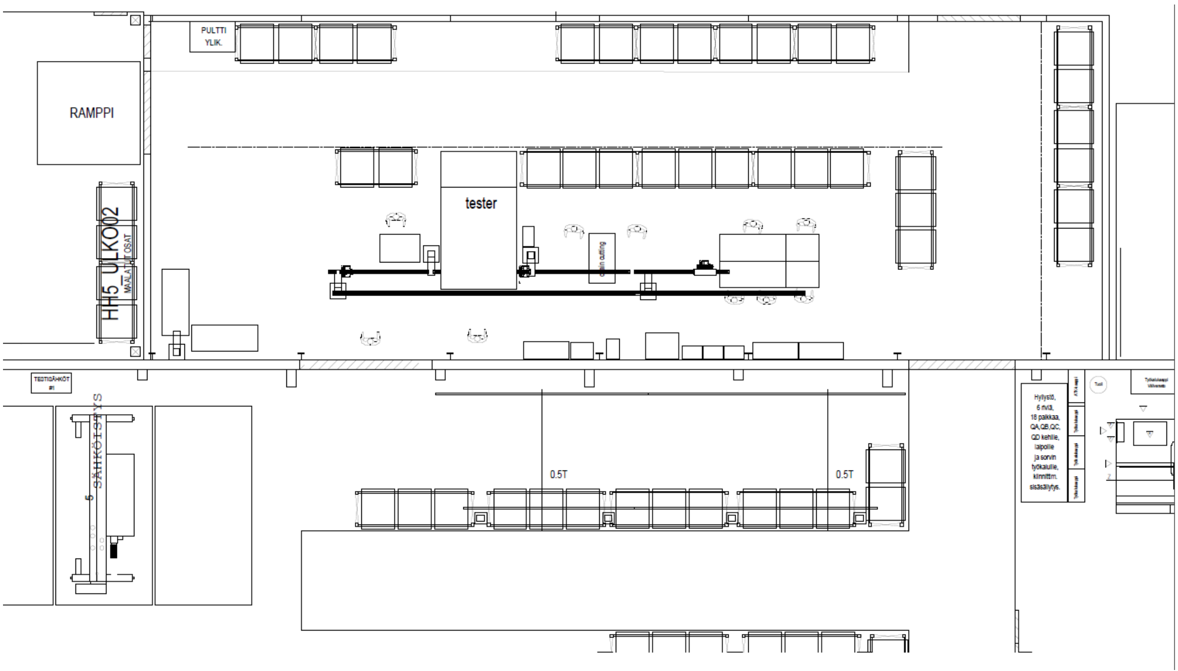
[43] Black J. Lean Production - Implementing a World-Class System (1st Edition). *Industrial Press*. New York, New York, USA. 2008. ISBN 978-0-8311-3351-1.

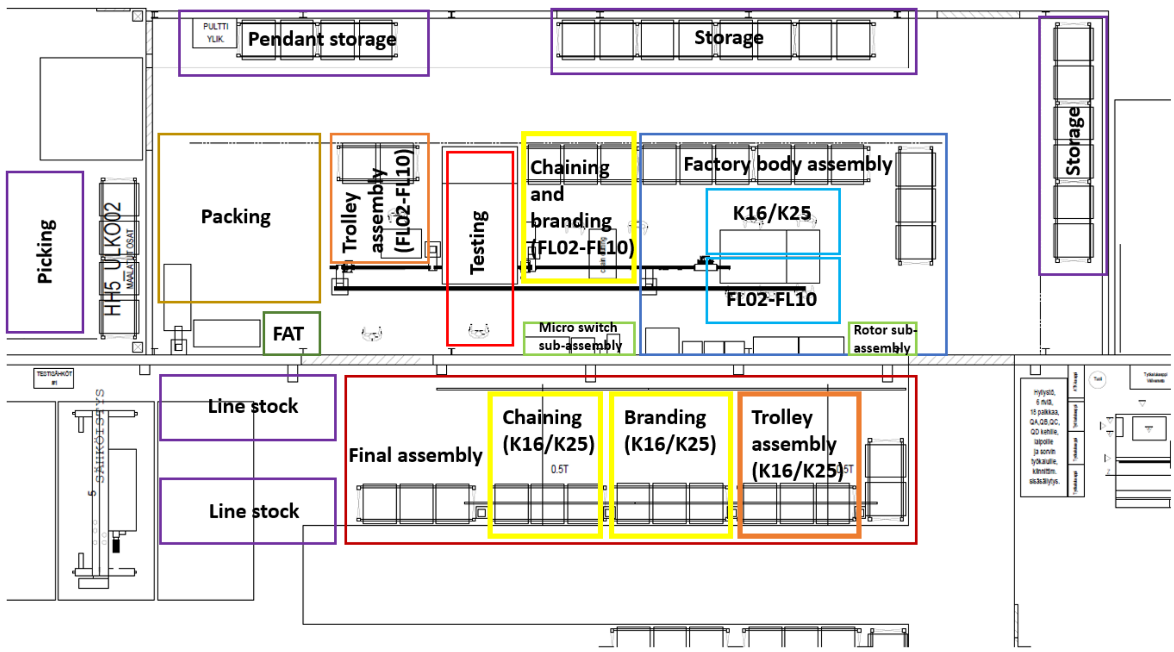
[44] Schoeller Allibert Oy. “Konecranes Agilon käyttöön koeajetut Schoeller Allibert laatikot”. Catalogue for containers suitable for AGILON. Hyvinkää, 2021.

[45] Konecranes. “Technical guide chain hoist 50 Hz”. Hyvinkää, 2016.

APPENDICES

Appendix A. Current state HH8 base layout and detailed areas





Appendix B. Checklist of planning rules for material flow design

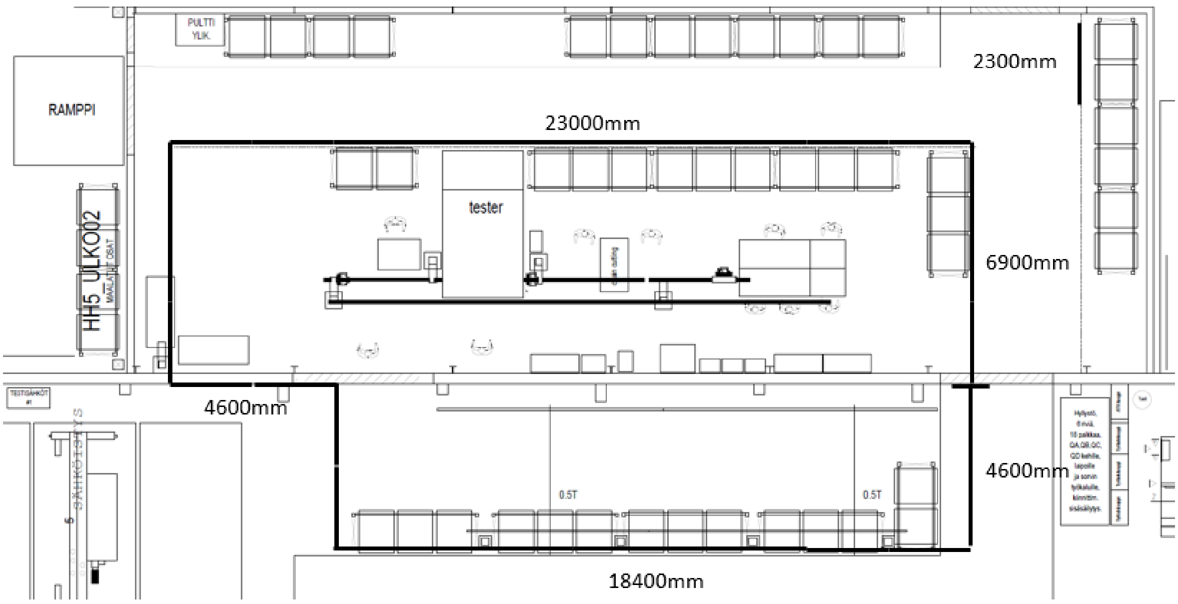
Aspect	Planning recommendation / rule	Observed?
Parameters	– form practical units (e.g. procurement unit = manufacturing unit = transport unit = storage unit = packing and shipping unit)	☐
	– classify parameters to facilitate the planning task => reduce planning effort	☐
Workflows	– undertake clear definition of workflows (collect and bring systems, control centers, stations)	☐
	– provide measuring points for the identification and monitor-ing of progress	☐
	– guarantee short throughput times	☐
	– plan main transports (materials) and secondary transports (e.g. waste) in an equally effective and efficient way	☐
	– limit handling processes to a minimum	☐
	– minimize control costs	☐
System/plants		
Transport route	– materials should flow in a linear fashion	☐
	– the material flow should only link a small number of areas	☐
	– plan short transport routes	☐
	– do not plan any route intersections	☐
	– do not plan movements in opposite directions	☐
Floor space	– allot minimal floor space and room occupation while securing the ability to function	☐
Engineering	– minimize the variety of types of technology used => favorable conditions for capacity utilization, for redundancy, for optimi-zation of maintenance, low stocks for replacement parts	☐
Logistics equipment	– variety of types (see above). Limit technology	☐
	– take automation into account	☐
	– achieve high capacity utilization of equipment and plants	☐
Logistics util-ities	– select as small as possible	☐
	– variety of types (see above). Limit technology	
Costs	– minimize investment costs	☐
	– minimize overall costs taking operating costs for n years into account	☐
People	– minimize number of required workers	☐
	– design workstation and workflows ergonomically	☐

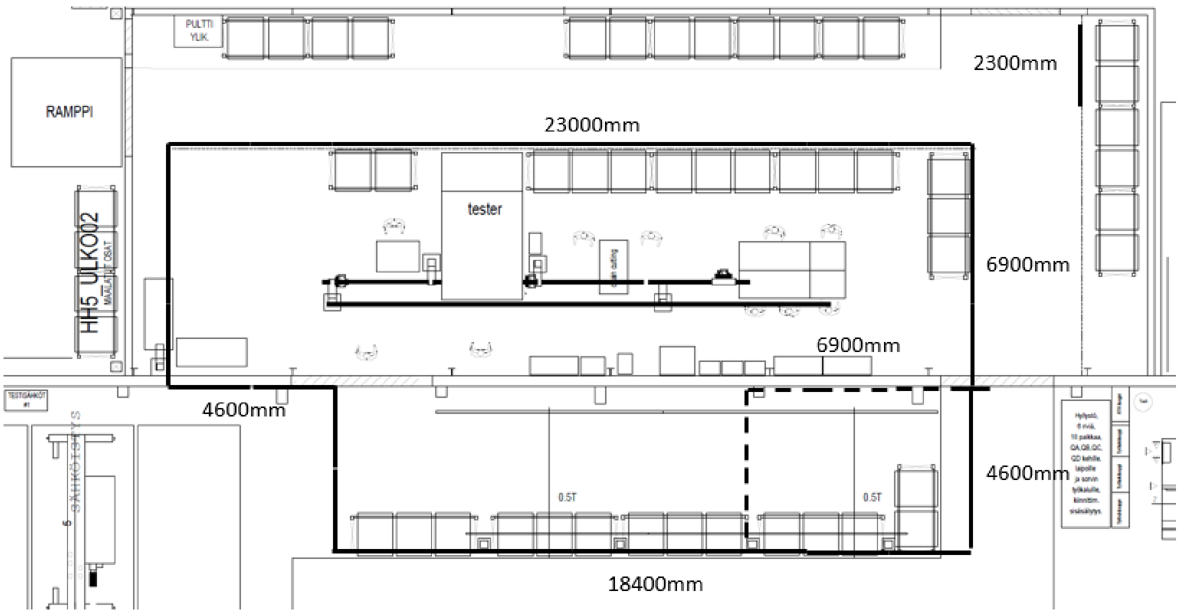
Appendix C. Examples of production material flow and logistics planning tasks

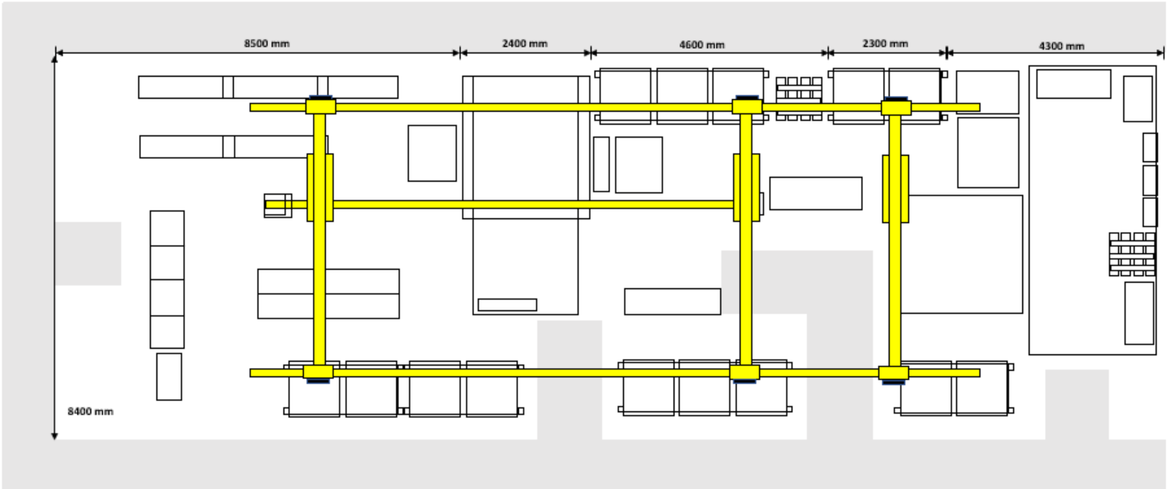
Logistics product/logistics service	
	– category formation according to shared logistical features – volume planning (primary and secondary demand) – calculation of lots – determination of the average arrival time interval – calculation of arrival rate – procurement planning, determination of resource requirements
Logistics process	
(1)	Material flow:
	– definition of the flows – analysis of the flow rate (continuous or intermittent flow rate) – calculation of inflow and outflow capacity – calculation of average duration in the system – calculation of probabilities for dynamic systems (arrival time, service time) – calculation of working time / performance time – calculation of service time (overall time – repair times) – conducting of functional analyses (branches, single server) – analysis of system parameters (applicable requirements & general conditions) – calculation of system load (technical processes having an influence from the outside, geometric conditions) – calculation of material flow indicators (capacity utilization, capacity reserves) – calculation of performance indicators (throughput, flow intensity, volume, speed) – calculation of maximum capacity – calculation of shipping time (supply time/loading time) – determination of the routes between the source and destination locations – transport optimization, route scheduling – optimization of empty running – increasing of loading capacity – calculation of traffic density – elimination of points of conflict – planning of transport system
(2)	Information flow:
	– definition of the flows and coordination with material flows – definition of measurement points in the information flow – selection of an information system (ERP system) – checking of the process for Kanban suitability – specification of logistics principles (e.g. supply, storage and picking principles) – selection of identification system – selection of suppliers and service providers – scheduling – setting up of simulation model and running simulation – planning and setting-up of information and energy flows – planning of the systems for data storage
(3)	Working cycle:
	– decision as to whether single cycles, dual cycles or multiple cycles will be implemented – calculation of the starting point for the conveying equipment's working cycle – duration calculation for individual and multiple cycles
(4)	Picking:
	– determination of the procedure used (man to goods, goods to man) – calculation of basic times for picking: → receipt of order and empty container → picking + handover of paperwork – calculation of travel times – calculation of sorting times – selection of picking procedure – determination of optimal number of lines for picking orders
(5)	Storage:
	– selection of basic principle – specification of storage sequence (e.g. FiFo, LiFo, etc.) – determination of storage organization – calculation of storage indicators (inflow, stock)

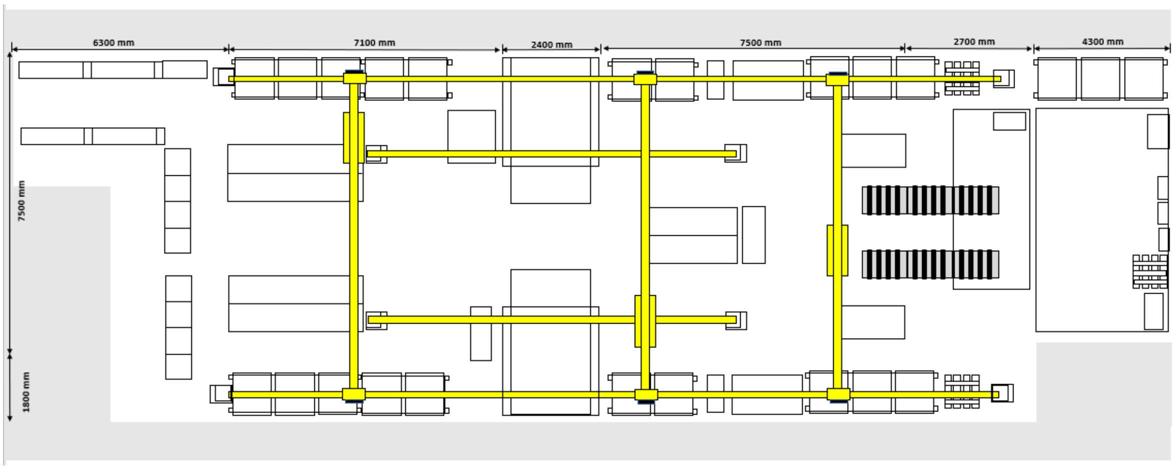
Logistics system	
(1)	Equipment/operating terminal:
	– determination/optimization of location – planning of machinery layout – calculation of flow intensity and throughput – checking of ground conditions (inside/outside; covered/open) for use of optimum conveying equipment – optimization of ground conditions (floor covering, ramps) – setting up of transfer points – planning of disposal
	– calculation of maximum capacity of equipment – calculation of amount of equipment required – calculation of the service rate of the control apparatus – dimensioning of waiting rooms – calculation of set-up times – calculation of average waiting time in the queue
(2)	Means of conveyance/transport
	– analysis of working cycle of conveying equipment – calculation of working cycle time → calculation of the time that the conveying equipment needs to collect and deliver an item → calculation of the duration of loaded and empty running – calculation of the time that the conveying equipment needs to reach full speed – calculation of conveying equipment's start-up and slow-down times – calculation of stopping distance of the conveying equipment – calculation of capacity of the conveying equipment – calculation of the amount of conveying equipment (e.g. in the case of shuttle connection) – trade off between route length, costs (capacity), amount and type of conveying equipment required (combined traffic) e.g. use of fork lift trucks + conveyor belt – calculation of amount of transport equipment required – selection of conveying equipment
(3)	Storage/Buffering:
	– where should the goods waiting to be transported by the conveying equipment be stored? – where will the goods be stored (buffered) in the interim? – division of the warehouse into storage areas – dimensioning of the warehouse – storage in high-rack warehouse: → calculation of the applicable movement time for each rack, calculation of selection cycle, determination of order of racks approached → determination of the size of store and the number of storage areas (capacity of the warehouse) – if necessary, dimensioning of interim storage areas – determination of optimal storage zoning – calculation of required buffer storage, dimension
(4)	Route:
	– calculation and optimization of route widths – calculation of route length and travel time – calculation of the route loading
(5)	Loading utilities:
	– calculation of the empty equipment to be provided – selection of utilities (for transport, storage, picking) – calculation of optimal loading unit
(6)	Overall solution:
	– calculation of maximum capacity of the entire system – parallel or series connection of operating controls – determination of location of goods inwards and goods outwards storage – verification of system reliability → determination of the availability of the internal transport system taking malfunction indicators into account → determination of the achievable operating times and delivery rate – calculation and optimization of reliability and availability of the system

Appendix D. Layout dimensions for HH8 and blank paper scenarios

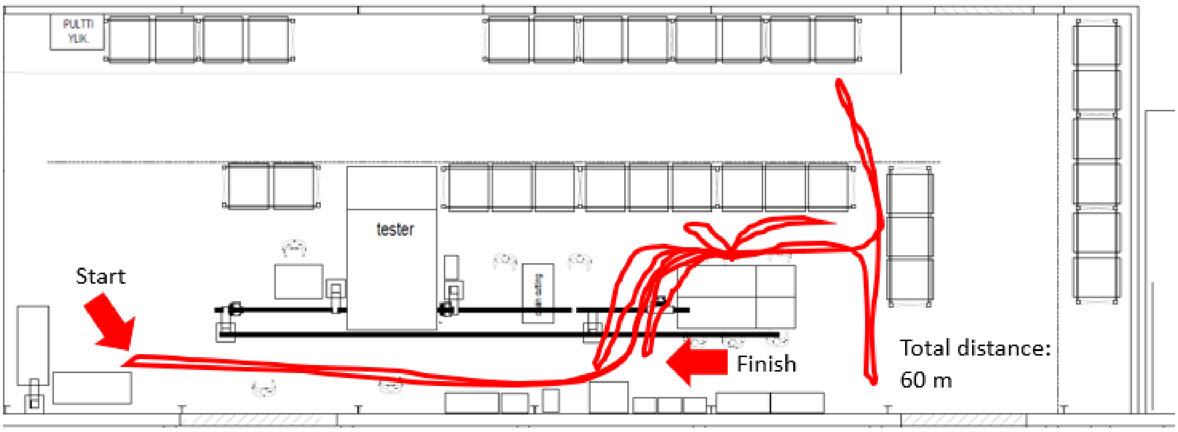


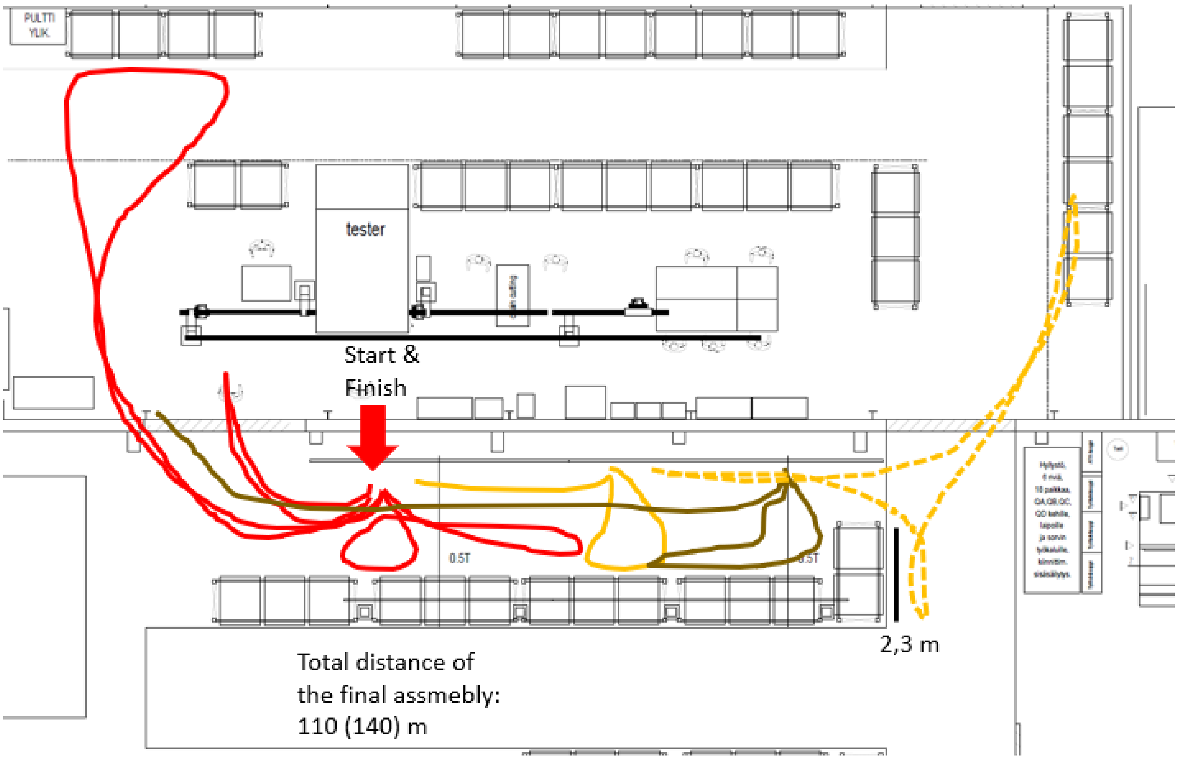


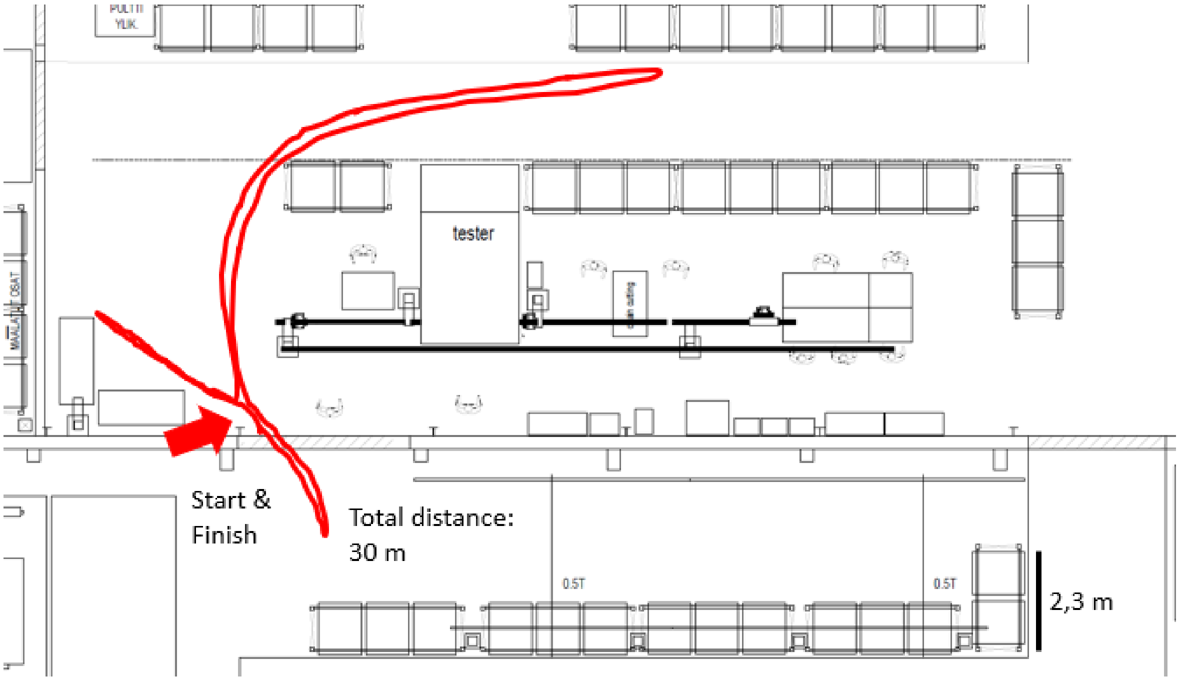

8500 mm
2400 mm
4600 mm
2300 mm
4300 mm
8400 mm


6300 mm
7100 mm
2400 mm
7500 mm
2700 mm
4300 mm
7500 mm
1800 mm

Appendix E. Assembler travel distances for assembly process steps in HH8






PULTTI
YLIK.
tester
OSAT
MAALAT
Start &
Finish
Total distance:
30 m
0.5T
0.5T
2,3 m

Appendix F. Assembler travel distances for assembly process steps in blank paper scenario 1