

Assembly station development by flow analysis and systematic layout planning

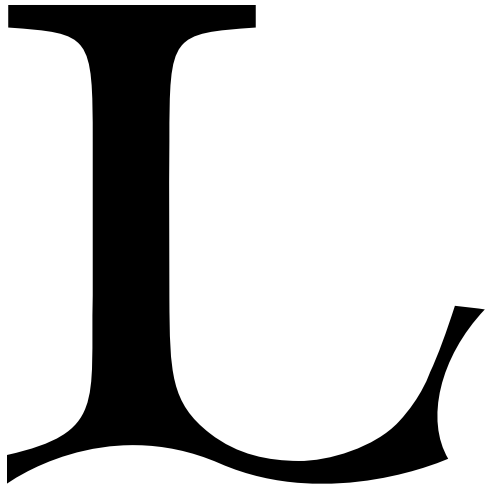
Mapping of the current state of production, evaluation of alternatives and development of concepts for improved flow and flexibility



Oskar Abrahamsson

Industrial Design Engineering, master's level
2021

Luleå University of Technology
Department of Social Sciences, Technology and Arts



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Oskar Abrahamsson

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SUPERVISOR: Therese Öhrling

EXAMINOR: Lena Abrahamsson

TEKNISK DESIGN – Industrial design engineering

Luleå University of Technology

Acknowledgement

I'm hopeful that this report will have a positive impact on the future development and the performance and work environment of the assembly stations. I would like to thank my supervisor Therese Öhring at LTU that provided well-structured guidance and answered my questions throughout the project. Further, this thesis would not have been possible without the help from my supervisor Anders Carlsson and the production workers/ development personnel at Modul System HH that gave me helpful insight, especially Jacob Alexandersson & Fredrik Liabäck.

Gothenburg, Sweden 2021

Oskar Abrahamsson

A handwritten signature in black ink, reading "Oskar Abrahamsson". The signature is written in a cursive style with a large, looping initial "O" and a long, horizontal flourish at the end.

Abstract

Modul system HH deliver modular storage systems and electrical solutions that can be combined according to the customer's wishes. This thesis combines argues for the importance for companies to keep improving their organization and production to remain competitive. By relating to a holistic view of the development of production environments, the project focuses on improvements for efficiency and social sustainability in the development of production. The project became relevant as the company has discovered difficulties in balancing production in the event of capacity changes and wants to develop rational flows and increase its flexibility.

The project is limited to exploring three assembly stations and the operations and flows that belong to the assembly. The project spiral's iterative 3-step development process was chosen for strategic planning. This methodology allowed the work to continue forward despite the lack of data. The first step deals with planning and processes where technology and users were examined. In this planning phase, a Gantt schedule was used in the ClickUp program to plan the project and to-do lists and deadlines could be set. A literature study was conducted to strengthen arguments and raise new ideas. The theoretical overview focuses on areas around production development with a focus on the development of layouts/assembly stations, psychosocial work environment and organizational management.

In the second phase of the project, requirements and wishes were mapped. This was done together with the company, the results from this step were then used to evaluate concepts before detailed development. The project also has several parts of the framework that Muther & Wheeler developed called Systematic layout planning. It provided the tools to understand important connections through relationships and proximity analysis. These methods were also used to evaluate the results. Interviews, observations, and 3D modelling were also performed in this phase to gather information and to understand different production structures. Semi-structured interviews were performed with product managers, production designers, production planners. From these methods, I was together with some employees able to conclude that customer order-driven product development is the focus. That production places demand on rapid implementations in production and that modularity means great flexibility needs and fast lead times. We also found opportunities to minimize repetitive and time-consuming steps through development based on the operator's point of view.

Concepts were developed through a development process based on proximity analysis, time studies and results from more subjective interviews. The concepts were then evaluated through an evaluation matrix based on formulated future requirements and wishes. The winning concept was developed in more detail and developed iteratively together with staff from the company. The final concept combines a new, more compact layout that considers proximity requirements between stations as well as flows of materials and operators. The final layout also introduces new types of material buffers and action proposals for improved collaboration and communication for increased flexibility.

KEYWORDS: Layout design, Flow analysis, Flexibility, Assembly design, Industrial Design Engineering, Human centred design.

Sammanfattning

Modul-system levererar modulbaserade förvarningssystem och elektriska lösningar som kan kombineras enligt kundens önskemål. Denna avhandling kombinerar argument för betydelsen av företag att förbättra sin organisation och produktion för att förbli konkurrenskraftiga. Genom att förhålla sig till en helhetssyn i utvecklingen av produktionsmiljöer riktar projektet riktar in sig på förbättringar för effektivitet och social hållbarhet i utvecklingen av en monteringsstation. Projektet blev aktuellt då företaget har upptäckt svårigheter kring balansering av produktion vid kapacitetsförändringar samt vill utveckla rationella flöden och öka sin flexibilitet.

Projektet är begränsat till att utforska 3 monteringsstationer och de operationer och flöden som tillhör monteringen. För en strategisk planering valdes projektspiralens iterativa utvecklingsprocess som låtit arbetet fortsätta framåt trots avsaknad av data. Första varvet behandlade planering och kartläggning där processer, teknik och användare granskades. I planeringsfasen användes ett Gantt schema i programmet ClickUp för att planera projektet, även to-do lists och deadlines kunde sättas in. En litteraturstudie utfördes även för att stärka argument och väcka nya idéer. Den teoretiska översikten har fokus på områden kring produktionsutveckling med särskilt fokus på utveckling av layouts/monteringsstationer, psykosocial arbetsmiljö och organisationsstyrning.

I projektets andra fas kartlades krav och önskemål tillsammans med företaget och dessa användes sedan för att utvärdera koncept i den sista fasen innan detaljutveckling. I projektet har även flera delar av ramverket som Muther & Wheeler tagit fram, systematisk layout planering gav verktygen för att förstå viktiga kopplingar genom relation och närhetsanalyser. Dessa metoder används också för att utvärdera resultatet. Intervjuer, observationer och modellering var också viktiga metoder för att samla information från olika produktionsområden och förstå sig på nuläget. Semistrukturerade intervjuer hölls med produktchefer, produktionsdesigners, produktionsplanerare. I denna kartläggning kunde jag tillsammans med företaget konstatera att kundorderstyrd produktutveckling har fokus, att produktionen ställer krav på snabba implementeringar i produktion och att molariteten innebär stora flexibilitetsbehov och snabba ledtider. Det fanns även möjlighet att minimera repetitiva och tidskrävande moment genom utveckling utifrån operatörernas förutsättningar.

Ett flertal koncept togs fram genom en utvecklingsprocess baserad på närhetsanalyser tillsammans med tidsstudier och resultatet från subjektiva analyser. Koncepten utvärderades sedan genom en utvärderingsmatris grundad i formulerade framtidskrav och önskemål. Det vinnande konceptet utvecklades mer detaljerat och utvecklades iterativt tillsammans med personal från företaget. Det slutgiltiga konceptet kombinerar en ny mer kompakt layout som betraktar närhetskrav mellan stationer samt flöden av material och operatörer. Layouten introducerar även nya typer av materialbuffrar och åtgärdsförslag för förbättrat samarbete och kommunikation för en ökad flexibilitetsförmåga.

NYCKELORD: Layout utveckling, Flödesanalys, Flexibilitet, Monteringsstation, Teknisk Design, Användarcentrerad design.

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1. Introduction

The manufacturing industry and technology sectors operate in variable and unpredictable environments and are facing challenges where flexibility and sustainability in production are crucial. This project addresses the need for businesses to improve their industrial management and production to remain competitive and sustainable. This thesis also argues for the importance of industrial engineers to have a holistic viewpoint in the development of well-functioning production environments. It accomplishes this by examining potential efficiency, organizational, and ergonomic improvements at an assembly station at Modul System HH AB in Gothenburg. This project is intended for a master's thesis and will be conducted during 2021 at the 20-week long spring term within the context of Industrial Design Engineering, master's in production design at Luleå Technical University.

1.1 Background

Modul System HH is a manufacturer and distributor of custom-made working van interiors, electrical systems, and other custom solutions, and is part of the Lifco-group. Their main office is in Mölndal, which is located just south of Gothenburg. Their products are sold in more than 50 countries around the world, and they have a global partner network. Their main products are manufactured in Mullsjö, which is located just outside of Jönköping. Their quality is guaranteed by ISO 9001 certification, and their manufacturing processes adhere to the European TÜV standard. Responsibility for production developments is delegated to a variety of manufacturing technicians, who can make decisions through a principally decentralized organization.

This project is centred around the creation of a new and improved layout with balanced operations, rational flows, and the possibility to change operator capacity. One core aspect of the background for the project is agility and flexibility in production. Kaschel et al. (2006) describe that this capability is becoming increasingly important as manufacturing systems operate in variable and unpredictable environments. Modul System HH has a large variety of different variants for every product and is operated by a customer-oriented product development strategy. This modularity in production together with many customer-specific orders have increased the need for product flexibility and change in operator capacity. Al-Zuheri (2013) mentions that there are many complexities in manual assembly systems, as systems are linked, interdependence results in consequences made on one unit depending on the actions made on other units at the same time. The number of variants a unit can assume is often larger and, therefore, there exists more uncertainty. Hence, Al-Zuheri describes that the optimization design process for manual assembly systems becomes complex.

They are currently working on streamlining the production environment to achieve a high degree of flexibility and short lead times. In their production development work, they primarily use Lean production tools to improve their production processes by minimizing waste, automating costly tasks and try to lower warehouse/buffer levels. These are all important factors in the development of their production and this project connects with many of these aspects together with the need to achieve good social sustainability. This is Important as Håkansson et al. (2017) describe that low perceived control over work could result in illness and stress reactions in studies regarding sustained lean transformation. They further state that standardized work and other kinds of practices aimed at optimizing flow, and continuous improvement practices appear to have had the most impact on workplace design.

1.2 Objective and aim

The objective is to use theory, analysis, and evaluation together with user participation to find effectivity deficiencies, physical or cognitive strain in production. Identified problems and evaluation results could potentially help with the development of solutions and recommendations to aid the completion of a new layout and contribute to future development.

The project aims to develop a conceptual assembly station that meets requirements and connects to modern theories surrounding production development. The developed concept should provide ideas regarding better product flexibility, possibilities for the alteration of personnel and help with the elimination of waste. To help with a structured approach and a clear mission several research questions for the project were formulated:

- Which aspects are contributing to production losses in the current station's layout planning?
- How can the assembly station layout be developed to help streamline the production?
- How can the working environment be developed to promote social sustainability?

1.3 Project scope & Stakeholders

The project is limited to exploring one assembly station, its layout, flows and product families. Possible concepts must be developed to fit into this assembly station area in the manufacturing plant. The products assembled here belong to the main categories of drawers & lockers which belongs to Modul Systems' products for modular workstations. Only the internal subsystems regarding these three product families are to be analysed and evaluated. Important stakeholders in the project are the production development personnel, product developers and workers at the assembly station.

2. Context

The company provides a wide range of products built from modules, allowing customers to choose from a variety of configurations. Management believes that they have an efficient production in Mullsjö because they have mobile employees who are well-versed in various elements and stations. They can assign personnel to workplaces where additional capacity is required. Despite having a departmental affiliation in production, some employees have knowledge of multiple areas and can thus vary their work tasks and learn on the job. Information is mainly transferred through team leaders responsible for different stations. They use daily production meetings for the steering of production. In these meetings, they discuss several important key performance indicators for the company as well as safety and work environment concerns. From the interviews, I gathered that they believe that the efficiency of the station itself is at a stable level. Production planners and designers believe that it can certainly be improved.

2.1 Product description

The analysed area includes four assembly lines for three main products in many different configurations included in the Modul System HHs standardized range. These products consist of metal drawers, extra-long metal boxes and lockers and all are intended for working van interiors. Modul-System HH (2021) describes that the products are modular and can easily be combined with other products in the range. The drawers are fully extendable and equipped with pull-out stops and are operated by roller bearing rails. In Figure 1 the modular storage system in a van is shown and drawers/ lockers are presented to the right.

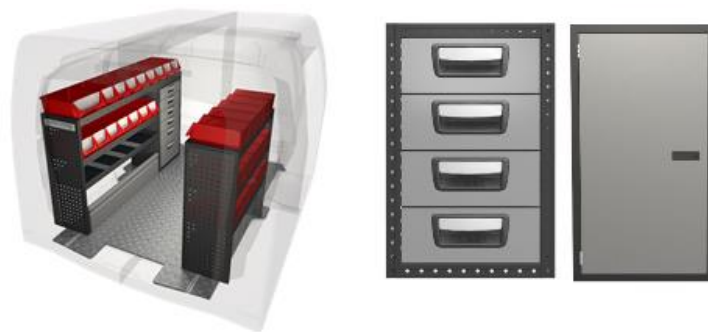


Figure 1. Modular storage systems/ Drawers and lockers. Modul System (2021)

2.2 Assembly station layout

Figure 2 depicts the current state layout, in which storage areas are yellow, operations are green, and transportation and waste management are grey. Operations that are automated to some degrees are marked out with a red robot symbol and the assembly personnel's workstations are marked with a worker icon. The assembly station area spans roughly 432 square meters which are calculated from an estimated 18-meter depth and 24-meter width after discussion with production developers. Every station gets components and materials from several different storage areas spread out near the operations and the materials and products are to a large degree moved by operators within the station, with the help of conveyors. The storage areas are placed so that they can be replenished from below and from the left side that is connected to the warehouse. The material flow of painted frames and doors into the station comes from the suspended transport cable called the "paint line" seen on the bottom right in figure 2.

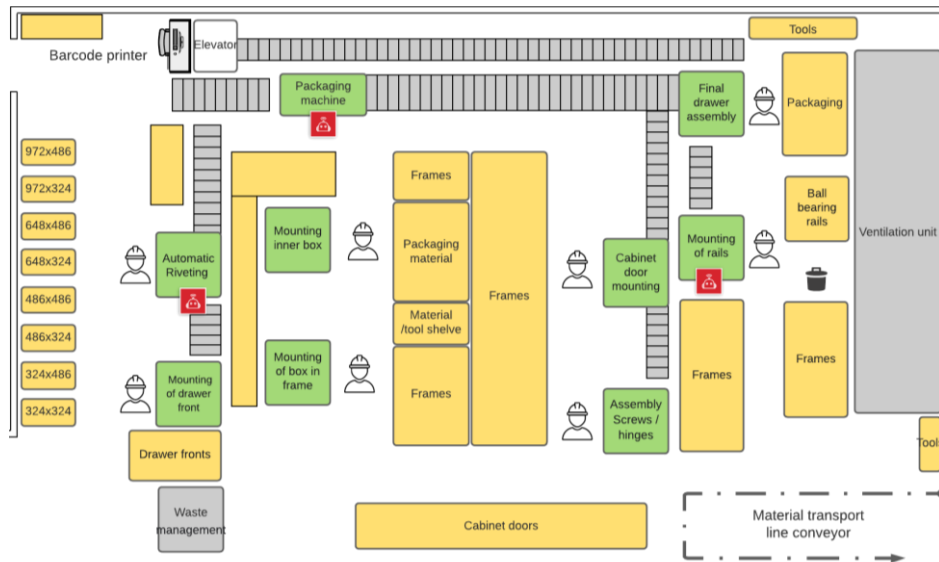


Figure 2. Current layout for Boxes, Drawers, and lockers.

Figure 3 depicts the different areas for the four main assembly lines. Three of them (1,3,4) could be considered flow-groups constructed as smaller assembly lines with a sporadic flow of material and manual transport. All assembly stations are placed in a process-oriented manner with conveyor belts connecting the material flows between the dependent stations 1 and 4. However, the company has decided to move the assembly of long metal boxes (station 2) to another part of the factory.

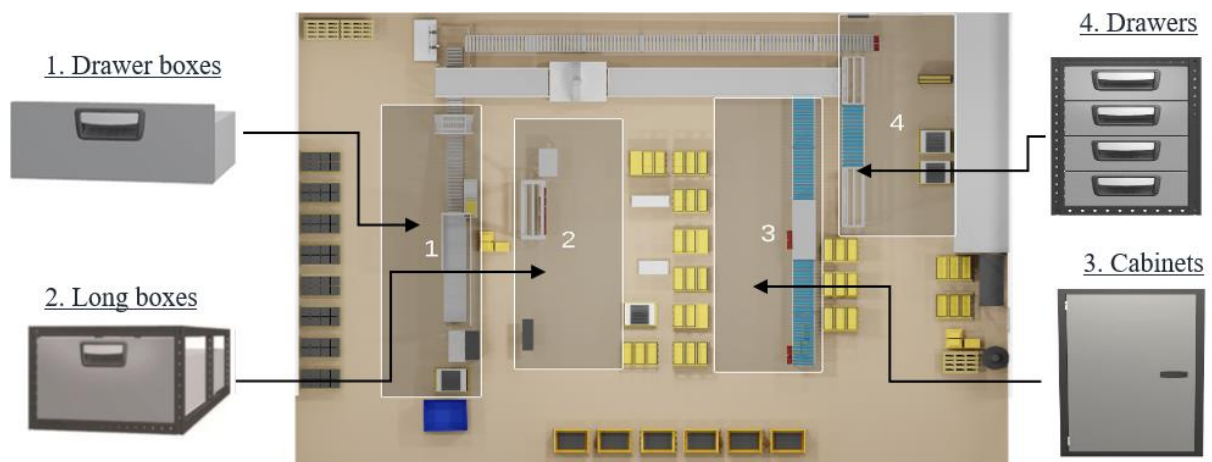


Figure 3. The four main assembly lines/stations (1-4)

Station one is dedicated to the assembly of drawer boxes, which come in four different standardized widths and three heights (as shown in figure 3). The lines are made up of high adjustable assembly tables with material supply access in the front, back, and to the right. Workers use this table to mount roller bearings and prep the drawers for riveting. It is important that the workers send the correct drawer boxes as the components are later fitted in specific drawers. The different configurations are determined by the production planning system which is connected to a PLC. The drawer boxes are automatically riveted in the caged riveting machine. This machine does require worker input of material. After the boxes are riveted, they are quality controlled by the worker before they are sent off on the conveyor belt to a material elevator. The elevator lifts the material onto another mechanical conveyor belt that sends the boxes to station four.



Figure 4. Current state drawer box assembly line (Station 1)

Station three is dedicated to the assembly of metal lockers and is constructed from an assembly table and manual conveyors. Materials such as fasteners and packaging materials are near working stations in red boxes as seen in figure 5. The station is fully manual and requires workers to perform every action. There are a lot of smaller assembly steps at this station and workers were seen assembling several items simultaneously to save time from unnecessary movement.

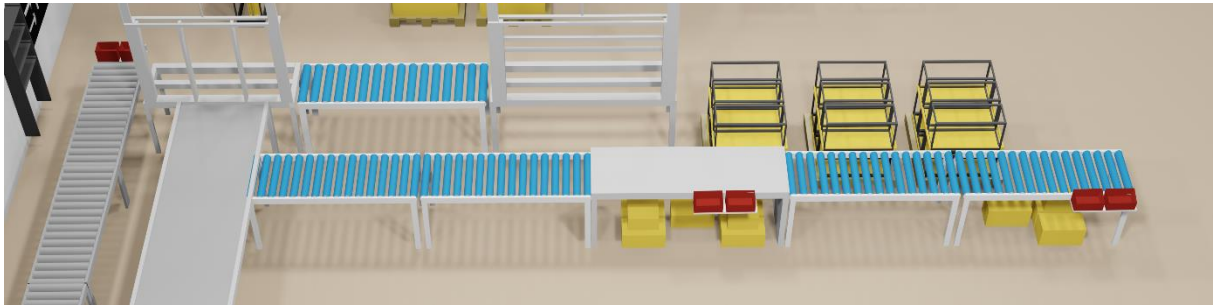


Figure 5. Current state locker assembly line (Station 3)

Station four is dedicated to the assembly of drawers and consists of two high adjustable workstations together with a roller conveyor to move the products through the operations. This station is mostly manual except for a PLC- controlled pneumatic cylinder aid system on the first station seen to the left in figure 6. This system correlates with the drawer box assembly station and is controlled by the production planning system and ensures correct mounting of roller bearings to fit the ordered drawer. A quite larger buffer of ball bearings is stationed at the drawer mounting station which is sufficient for several day's needs. To minimize unnecessary movement this station has stationery boxes for bolts and washers, and it has a trolley to act as a buffer for components.

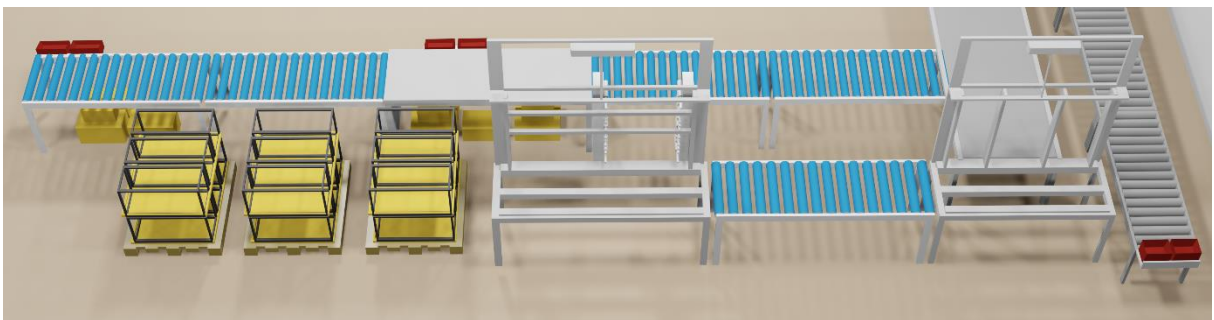


Figure 6. Current state drawer assembly line (Station 4)

The mounting of boxes in drawer cages is completed on the second table in the process. The boxes are transported by conveyor belt from the drawer mounting station, where the operator inserts a screw in the front of the drawer before installing it. The conveyor belt from station 1 is used as a buffer, and they calculated that it should be at least 4 meters long to meet the current buffer demands. Aside from frames, the station is reliant on packaging, screws, and washers, as well as the correct type of box sent in from station.

3. Theory

The theory chapter focuses on areas surrounding production development with a particular focus on assembly stations and surrounding organisational management. Popular management theories and their impacts are also included with a focus on Lean production as methods from this strategy are used within the company today. It combines theories surrounding organisational and social factors, ergonomics, and human-centred design to contribute to creating attractive industrial production environments. By combining literature from these research areas, this overview will provide ideas and possibilities to improve the long-term work and health of the occupational group. Furthermore, theories regarding evaluation and analysis of production systems from a more rationalistic perspective are also of importance for reaching goals regarding efficiency, production balancing and flexibility.

3.1 Industrial design engineering (IDE)

Djokikj (2013) describes Industrial design engineering as a discipline aimed at connecting the link between industrial design and design engineering. It combines related disciplines within both practical skills and scientific evaluation to improve or change products, systems, or environments. The field aims at looking at things in a way that tries to understand how it should be and not how it currently is. It follows a human/user centric perspective and mindset in the development of innovative and sustainable ideas. Felin & Foss (2005) argue that organizations are made up of individuals, and that an approach, which lacks the individual, is fundamentally problematic. Osvalder and Ulfvengren (2015) describes that technology systems that are developed must have good user-friendliness and the basis for development should lead to increased efficiency, safety, and an improved working environment. IDE within the fields of production and organizational development focuses in these areas using theories from production development, logistics, ergonomics, and human factors with the goal of advancing sociotechnical systems. One main principle of IDE is the usage and highlighted importance of participatory design where stakeholders/users are involved in the process. The combination of rational and subjective/ more participatory methods should in theory provide a wider understanding of the overall system. In turn, this way of working could result in important aspects not being overlooked when evaluating the layout, processes, and social aspects.

3.2 Organization of industrial production

When developing a production environment, it is important to consider that different company ideals regarding production and organisation are in continual interaction with a surrounding external context. Changes in societal norms and values lead to change and modification of management. By looking from a normative perspective, new organisational models are directed and marketed. Røvik (1996) describes these models as prescriptions for specific problems that industries are facing. Abrahamsson & Johansson (2013) describe that there is a consensus concerning arguments in favour of improvements to the work environment and the socio-economic viewpoint. To reach attractive & socially sustainable workplaces, Abrahamsson et al. (2019) define three essential aspects of organisations for most individuals: belonging, communication and influence. Abrahamsson & Johansson describes that a socially sustainable working environment suits individual aspects, both physical and psychological, regarding workloads and that production design strongly relates to the balancing of demands and challenges at a reasonable level.

Bohgard et al. (2015) describe that it is crucial in the management and development of work organizations and processes that employees' working conditions and the promotion of health in working life are considered. This is to avoid relationships between the individual and the environment that are stressful and cause alarm reactions in employees. Possible problems are related to many aspects of industrial production, like skills, tools, social support, time, and opportunities for recovery. Abrahamsson (2000) presents that a better working environment gives a workplace higher status from external perspectives and personnel show more interest and motivation for their work, resulting in a more flexible organisation. Abrahamsson says that the most efficient way of optimising the production

and thus the competitiveness of a company is to foster co-operation between man and machine and production technology and work organisation. Abrahamsson & Johansson (2013) say that even if it is difficult to estimate an organization's monetary or productivity value, there are solid indications that an organization with a good psychosocial work environment function better, is easier to develop, and provides better opportunities for flexibility and cooperation.

3.3 Development of production systems.

Garza-Reyes et al. (2014) state that manufacturing organisations worldwide are under immense pressure from a contemporary market to pursue operational excellence and improve their performance to reduce their costs and provide products of higher quality in shorter lead times. Giannakis & Louis (2016) brings up a similar point that the growing need for customised products and services in many industries has made modern global supply chains more complex than ever before. Ejsmont et al. (2020) say that customers are used to receiving products and services specially tailored to their needs together, resulting in a growing number of products in portfolios which influence the increase in the complexity of the production. Lindskog et al. (2016) explain that the design process of production systems is complex with many different aspects to consider for developing and installing an effective system. Aspects can be strategic, technical, and economical as well as others related to environmental and social aspects.

The integration of these main activities is critical in the many different approaches to addressing these aspects of production development. Abrahamsson & Johansson (2013) say that workplace development should make work easier for employees and that it is important to include them in the process to make them feel included and gain a sense of participation and influence.

Main engineering tasks can be divided into two areas: "Production and process planning for the manufacturing of products" and "Facility planning and activities to design or modify the production". Important success factors during the design process are typically the ability to identify and manage risks, develop plans, and solve problems regarding material flows, material handling, workstation design & maintenance (Lindskog et al, 2016).

3.3.1 Measures of operational performance

Bellgran & Säfsen (2005) presents that the goal for companies in a highly competitive market is profitability, good return on investment and high productivity. There are many contexts where a good representation of a system's performance is needed to reach demands and set up goals. Jonsson & Mattsson (2016) describe that it is not enough to just create an efficient production and organization. To create competitiveness, it is important that you give the highest priority to the right logistics variables for your industry. They say that there is no reason to provide something that is not requested by the customer. To decide what to have and how it should be implemented, it is important to integrate the logistics strategy within the organization.

3.3.2 Flexibility & agility of production

Ferreira et.al. (2020) describe that flexibility is the ability for manufacture systems and supply chains to adapt to changing requirements with minimum time and effort. Kaschel et al. describe that the concept of flexibility can be divided. *Process flexibility* is the ability of an industrial process to operate under dynamic operating conditions and changes in customer requirements. Jonsson & Mattsson (2016) describe that it is controlled by delivery times, lead times, changeover times and production series. Kaschel et al. (2006) describe that *product flexibility* is the variety of factory options for a certain product. Jonsson & Mattsson relates it to the company's ability to quickly adapt production and material flow to demand shifts between product variants with existing capacity.

Tukamuhabwa et al. (2015) describe that supply chain agility is mainly related to responsiveness and speed to respond to changes. It is the capability of systems to be agile and to respond to unexpected or unplanned events quickly. Agility is mainly composed of two attributes: visibility and velocity. Visibility refers to the ability to see through the entire supply chain and velocity focuses on the pace of flexible adaptations and readjustments of a supply chain (Ferreira et.al., 2020, Tukamuhabwa et al., 2015).

3.3.3 Bottlenecks

Wang et al. (2005) describe that the performance of a production system is affected by the resources available. Usually, the limitation of a system can be traced to the limitation of some kinds of resources, commonly called bottlenecks. To improve the performance of the system, it is necessary to improve the bottlenecks by adjusting system parameters iteratively until application demands are satisfied. Wang et.al. mentions that many factors could be considered bottlenecks and that there is still no commonly accepted definition or detection technique. They range from machine capacity to the number of operators and, due to the diversity of the bottlenecks in different application scenarios, it brings difficulties in applying theoretical results to real applications. They describe two primary categories: *performance in processing* (PIP) and *sensitivity-based definitions*. PIP focuses on real-time performance of the system and the latter on potential improvements. From a PIP perspective, the measuring of average waiting time and average utilization are important measurements for identifying bottlenecks. Stations with the longest idle waiting times or highest busy/idle ratio are considered as the bottleneck. From a sensitivity-based perspective, Wang et.al. describes that a bottleneck can be located by looking at which operation mostly affects the overall system throughput and looking at the sensitivity of the operation regarding performance.

3.3.4 Production layout and processes

Shingo (1997) argues that when making efforts to make production more efficient, you must first try to understand and improve the production flows before trying to improve the operations. When designing a manufacturing layout, Phillips (1997) describes that a continuous, ongoing improvement plan for production processes, materials handling, and plant layout is essential to achieving an advantage.

Philips describes that equipment and systems planning must be integrated with the manufacturing process- and layout planning. Philips also describes that product versus quantity charts can help to decide on the most efficient types of production method and that product focus is the key determinant of production system type, see figure 7. High quantity, low variety products call for dedicated equipment in a product-focused layout, whilst low quantity, high variety products require a more flexible, process-focused layout. He argues that flexibility objectives must be clearly stated because flexibility should always be incorporated into the layout design if production efficiency remains stable.

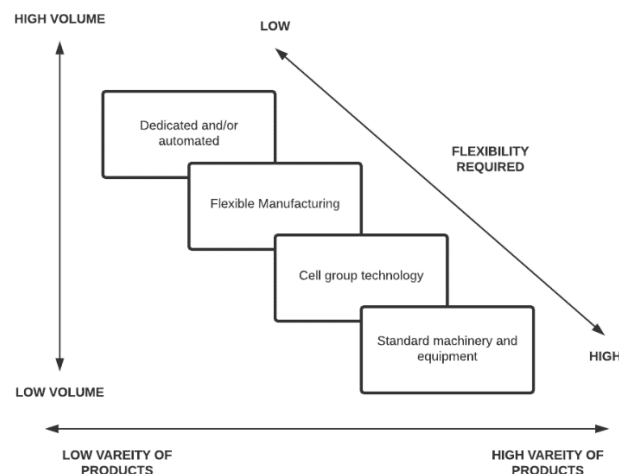


Figure 7. Recreated picture: Product/Quantity Chart (Phillips, 1997)

Al-Zuheri (2013) describes that the socio-technical nature of manual assembly systems and the assemblage of many system variables like tooling, operators, and material-handling contribute to the complex nature of the system. He describes that despite the trend towards the increasing implementation of automated systems, there is still a justifiable need for manual assembly. Manual assembly systems enable manufacturing companies to respond quickly as humans are more flexible than machines and the human mind possesses creative and intuitive functions. Al-Zuheri presents the content in Figure 8 and describes the performance of assembly system types. He describes that increased automation leads to productivity increases but it also sharply decreases product flexibility. Based on this, he argues that the output rate of manual systems is dependent on several factors, e.g., ergonomics, layout, and workspace.

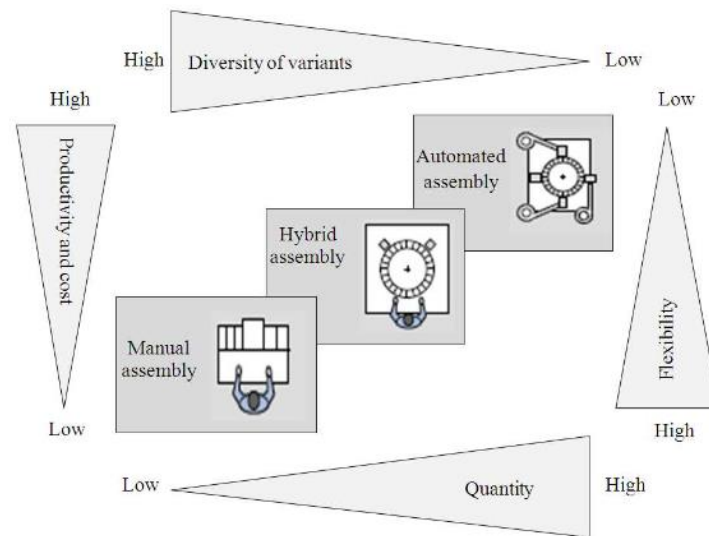


Figure 8. Assembly based on variants, productivity, quantity and flexibility, Al-Zuheri (2013)

3.3.5 Production structure

Phillips says that splitting or combining operations can offer paybacks for many companies. Jonsson & Mattsson (2016) describes two main production dimensioning aspects, singular or parallel structure. A singular structure has enough capacity to meet demand on its own. This structure enables easier automation and can decrease unit production costs. They describe that from a logistic and flexibility perspective, a parallel structure could pose a lower disturbance sensitivity in material flows and poses flexibility advantages as it enables easier systematic capacity changes. Neumann & Winkel (2005) say that the trend in Sweden today is towards more serial organized production. They mention that parallel systems have the potential for higher effectiveness, but sometimes it appears that this is difficult to achieve, thus, a serial flow is generally chosen. Phillips mentions that another possible improvement is the implementation of a U-shaped layout which allows workers to leave their positions to help each other to catch up. This, together with temporary internal buffers, he argues, will increase overall production levels.

Bellgran & Säfsen (2002, chapter 7) describes that the manufacturing of frequently updated products places demands on reconfigurability when designing sustainable production systems. It is not economically justifiable to develop new systems for every product generation. A system could have a chance to meet these demands by using standardized and modularized design principles. Bellgran & Säfsen mentions that modularity is also a used tool to increase flexibility as these modules can be used to increase capacity in bottlenecks, lower disturbance sensitivity and allow for fast adjustments.

3.3.6 Production planning

Philips (1997) describes that one of the determining factors for a manufacturing layout is based on whether the company uses a scheduled-push or a demand-pull manufacturing planning. *Scheduled push* production systems fluctuate based on demand and inventory levels and can be changed to manage seasonal fluctuations or to hit predetermined targets. Systems with this tactic favour traditional batch-oriented process layouts where inventories are used to help level factory load. Philips further describes that a *demand-pull system* is set to produce only that amount of product that has been ordered. The philosophy aims to minimize inventories. The system favours a JIT- approach and single part flow in a manufacturing cell type layout.

3.3.7 Layout planning & Material handling

A plant layout based on relationships tend to focus heavily (sometimes too heavily) on materials transport handling. In the final analysis, material handling costs, cycle time, the elimination of storage queues and minimizing of no value-added activities are the prime factors in optimizing layouts. He also argues that production expansion is important to consider operations that will need a large expansion area should never be placed in the centre of a plant. Activities that probably will expand must be placed where expansion is possible (Philips, 1997).

Jonsson & Mattsson (2016) describes that when planning the balancing of capacity in production, you should plan for higher capacity at stations later in the production chain to minimize disturbances in material flows. This relates to the effects of variation and unpredictably in production, time variation from manual stations sends disturbances down the production line which creates temporary capacity waste, especially in assembly line structures.

A factory layout should be planned in a way that enables material flows and prevents intersecting material flows, which results in a short direct transport, material flow-oriented layout. The arrangement of recourses could benefit from having the material flow in the value stream as the foundation for a flow-oriented layout (Lindskog et al., 2016). Philips (1997) say that the reduction of labour costs related to material handling and minimizing overhead, and factory costs strongly contribute to low total costs and prices and that you should always plan for straight running aisles without turns.

Inventory management is an important part of material handling, one strategy that can be implemented when larger flexibility is needed is supermarkets. Supermarkets are described by MudaMasters (n.d.) as a method for managing inventory without knowing the order of parts needed as in other pull strategies like FIFO or one piece flow. A supermarket consists of multiple parallel FIFO lanes where parts are stored by type. When parts are used information is sent back in the value stream to replenish the used parts with two-bin or Kanban card systems.

3.4 Assembly station design and performance

Huang et al (2002) presents the building block of a manufacturing system as a unit production process (UPP) and that a factory can be decomposed into combinations of these processes. Boysen et al. (2007) describe an assembly line of workstations arranged along a conveyor belt or a similar mechanical material handling device. A set of operations is performed repeatedly on any workpiece which enters a station, whereby the period between two entries is referred to as cycle time. It can also be the time between two products coming of the line. The total amount of work necessary to assemble a workpiece is split up into a set of operations named *tasks* that each are associated with a *processing-or task time* and the cumulated task time is called *station time*. Station task times could be smaller than the cycle time, which results in a station having idle time each cycle. To ensure high productivity, a good balance should have as few idle times as possible (Boysen et al., 2007).

3.4.1 Positive factors for assembly systems

Bellgran and Säfssten argue that there are almost as many descriptions of a good production systems as there are production companies, answers are dependent on experience, viewpoint, and personal opinions. Säfssten and Aresu (2000) mapped characteristics of well-functioning production systems and split the results into technical and social aspects of production, see Table 1. The results are in correlation with the general description of productivity and are dependent on several fundamental conditions for the following characteristics to function. The following technical properties are reliant on functioning system and material suppliers, good product modularisation, assembly layout, and product design. Social properties are reliant on functioning work methods and descriptions, competence development, group organization and good division of responsibilities between teams.

Table 1. Positive assembly line properties (Säfssten & Aresu, 2000).

Technical assembly station properties	Possible results
Modularized production	Higher product and process flexibility.
Fast adjustments	
Reconstruction flexibility	Better delivery security and reliability.
Standardized systems	
Cooperation between functions	Competitiveness regarding prices/quality.
Flow/capacity balance	
Connected and efficient flows	Effective assembly, shorter cycle times
Minimal material handling	
Low disturbance sensitivity	Higher quality built into products
Correct balance for subsystems	
Social assembly station properties	Possible results
Ease of use	Workplace motivation, stimulation, and learning.
Visibility	
Cleanness	Consideration of human limitations
Variation in tasks	
Self-control	Social sustainability and healthy workforce
Responsibility	
Capacity flexibility	Good human machine interaction
Good ergonomics	
Good organization	

3.4.2 Assembly line balancing (ABL)

Phillips argues that standard processing or operation times must be known to perform assembly line balancing. He argues that many planners try to avoid the use of buffers, but that in practice, temporary buffers can be very useful to optimise a system's performance. Boysen et al. (2007) describes that an ALB problem is part of the optimization part of production and involves assigning assembly tasks among stations in such a way that each station takes equal time. Paksoy et al. (2012) argues that according to assembly line managers, the most important goals related to assembly line balancing are the minimization of the number of workstations and the lowering of cycle times. If the stations are not constant and given that the situation can change and become complex in some assemblers that deal with a supply chain network. When making decisions, supply chain activities must be considered, and when balancing assembly lines, these two major issues are completely intertwined (Paksoy et al., 2012).

Qattawi & Chalil Madathil (2019) describe that ABL is often done from a mathematical perspective with the assumption that the design can be changed or altered based on the optimization results. They describe that there are a high number of constraints regarding fixed design elements that often lead to optimization results that are not valid, reducing the solution space, and leading to unsolved problems. Furthermore, the introduction of specialized products with variations in tasks can shift the line balance and affect the production takt time. This variability requires a rebalancing every time a new part or family of parts is introduced into the system and Qattawi & Chalil Madathil say that this design challenge is persistent when the demand for new product families is low. Talapatra et al. (2019) argue that a company must manage the production line well and distribute workload over different workstations to obtain the maximum production line performance or efficiency.

3.5 Lean production

The company uses some Lean practices in their development process as the modularity of their production in combination with a customer-oriented product development places high demands on fast lead times and small warehouse levels. Lean production is a philosophy or a production development methodology to design effective production systems by introducing a number of production principles that largely builds on the Toyota production system or TPS (Sederblad, 2013). TPS philosophy was developed over several decades and was originally an organizational model for flexibility in mass production most famously developed by Taiichi Ohno and Shigeo Shingo (Bohgard et al., 2015). The system design ensures that the required production capacity is met and deals with customer demand regarding: takt time, continuous flow, material supply, and production planning and control (Lindskog et al., 2016).

Lean production focuses on continuously improving the processes and eliminating all non-value adding activities and reducing waste within an organization. It is as an integrated activity in SCM designed to achieve high-volume flexible production using minimal inventories of raw materials and describe that there is a strong association between lean production, product quality, and business performance (Agus & Hajinoos 2012). Waste is describes by Bohgard et al. (2015) as the heart of Lean production, waste does not contribute to value for the customer and should thereby be eliminated. They describe that it is everyone's responsibility to continuously observe and contribute to the minimization of waste in the organisation. Womack & Jones (1996) claim that Lean ideas are the single most powerful tool available for creating value and eliminating waste referring to former Toyota executive "Taiichi Ohno" who identified seven types of waste: Transportation, Inventory, Motion, Waiting, Over-Processing, Over-Production, & Defects

Garza-Reyes et al. (2014) states that evidence suggests that lean methods and tools have helped manufacturing organisations to improve their operations and processes. Bohgard et al. (2015) describes that Lean production mainly correspond with manufacturing industries where work tasks are repetitive, have short cycle times, detail oriented and standardized. Valamede & Akkari (2020) describe the main tools for Lean as JIT, Kanban, Poka-Yoke, VSM, Kaizen, & TPM. Agus & Hajinoor (2012) describes

that Lean production introduced a way of thinking that includes the integration of vision, culture, and strategy to serve the customer. It focuses on using the least amount of effort, energy, equipment, time, facility space, materials, and capital while giving customers what they want. Womack & Jones presents the expanded Lean thinking philosophy as five core principles identified as:

Identification of value. Value is defined by the customer and lean focuses on eliminating waste in the production process and increasing the flow of activities that increase the value of the product from a customer's viewpoint.

Optimizing the Value stream. Mapping actions needed to bring a product to the customer and sorting them into three main categories: Add value, add no value but are currently necessary, and those that add no value and can be eliminated.

Generation of smooth flows. It means optimizing value adding steps and balancing production, the first step is to focus on the product then the second step focuses on removing boundaries and thirdly to rethink work practices to eliminate waste in the form of backflow, scrap and stops.

Let the customer pull the production. Means that anyone upstream in production should not produce anything until it is needed, and when it is needed you need to make it fast. Agus & Hajinoor (2012) describes it as synchronizing customer demand and information flow.

Pursue Perfection. There is no end to the process of continuous improvement, the “peruse perfection attitude” should start with a policy or vision of the ideal process. By understanding the main principles, you should stepwise try and reach goals and create projects to get there.

3.6 Human centred production system design

Neumann & Winkel (2005) describe that there is often a lack of tools for both predicting and solving ergonomic problems during the design phase, leading to disorders in some forms are solved reactively. There is a need for those that design the systems to work with significant improvements proactively, to integrate ergonomics into every phase in the design of a system. Hitchcock et al. (2004) argue that integration of ergonomics in the design process helps minimise the risk of musculoskeletal injury when importance factors other than equipment design, such as task design and training. If the design process advanced without sufficient ergonomics or user involvement, usability and safety could be compromised. It is essential that ergonomic aspects are clearly communicated in the development to benefit from the ergonomic contribution of minimising risks and optimising performance.

3.6.1 Effects of production system rationalization

Håkansson et al. say that there is an ongoing debate among researchers and practitioners on how lean practises affects employees, their work characteristics, and, specifically, their workload and control over their tasks. They say that studies of how lean production's effect working conditions are mixed but point toward worsened conditions. Nordic companies that often implement a more hybrid version of lean with stronger sociotechnical ingredients could affect the result positively compared with global studies due to a more sustainable transformation of work tasks. Abrahamsson & Johansson (2013) describe that Lean production methodology can result in employee health and well-being can be compromised and that there is a risk of reduced motivation and reduced opportunities for learning. This depends on the number of short-cycle and repetitive work tasks resulting in monotonous work with uneven physical loads. They mention that a focus on order and standardization means that workers' autonomy and the extent to which they make their own decisions are significantly reduced.

Håkansson et al. describe that on task level, skilled and diverse jobs, in combination with the participative lean approach, seem to have contributed to shaping sustainable conditions. Westgaard & Winkel (2011) say that worker participation, resonant management style, information, support, group autonomy were modifiers with a favourable influence on sustainable production systems. They conclude

that production system rationalization represents a pervasive work-life intervention without a primary occupational health focus. It has a considerable and mostly negative influence on worker health, but this can be reduced by attention to stated modifiers.

3.6.2 Physical ergonomics and environmental factors

Hägg et al. (2015, chapter 4) describe how the design of the workplace and the worker's body dimensions determine which body position is assumed at work. The muscle force that is possible to develop at a certain work step is often more dependent on the body position the person in question assumes over the individual ability to develop the force. If you work for too long with a bad posture, there is a risk that you expose muscle groups to an unwanted static load or handling at harmful angles.

Swedish Work Environment Authority (AFS, 2012: 2) mentions that in general, strenuous work when turning the torso, fast or heavy lifting should be minimized when working with workplace design. They mention influencing factors in manual handling, physical exertion, work environment that can pose a risk of injury. Load properties is also important and (AFS, 2012: 2) mention that load properties need to be taken into consideration. Avoid situations where the load is too heavy or too large, is difficult to grasp or is placed in a way that requires workers to handle it away from the body. They present guidelines for system design properties regarding body postures that can help minimize injury:

- Offer variation in posture
- Avoid inclined working positions
- Keep upper arms close to the body
- Avoid twisted or asymmetrical positions
- Avoid keeping joints in the outer position
- Correct positioning for heavy lifting

Furthermore, loads don't have to be heavy to pose significant risks, Bohgard et al. (2015, chapter 4) describes static load as a lasting continuous load without possibilities for variation of tasks or work positions. They describe that repetitive work with low load gives rise to a working procedure without complete muscle relaxation which can lead to damage in tendons and fibres by prolonged static work.

AFS (2005:16) describes that within industry settings noise levels could potentially lead to unwanted strain and stressors, thereforen the employer must examine the working conditions and assess the risks due to exposure to noise at work. The daily noise exposure level LEX, 8h [dB] must not go above limit values for noise regarding hearing damage risk at 85[dB].

4. Method

4.1 Project process

To conduct strategic planning throughout the project I will mainly use the method “project spiral” that Bohgard et al. (2015) summarizes in the chapter “Development processes”, see figure 9. It is a planning methodology that is centred around an iterative work arrangement. The spiral consists of repeated planning laps where the emphasis of the work is shifted forward.

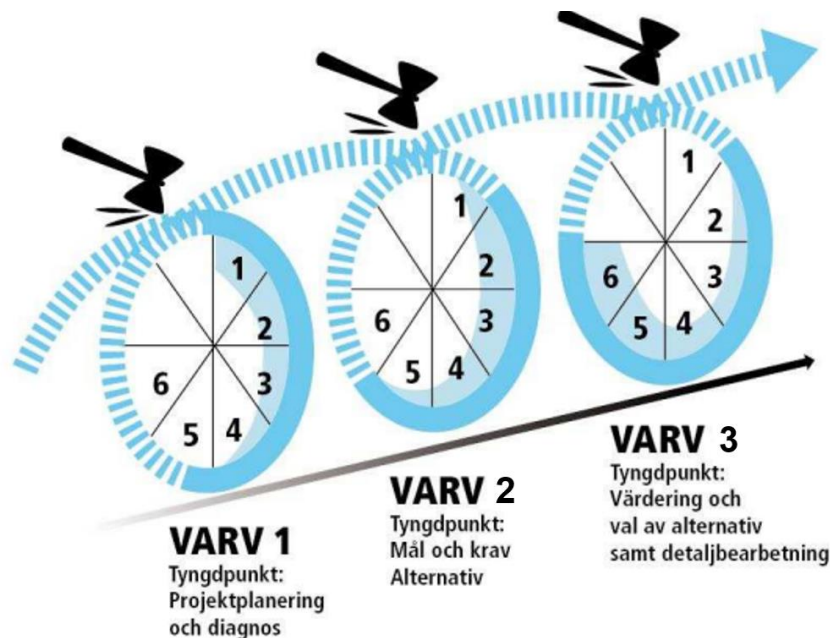


Figure 9. Project spiral (Prevent, 1995)

Round one had a focus on project planning and diagnosis with the goal of mapping and analysing the needs in current and future state. The current state evaluation focused on empirical data collection and developed the foundation for the project. Its main application is to find and formulate problematic areas where there exists a potential for further development. The current state analysis focused on areas that are essential for the sustainable development of the production in the existing facility and the company's future state. The goal was to understand the companies long term development requirements and business plans. This was done by mapping and analysing the production processes, production planning, area requirements, workplace design and its work environment. This step also included looking at the different types of machines and equipment at the station to be able to locate existing bottlenecks and flexibility problems in the assembly station. I need to answer the following central aspects:

- The functions and tasks the system is performing and going to perform?
- How are things operated today and which technical solutions exist?
- How does the users interact with and think about the system?
- Are there any regulations, demands or guidelines for future solutions?

Round two had an emphasis on requirements and the framework for the development of different concepts. Central aspects of this development phase are identification of demands, continue to map the current system and gain better understanding of functions and usability. When the needs were identified these were combined these with the results from the data collection and formulated problems to perform a problem analysis. This analysis worked through formulated problems and mapped out what needs to be done to improve/ fix the problems. Demands are then summarized in a specification of requirements that determines what the system should be able to do regarding the following requirements:

- Work environmental-, functional-, and production requirements.

When the performance requirements were mapped, the conceptual development phase began. This was a more creative part and contained most of the ideation work. Creative methods were used to generate ideas that are supposed to meet requirements. The conceptual development is in this phase connected to the ergonomic and human centred support systems.

Round 3 had an emphasis on evaluation and choice of alternatives as well as detailed development. The goal here is to evaluate and decide which concepts that will influence the final system design and develop a foundation for detailed concept and future construction. The construction phase determines the final composition and all involving components are tested and modified. The system is tested against the requirements of specification and results in drawings, 3D visualisations and instructions. Lastly the gathered and developed data is documented and presented, and final adjustments can be done from the feedback.

4.1.1 Systematic layout planning

Another method framework that was used to inspire the development of a new layout is the methodology that Muther & Wheeler (n.d.) developed, being the “Systematic layout planning” framework for manufacturing/ industrial layouts. In this project some these methods have been utilized and tweaked to be combined with other methods to fit with the framework from the “project spiral”. The methods that Muther & Wheeler present are divided into six steps that are supposed to be performed sequentially:

1. **Map connection demands:** A proximity Valuation Chart is set up that maps the connections between the functions and areas within the station.
2. **Establish functional requirements:** The area requirements, technical aspects, service needs, and equipment are mapped to gain insight into requirements for the system to work.
3. **Map the relationship of the functions:** Sketch out the connections between the functions and their importance related to the requirements of proximity. Use (A, E, I, O and U) to show the degree of closeness desired. Use an X to show that proximity is not desirable.
4. **Sketch alternative “Block layouts”:** Geographically and scale accurately group and identify the areas for every station and note facility limitations and production planning.
5. **Evaluation of alternatives:** This step is about evaluating the different layout requirements against each other based on the requirements specification using a rating scale.
6. **Detailed development:** The final layout is developed where every function, machine and workplace are included. Functional demands are tested, and workers are consulted to identify risks and eventual problems.

4.2 Project planning

To be able to follow a structured work framework, a GANTT-chart was set up in the early planning stages. The program ClickUp was used as it provides a clear overview of the work needed with a good user interface and the possibility to add checklists and reminders to the planned methods. The chart was more detailed in the beginning, as the goal for the project’s goal for the development phase was not clear in the begging. Because of this, the GANTT chart was updated with more methods iteratively as answers to problems and possible solution needs were identified.

4.3 Literature Overview process

The main resources to find articles for the literature overview were ResearchGate, ScienceDirect and the Luleå University library search engine. The focus was to gather information that would be of assistance in the specialized design of the production system phase of the project and help with the evaluation of current state. A “Snowball approach” was used where sources connected to my research area was found using the reference list of studied articles. This approach gave insight into which areas of production research that was often cited in the scientific articles and located authors that were heavily referred to by other researchers. Books about production planning, logistics and human work science was also used to provide topics to write about and many scientific articles. To further gain insight into areas of interest, emails were sent to researchers at Luleå university of technology asking about articles, research fields and authors addressing the current research surrounding production design.

4.4 Data Collection

To combat problems in data collection problems Philips (1997) describes that there is a need to be wary of optimism from management, and that you need to compare data from different sources. Therefore, a holistic and analytical approach was used where data was gathered from people on different levels in the organization. The data collection phase is crucial as it maps the current state of production, helps analyse the production and aid the development and evaluation of concepts.

4.4.1 Interviews

Osvalder et.al. (2015) argues that interviewing is one of the most fundamental methods for gathering information regarding people that are working and making decisions. They provide knowledge about peoples’ experience, observations, values, and opinions if done correctly. Interviews provide subjective data, and, in this project, semi-structured interviews will be planned before the interviews according to Wikerg Nilsson et al. (2015) with questions that needed to be answered by the interviewees but still open and flexible depending on what the interviewees talked about.

In the mapping of current state possibilities and functions, interviews were the main method for gathering information from different areas of production. Semi structured interviews were based on important questions for the mapping of current and future state with emphasis on requirements. The interviews were held on Microsoft Teams meetings and were recorded with the participants permission for later transcription. Three main interviews were held with a product manager, a production technician, and a production planner in the early stages. Many smaller discussions were later held as a compliment to the interviews to review new information as it was gathered.

To find information about the workers’ experience, opinions and improvement possibilities, semi structured interviews were held with the two operators at the station during a visit to the factory. These interviews concerned the current layout and flows, extra difficult or time-consuming tasks together with current production hindrances. They also concerned the human interaction and work at the station regarding workload, possibilities for recovery and self-control. Communication and information channels were also discussed. Finally, physical, and cognitive loads were discussed, and the operators could provide their input on working postures and manual handling, questions seen in appendix 1.

4.4.2 Observations

Observation is described by Osvalder et.al. (2015) as an objective method for collecting information about people in different scenarios that are of interest for the study. The result from these visits yield knowledge about behaviours, decision making and risks which those under observation are not always aware of themselves. The data from observations can be both qualitative and quantitative depending on the chosen method of observation. These observations were performed by approaching operators asking some questions about their work to gain insight of the different stations, the relationship between them and their working conditions. After the observed work at their stations, working paths, necessary movements, ergonomic strains, and physical constraints in the working environment were evaluated.

Results from the observations were then discussed with employees and production planners to formulate problematic areas and demands on future production systems. Figure 10 depicts a picture from the visit over the box assembly station with the automatic riveting machine to the left.



Figure 10. Box assembly station from observations at the factory in Mullsjö

As Hitchcock et al. (2014) mentions in theory, the integration of ergonomics in the design process helps minimise the risk of musculoskeletal injury and that a design process that advanced without sufficient ergonomics or user involvement could compromise usability and safety. To ensure that the users would be included and had the ability to affect the results, another study visit with the goal of discussion and observation was used to confirm assumptions, discuss the calculated time data, and ensure that the most frequent production hindrances were included in the problem analysis. By speaking to the employees, insight was gained surrounding the workers' autonomy and the extent to which they make their own decisions. The visit also focused on gaining insight into communication between stations, information systems and the overall working environment.

4.4.3 Subjective and objective ergonomic evaluation

During observation and discussion with workers at the stations, questions surrounding the most straining stations and tasks were formulated. The employees could describe the load and possible strain they felt on the body with the help with a Borgs RPE-scale and body map. Both the workers at the station were asked to participate and to give their input, which they wanted. The subjective analysis acted as a good conversation starter and some additional hindrances and straining tasks was localized.

When the extra straining stations were localized the physical working conditions regarding manual handling was evaluated with the rapid ergonomic assessment tool named KIM 1. The tool is presented by the Swedish Work Environment Authority and is presented as an evaluation form that can evaluate lifting, holding, and carrying. Together with a worker the total repetitions, load weight, working posture and work environmental factors was checked and the tool calculated a task risk measurement on a scale from one to four. A risk score of one describes a low load at the station, physical strain based on the tasks is unlikely, a score of four points at a high load where ergonomic overload is likely, and the workplace needs to change. Between these two measurements, at a risk score of two the load at the workstation could result in positive improvement for individuals with lower physical ability. At a score of three indicated that there exists a heavy load where physical overload is possible.

4.4.4 Focus group workshop

Osvalder et.al. (2015) describes this method as a group discussion/ interview with people from areas connected to the study lead by a moderator. The goals are in line with the ones from an interview, but the strength of the method lies in the fact that people encourage others to make associations based on their understanding of the topic. To aid the discussion, visual or physical elements can be used as discussion prompts, e.g., mock-ups, pictures, or 3D-visualizations. A focus group gathering was conducted in preparation for the ideation phase.

Its purpose was to gain insight into requirements and wishes for conceptual systems from managers and production designers' perspective regarding production, functional requirements, and ergonomic aspects of production. The meeting was held on Teams where I had created a tool to guide the valuation and formulation of demands by ranking important factors from theory and interviews against each other. The ranking of requirements was done by the usage of three different lines that ranged from least important being (wishes) to most important (demands), seen in figure 11 is the workshop template that was used. Many different requirements that had been brought up in earlier discussions and by interviews and observations were already placed as text objects in the file so that the participants could move around and place objects on the line scale. It was also possible to write new ideas and requirements and place them accordingly. The placement of requirements on this graph was later used to find the most important requirements and determine their respective weight value before the concept evaluation.

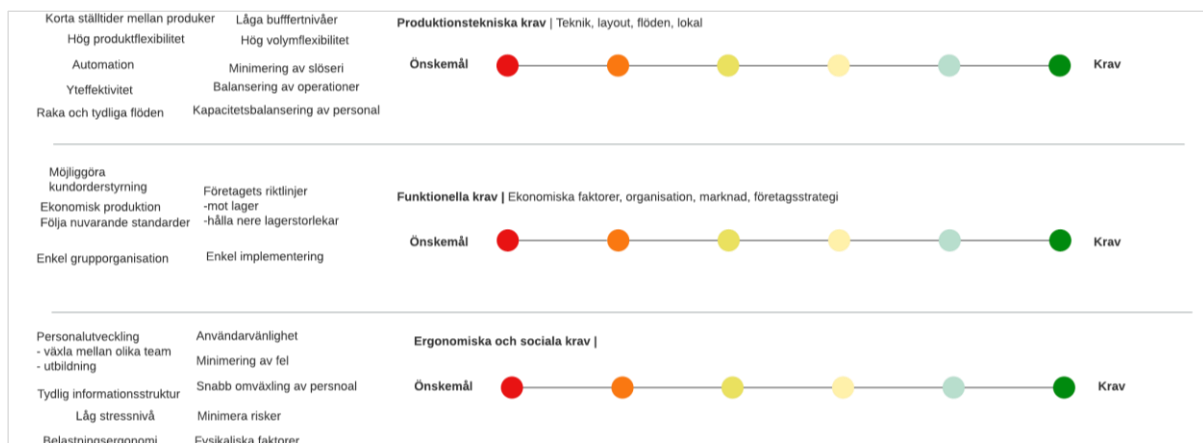


Figure 11. Focus group workshop template made in LucidChart

4.4.5 Modelling of current assembly station

Huang et al. (2002) describe that two preparatory works should be carried out before identifying opportunities of productivity improvement. One is to model the system, including its production equipment and the overall process flows. The other is to measure the productivity of the manufacturing system. Lindskog et al. (2016) describes that a realistic visualization of the production system is a valuable support during the design process of production systems. Having such visualization available during e.g., project meetings, will increase the quality of discussions by giving the participants a shared clear view of the planned system and its issues, which can result in fewer misunderstandings. Photos from observations and discussion with production developers were used to model the work environment and its separate assembly stations. The modelling was done in the 3D modelling software Blender as it provided tools to render and quickly model specific workstations. In the early stages this program was used mainly for fast modelling and rendering over precision and accurate measurements. The model was used as a discussion tool and many measurements and estimates could be derived from the model during the development process. E.g., appendix 5 depicts the estimated existing area needs for different functions which were measured from the 3D model.

4.5 Flow analysis

Bellgran & Säfsten (2005) describes that a flow analysis of production needs to consider three main aspects: Processes, material flows and layout. Lindskog et al. (2016) presents a framework called the “Seven flows of manufacturing” and they describe it as a less abstract alternative to *Value Stream Mapping* (VSM). They say that a more precise definition of the planned system could be achieved by the 7-flows of manufacturing. The conducted flow analysis consisted of several methods from different sources together with the information from interviews, observations, and focus groups to analyse how the system works and who does what, when, etc. The 7-flows are seen in Table 2

Table 2. Seven flows of manufacturing Lindskog et al. (2016)

1) Raw material	5) Machines, equipment, and tooling
2) Components and sub-assemblies	6) Information
3) Product processing / Finished goods	7) Engineering
4) People	

4.5.1 Process operation flowchart

Bellgran & Säfsten (2005) describes that a flowchart is a diagram of the separate steps of a process in sequential order that be used to develop understanding of how a process is functioning and can give insight into possible improvements. They describe that it is useful in development projects as it summarized process activities and their connections. It could help with the identification of waste and uses different symbols to categorize activities in the production flow. This method was used to summarize current operation balance and operation times in an easily understandable manner. The data was collected from earlier production development reports and time studies that was given to me by the production designers. The data was summarized in an Excel sheet where I had to calculate or find the specific operation time for different production steps. The data was then further summarized in a flowchart using LucidChart. I tried to keep the diagrams simple and did therefore not include all smaller buffers and information flows. Here, I mainly focused on the different operations and their important component/material flows. The results were further explored to see how different configurations of products affected the assembly balance.

4.5.2 Material flow mapping

Philips (1997) say that you should determine flow points before creating any block layouts. Bellgran & Säfsten (2005) describes that material flow analysis is a part of the evaluation of a production system where the aim of the analysis is to establish the movement pattern of material flow. In this project this method was used to identify functions that need material or components. By identifying these material buffers the flows could be analysed to find intersecting and important connections that would help with the development of new layouts. This step was done using Lucid Chart and pictures from the modelled production system from blender. I divided the material inputs into the station into two major ones, A & B and the material out from the station C. Then the different material flows where localized to and from the station focusing on raw material, components, and finished products. These flows were visualised in different colours depending on the material in/output and summarized in a picture that shows all buffers, storages, and material flows.

4.5.3 Hierarchical task analysis

HTA is a method that Osvalder et.al. describes gives a better understanding for the work structure and sub-assemblies. The method provided a detailed description of operations that workers performed to carry out their tasks. The input data was obtained by performing user interviews and performing observations where I asked the observed worker to describe the different steps and the goal for the task. The overall goal was then divided into sub-goals which had to be done to fulfil the goal of assembling a product. The result provided an overview of various operations and the relationship between them and how the worker feels about possible hindrances and possible problems in their work. On site, all the different tasks were written down and discussed before Lucid Chart was used to create a visual hierarchical structure for the different products, figure 12.

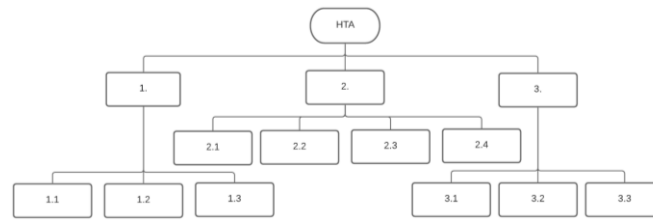


Figure 12. Hierarchical structure for HTA

4.5.4 Link Analysis

After the HTA analysis where the tasks were summarized and connected Osvalder et.al. describes that a link analysis can be used to describe how things and users move throughout the system. The movements could be physical movement of personnel, material, products or in which order workers do their tasks. The flows of the system were gathered to later determine suitable placing for machines, workstations, tools, and information systems. The method is suitable for analysing designs where efficient positioning should be achieved. Osvalder et.al. describes that the link analysis is greatly assisted by having previously carried out an HTA analysis. An example of connected links is seen in figure 13.

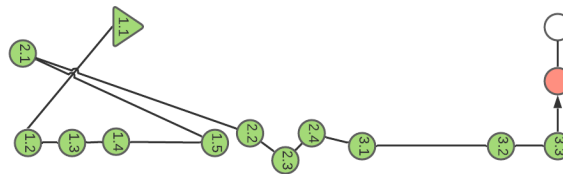


Figure 13. Example of connected links from current state

Results from the HTA analysis where thereby used as the foundation for the link analysis, the method was performed for every assembly station. The processes from the HTA were marked out on a picture over all stations and resulted in the mapping of common connections between various subsystems and was presented visually for easier examination later. Only the most important sub-processes were chosen as there were too many smaller sub-processes, these processes were then looked at critically and wastes were identified and later discussed with production designers at the company.

This method was also used as a part of the evaluation of concepts as it gives insight into the flows of the conceptual system. This was done by using the already made links from current state of production and placing them over the new 3d models of the concepts in the program LucidChart. By placing the links in their corresponding position, improvements from current state could be seen. This method also showed possible problems with the production flows of developed concepts which could be of importance before the evaluation and detailed development.

4.5.5 Proximity Valuation Chart

In this project, a proximity valuation chart created from Muther & Wheeler (n.d.) framework was used to map connection demands. A was set up that maps the connections between the functions and areas within the station, see figure 14. Desirable proximity is noted with any of the codes A, E, I O or U, which is a scale from "absolute necessity" to "insignificant". The reasons for the valuation are also noted, which gives the opportunity to check back later. The reasons for the evaluations are also noted by the numbers 1-3 connecting to "material flow", "information flow" and "workers/equipment". This analysis was performed during the material flow analysis as it provides a clear overview of the connections between different functions. When performing the analysis, the code E was consciously merged with A as the stations' total area is small and the separation between A and E would have been insignificant.

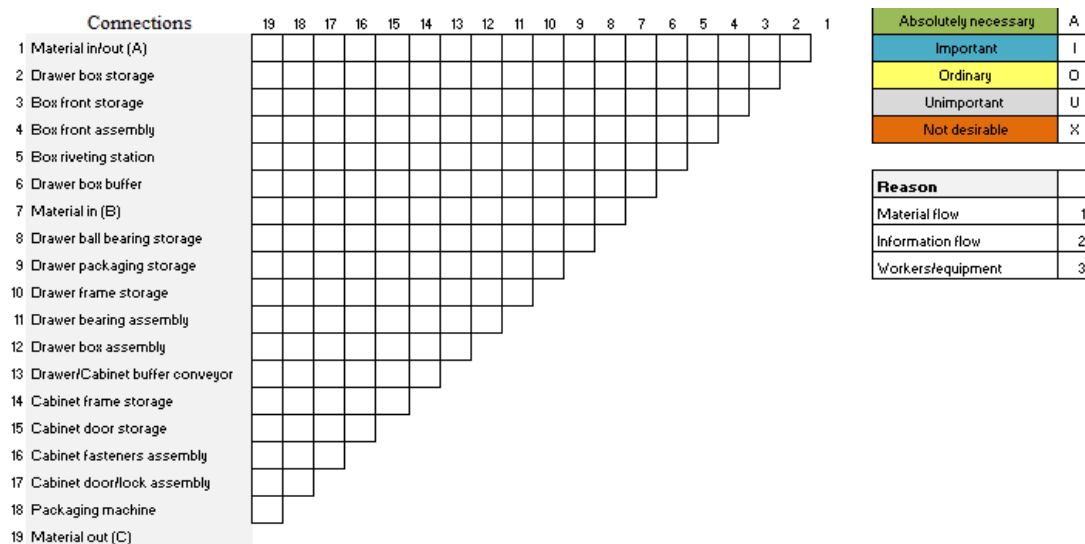


Figure 14. Proximity valuation chart created from Muther & Wheeler (n.d.) framework

4.5.6 Relationship analysis

Philips (1997) describes that establishing relationship diagrams for existing plants is a difficult task due to the many physical and other constraints that exist. The relationships between functions were mapped out by using a created image of the current layout. This was done by using the connections between functions and their importance related to the codes from the proximity valuation chart from Muther & Wheeler (n.d.). The different proximity requirements were used to draw lines between the points where the line design represents different proximity requirements. Relationships that are considered necessary (A) were marked out first by using double lines, important relationships (I) followed with single lines and ordinary relations (O) were mapped out by using dotted lines. This step was done to see current relationships but also help with the development of new layouts later. Philips (1997) mentions that the goal is to retain the original relationships when developing new spatial relationship diagrams.

4.6 Future state mapping

The combined results from the data collection were used to perform a problem analysis to determine requirements as a means of identifying needs and improvement potential for the future state.

4.6.1 Strategy and current problem analysis

Bohgard et al. (2015) says that this analysis works through formulated problems from current state and map out what needs to be done to improve/ fix the problems. In the project these demands were summarized in a specification of requirements that focuses on the long-term effects of production development. In this step different approaches that build on rational production planning and forecasts where problematized based of their possible effects, both positive and negative. Several different production structures and both technical and social assembly station properties were discussed with the company. Most of these discussions were done through Microsoft teams meetings but also by a visit to the factory to talk with the employees about possible improvements. This step resulted in a better insight into the production strategy and framework for the concept development. The results were summarized in a matrix, they were separated into three main areas, and were given the notation *Demand* or *Wish*.

4.6.2 Specification of requirements

The method used for the valuing of demands came from Muther & Wheeler (n.d.) systematic layout planning. Firstly, the most important factor was located and given a weight of 10, then all other factors were compared in relation to the most important one and thereby gaining their respective weights. The weight of the different demands was based on earlier interviews and workshops and were performed on my own. The results were later readjusted with the help from production personnel before the evaluation of alternatives to make sure the weight of the demands aligned with the company's view.

4.7 Ideation and concept development

The development phase consisted of ideation and brainstorming sessions, relationships diagrams, block layouts and resulted in three main concepts. These concepts were then evaluated against each other on the fulfilment of different demands from the future state mapping. The winning concept was developed further and used many aspects and ideas from the other 3D modelled concepts. The final concept was also evaluated against the production system from current state regarding flows, area needs and working environment.

4.7.1 Brainstorming & Mind mapping

Some discussion and smaller brainstorming sessions were performed in Teams chats with production development personnel and technicians in the form of smaller meetings. In these meetings possible improvements and the company's earlier production development projects were discussed. These meetings were spread out over the entire idea and concept development phase and were often focused on the generation of smooth flows and the goal was to try and find ideas for the optimization of value adding steps, balancing and production improvements. Many of these ideas were then incorporated in concepts in some way. The screen-share feature and the usage of the developed 3D-models gave insight into many restrictions and possible hindrances. Together with block layouts these visualizations allowed for fast rearrangement of machines and equipment to try out ideas and spark discussion. An individual mind map was set up to categorize different ideas and limitations, seen in figure 15. Many of these ideas stem from the discussions and the mind map was categorized into three main areas of importance for the conceptual layout: *Production structure*, *Layout/equipment*, and *work environment* with sub-categories derived from the literary overview, a clearer version is seen in appendix 7. The program LucidSpark was used to display the ideas as it offers an infinity canvas and many tools for mapping ideas clearly. This mind map acted as a summary of ideas and was used continuously during the ideation phase.

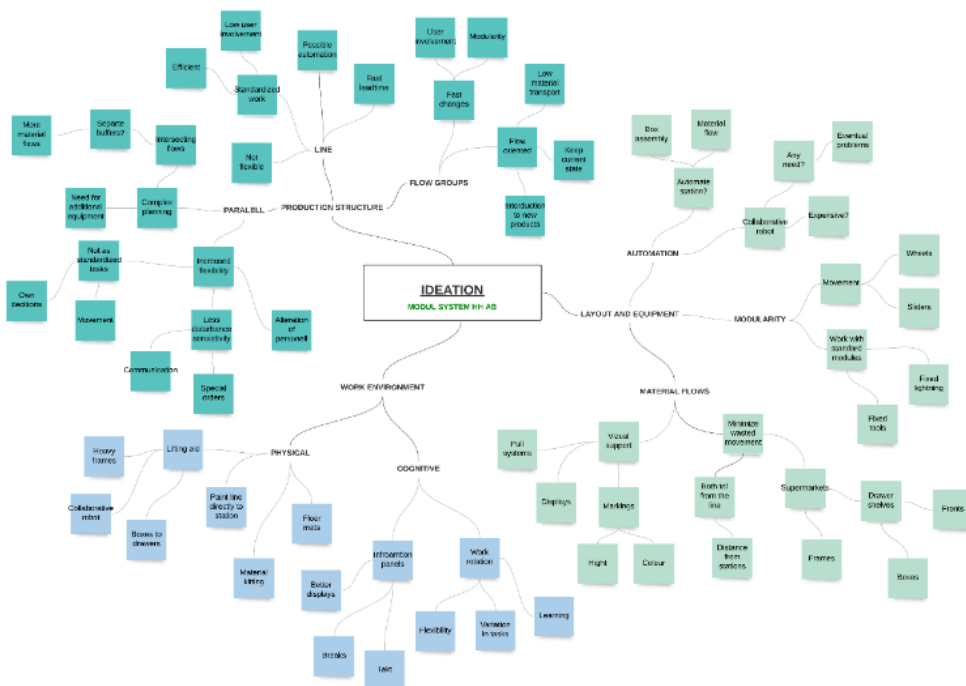


Figure 15. Mind map was categorized into three main areas of importance for the conceptual layout

4.7.2 Block layout development based on connections

Muther & Wheeler (n.d.) writes that after the specification of requirements is completed in the systematic layout planning the next step is to sketch alternative block layouts. This method was used to relatively quickly explore many different ideas and see if any new solutions would arise. The method is used to visualize and identify needs for every station and note facility limitations and production

planning more accurately. The block layouts were mapped out from the relationships of the identified functions and closeness needs, by outlining the connection of the functions and the usage of different line widths to display the rating of desired proximity.

The functions were represented by a circle with the respective function number and the process started with drawing all pairs of functions with an “A” or “I” connection, see figure 16. Then the diagram was redrawn to achieve the best arrangement of A-valued functions based on different layout ideas, the ordinary, and undesirable connections where also considered but not drawn as these makes it difficult to see the important connections.

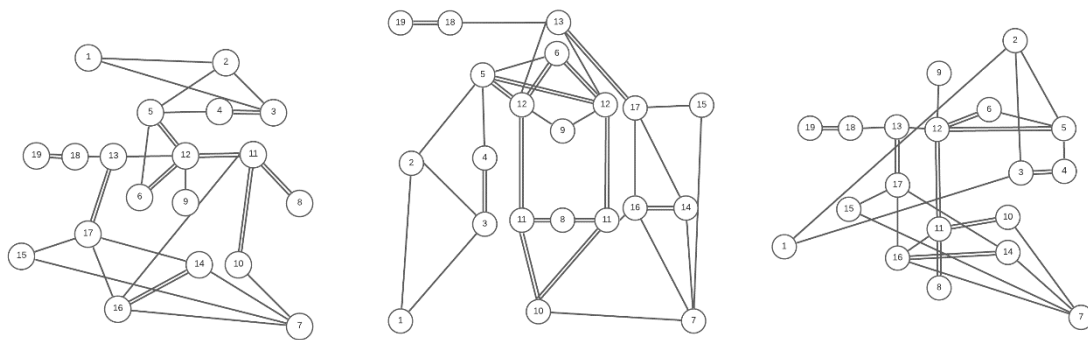


Figure 16. Different relationships diagrams for concept development

By using relationships diagrams and a block layout of the current state as the base, several new block layouts were put together, some examples of these layouts are seen in figure 17. Ideas were based on existing equipment and experimentation with different production structures, some incorporated straight-line structures, more flow-group oriented, parallel, or singular etc. Not all the block layouts had relationship diagrams as their direct base, several alternatives were developed as slight alterations of each other. This was part of the ideation process, and many new ideas were formulated.

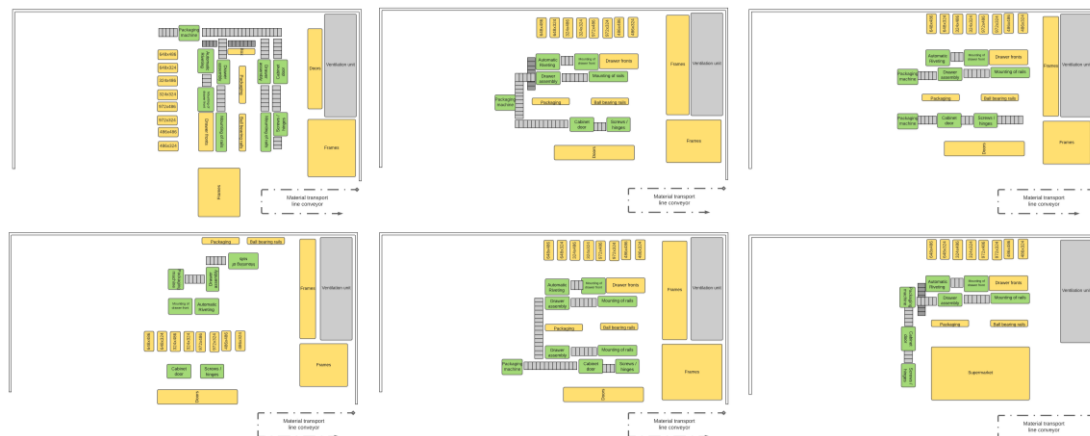


Figure 17. Alternative block layouts made in LucidChart

After choosing some of the best ideas with strong connections to the relationships, the usage of 3D-models was an important part of the further development of the concepts, see figure 18. By using the model of the current state, concepts could be created from the block layouts that resembled what they would look like in reality. By doing this step early in the process it helped recognise possible hindrances in material flow, worker movements, or maintenance needs. These 3D models acted as a visualization/ discussion tool and possible improvements could be identified in meetings with personnel.

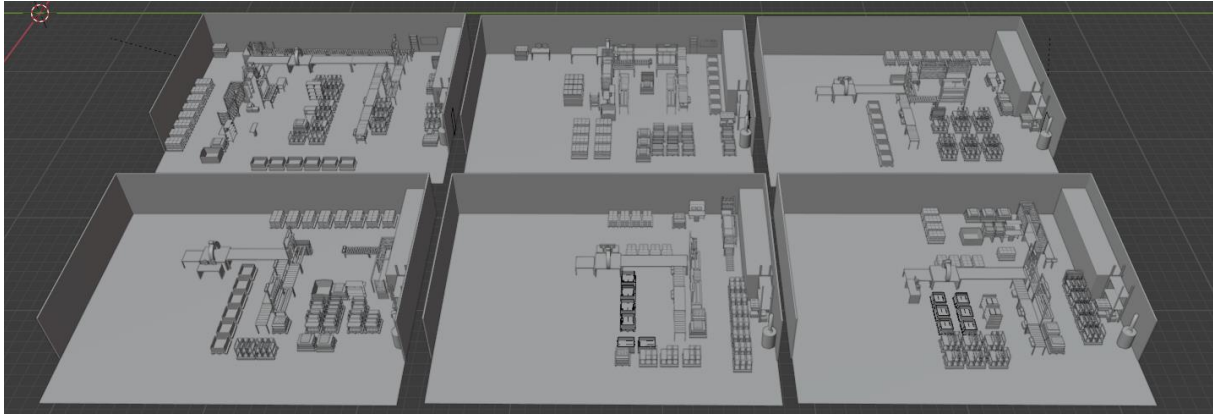


Figure 18. 3D models acted as a discussion tool and possible improvements.

4.7.3 Evaluation and workplace input

The different concepts were presented alongside the current state analysis of the production system at the company. At this meeting the company project supervisor, production designers and technicians could express their opinions surrounding improvement possibilities and problematic areas. Insightful input was also gained regarding specific technical limitations like the size of buffers and adjustment possibilities. At a later meeting with development personnel the weight values of the different requirements were discussed and the formulation of some of the requirements was altered.

When evaluating the concepts, the evaluation framework from Muther & Wheeler (n.d.) was used where each requirement was denoted with a letter for every concept, figure 19. The letter represents a factor (A = 4, E = 3, I = 2, O = 1, U = 0 and X = -1) and are then multiplied by the respective weight value. The different letters are based on Muther & Wheeler (n.d.) and are not solely a factor, the letters also have another function to help with the evaluation, A means the concepts fits the demand perfectly, E symbolises that the concept has an effective solution, I stands for interesting, O for ordinary, U for insignificant and lastly X for not desirable. The sum of the scores for each alternative was calculated, the concept with the highest score fits best with the design specification. But it is important to note that the other concepts will not be eliminated and in the specialized design phase, ideas from the other concept will be considered in the further development.

Project	Date	Resp					
Master's thesis Moduls System HH AB	2021-04-22	Oskar Abrahamsson					

Demands	Weight	Parallell	Serial	Flow	Modul	Note.	
Allow fast readjustment (Product flexibility)	10						A = Perfect
Allow capacity changes (Volume and worker flexibility)	9						E = Effective
Offer fast cycle times (Inventory & waiting waste)	8						I = Interesting
Low manual material handling (Motion waste)	6						O = Ordinary
Streamlined flow between connections (Transport waste)	7						U = Insignificant
Surface-efficient layout (Future expansion)	5						X = Not desirable
Economically sustainable initial cost (Cost)	8						
Integration with company's logistics strategy (Push strategy, batch oriented production)	9						
Easily reconfigurable to match new products (Modularity and resuability)	5						

Figure 19. Remade evaluation framework from Muther & Wheeler (n.d.)

4.8 Specialized design of the production system

Philips (1997) argue that you will not be able to make the perfect layout as there are too many constraints and that rearrangement of an existing plant will force you to make the best of the situation. Benefits are usually achieved if the total number of no value-added operations, pickups and set downs are reduced. Those reductions coupled with inventory reductions should be more important to the planner than simply reducing materials transport distances. In the detailed development phase, a larger focus was placed on actual machine and equipment placement. Many of the smaller material buffers, waste management and workstations were moved around within the boundaries of the current state area and many smaller daily operator tasks were included in the layout planning. Many of the ideas and smaller hindrances that exists in the current state were discovered after a second visit to the factory. Operators could give their improvement ideas and I tried to incorporate these into the layout. The ideation part of this last step was done in Blender where many of the ideas from the 3D modelled concepts. This phase of the project tried to answer many questions that need to be answered for the station to function. Philips presents a list of these that helped with the evaluation of the new layout. They range from material pickup and set down points, material availability at the stations, any additional aid tools that are needed or possible expansion. The complete list of points that needs to be evaluated can be seen in appendix 10. This list together with operator feedback gave a relatively good understanding of the possible impact of changes.

4.9 Method Discussion

During the focus group meeting, I conclude that it would have been very informative and important to have had people working with the work environment and ergonomics present to gain their insight. There also exists in literature many reasons to have included several workers from the stations in question in this meeting. To compensate for their absence, I asked operators about their opinions afterwards at a later visit to the factory during my observation. In this project, most of the steps were done in the manual for systematic layout planning but not exactly as instructed. The reason for not following the systematic layout planning approach exactly is that it takes a very rationalistic approach where work environment and worker input can be overlooked. In this project, the areas that focus on the mapping of proximity demands together with a relationship analysis was used to help with the current state analysis. The usage of other flow analysis methods like HTA and Link analysis gave important insight into the stations and how processes are performed between tasks. These results helped with the setup of important connections and closeness needs, especially those dependent on worker movement and daily tasks unrelated to the main material flows.

Philips mentions the importance of a flexibility evaluation, in the project this step was quite hard to evaluate using specific methods as there exists some uncertainty regarding the future state. No specific method was used for this step and instead I relied on discussions and interviews when deciding on important flexibility aspects regarding products and volume. If possible, a more structured measurement framework will be used in future projects to specify the needs more precisely. One thing to mention is that the basis for time study data is to estimate to follow a linear correlation between the number of boxes. The evaluation is based on videos on two cycles and one visit to the factory where only one type of drawer was being assembled during the stay. Another factor to consider is that current data for production volumes and demand for different products are based on historical data and forecasts. The usage of 3D models was an important part of the project and as Lindskog et al. (2016) describe, these more realistic visualizations were valuable support during the design process. Having visualization available during project meetings was an easy way to convey thoughts and ideas for fast feedback. It felt like the participants gained a clearer view of the planned system and the vision. The most important part was that the production technician could give insight regarding possible limitations regarding material transport and production planning. In future projects, the usage of a production flow simulation would have been valuable to evaluate different concepts before moving on to the detailed development phase.

5. Current state description

This chapter contains the information gathered surrounding the current state of production by focusing on production characteristics like processes and their connected flows, current layout, and production planning together with workload of operators.

5.1 Production and properties of the assembly

When asked regarding important factors for production, managers and production planners explained that the company wants to achieve fast lead times, that there is a strong focus on quality, and that flexibility is of great importance. The company strive for lead times that are no longer than a few days throughout the factory and several of the products go directly from cutting and welding directly to assembly storage. Flexibility through the ability to customize solutions and to adjust and produce in large differences in volumes are described as one of the most important means of competition. Other important order qualifiers are the offering of short lead times on a large range of products and the work of trying to lower the weight of products. Figure 20 depicts the current state production system where several assembly lines are placed within proximity to the paint line where frames and doors are painted before further assembly. There are some automated functions built into the system like riveting and conveyor belts, but workers are performing the assembly and almost all material transport. In the figure, the most usual working stations are mapped out with green figures representing workers. Usually, the workers are not stationary and move around n between the marked stations often during the day.

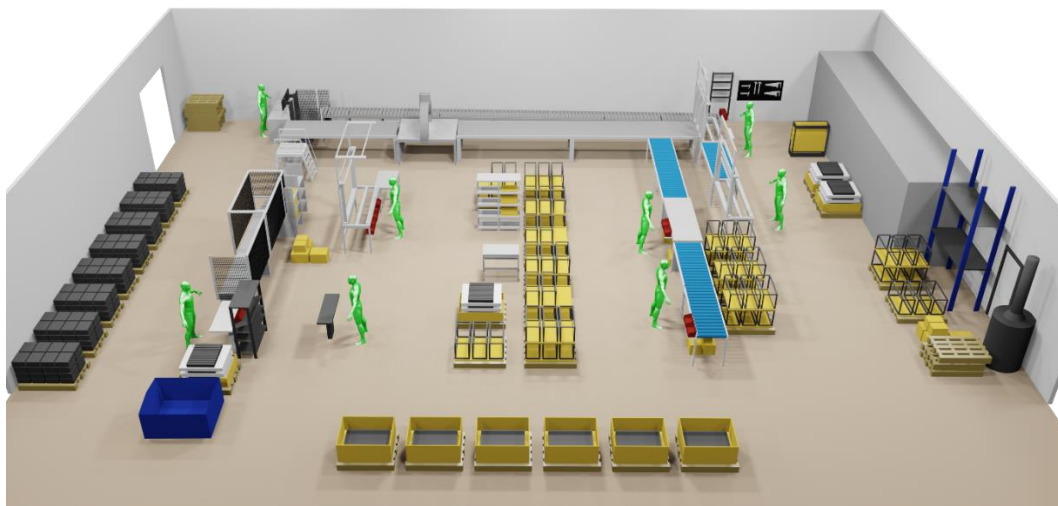


Figure 20. 3D-model over current state layout

5.1.1 Production development

A production layout planner is responsible for the production of prototypes and current products, when new products are created, the designer is responsible for taking over the designers' work when they are finished with CAD models. Ensures that produced products work in all processes regarding assembly such as: bending and punching, etc. Responsible for the structure for the manufacture and development of stations to meet requirements from new products. The layout planner works jointly with product development and the logistics department to do tests so that production works as planned. A production order planner prioritizes what production orders that should be sent through the production and provides fitters with their necessary materials. The production planner works mainly based on a base stock system but can prioritise customer orders, where the main tools are Microsoft Dynamics AX and Excel.

5.1.2 Production planning

The production process is built on an assemble-to-warehouse system where production is determined through a Microsoft Dynamix AX business system that controls production through safety levels. It works by providing suggestions on which products should be produced to meet delivery demands. Production is controlled by a batch-oriented flow where the demand for certain products controls the batch size. These production orders are then prioritized by production planners at the company to meet future needs. The refill levels are calculated based on historical data regarding annual needs and the consumption of the last four months, where they aim to have 2 to 3 weeks of consumption in stock. However, there is variation, and it is not uncommon for these inventory levels to be consumed faster. The company is up to the desired inventory levels around 1 month of the year. The company thus does not reach its set inventory levels but the production planner says that it is not a huge problem because of relatively short lead times. Their main strategy is trying to only manufacture the components needed in production and lower material buffers in production. The strategy is trying to make sure that they can deliver to the customer from their warehouse and continuously keep inventory levels linked to the demand for a product. For their overall production, this is not always possible as demand can vary and customers do not just buy products that are in stock, then they must produce against customer orders instead.

5.1.3 Current production demand

Product variance is quite high but the assembly steps for the different lines do not differ too much as the workers are performing the same steps but on products with different dimensions and number of components. The stations that the project deals with have a more static demand. Differences in the demand for these products move quite slowly and have historically linearly followed the economy in society according to a product manager. The number of variants of the different products at the stations is also considered static but, in a discussion surrounding future state they mentioned that there could be incentives to be able to run more special orders in the production. Future production regarding drawers' lockers and long drawers is seen as consistent and the station's assembly steps are considered to remain stationary. The focus for the assembly station area is the drawer assembly with a yearly demand of ■■■ drawers per week based on 36 working weeks per year and a daily need of ■■■ drawers based on 253 working days. Figure 21 shows a simplified frame distribution that categorizes the drawers based on length and width where the different variants could have the height: 270, 378, 486, 864 or 972 mm. Because of the many different dimensions, there are ■■■ different drawer units in the received data.

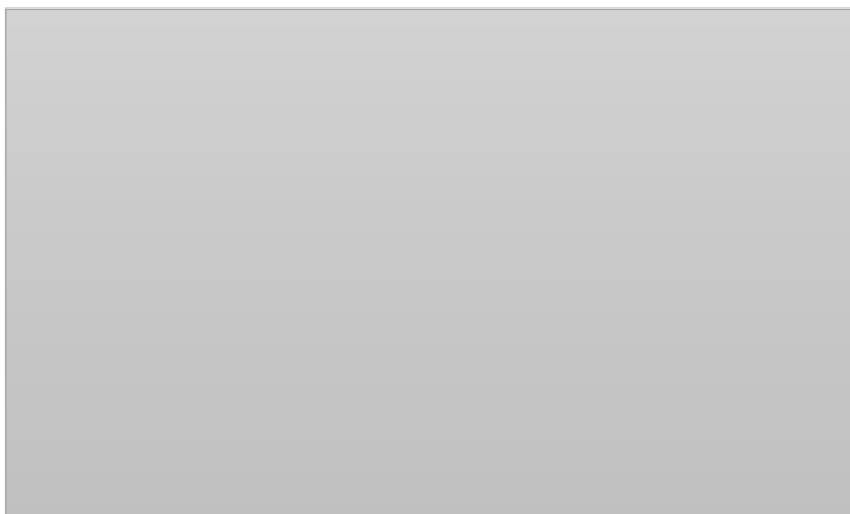


Figure 21. CENSORED Drawer frame distribution (2020)

The locker distribution is not as complex with ten main configurations and a much lower yearly demand in comparison to drawers, the yearly demand reaches of ■■■ lockers or estimated ■■ drawers per week, figure 22. The production of lockers is not as constant as the drawers and therefore have a lower priority.

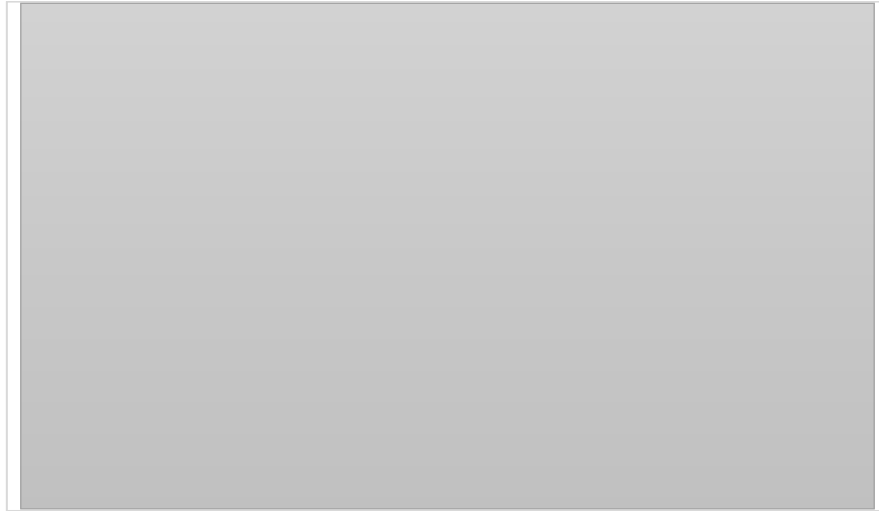


Figure 22. CENSORED Locker frame distribution (2020)

In the current state of production, when special orders arrive, loose components are sent from the warehouse to the customer, who can assemble ordered products themselves. Special orders are custom made compositions of the company's standardized range of frames, drawers and accessories that match the customer's needs and are not included as finished products. At present, special orders contribute to complicated logistics as parts are sent and packaged separately and are more susceptible to damage during shipping. The company, therefore, sees advantages in succeeding in creating a process that has the opportunity for fast customized orders with short lead times.

5.2 Work environment

The work environment is managed by production developers together with safety representatives in the factory, the product development department and their production developers also work to ensure that new equipment does not contribute to the deterioration of the work environment through its design. They describe that there is communication between different departments to reconcile possible risks and the management of these.

5.2.1 Production personnel

At both the “Long boxes- and Drawer line”, they work in two shifts. It can increase and decrease in certain periods, but on average they work in two shifts with 3 people on the drawer line and two people on the long box assembly. The locker assembly is included in these hours and is done when there is time left. The assembly itself is not too complicated and workers usually have a colleague in proximity.

5.2.2 Organizational work environment

Managers want to get everyone involved in several aspects; they work towards establishing a flat organization where employees have contact persons where information can be sent in both directions through contact persons. The communication goal is having committed employees, which the company believes is of the utmost importance and argues that the entire flat and participatory system could fail if these aspects were weakened. In the event of any problems, the management described that employees can contact everyone within the organization and describe obstacles or problems for a transparent organization. Everyone should have access to everyone and do not always have to go through managers or other information channels, so workers can communicate directly with the intended recipient. The interviewed manager said that they view the opportunity for education and learning at work positively, the staff in the factory is also used in development projects and some can

travel between different locations and perform specific tasks. Employees are also moved between assembly workshops and this flexible approach means that the company exists throughout the organization to benefit the company and provide stimulus to those individuals who like to be challenged and tested on different roles in working life.

5.2.3 Work at the stations

When asked about workloads and possible stressors in the workplace, operators mentioned that there is more pressure, especially during full operation. This is because the intensity increases when many frames are waiting at the same time as new frames arrive. This scenario places demands on the worker who performs the mounting of boxes as it is the most time-consuming station. There are opportunities to rotate work tasks, and the asked operators said that they have some opportunity to control the way they work. Although they mentioned that the work can be quite repetitive especially tasks like the placement of ball bearings and boxes. The unloading of drawers/lockers onto pallets for the warehouse and manual handling of drawer/locker frames before assembly were classified as the most straining tasks. When asked to describe where they feel strain in their body the workers mentioned that they can feel medium load mostly in the back and shoulders, see appendix 2 & 3. Important to mention is that not all the stations have ergonomic floor mats and one worker mentioned that they could feel strain in their feet.

They mentioned that the load is moderate and tolerable, sometimes extra-large frames for drawers with many boxes can be difficult to carry. To analyse the manual load when lifting frames from the buffer to the station, KIM 1 from the Swedish work environment authority was used. The task is done roughly one hundred times a day, with a load of less than 10kg and with pretty good working postures. The operators had to manually lift components in minor twisted and inclined lifting postures but had room and time to manoeuvre for a better working posture. The assessment template resulted in a final ergonomic risk score of 16 points which translates to risk area two out of a maximum of four. This means that there exist possible workloads that could be harmful to people with lower physical capacity and there are incentives to make changes in the workplace design. It gets a bit worse after the boxes are mounted and the drawers are lifted from the packaging conveyor onto pallets for storage or shipment. The load is now higher, and the placement of large drawers and lockers is done in rotated and elevated positions. As the weight differs between the products a clear ergonomic rating was hard to achieve, workers at this station could feel strain in the shoulders and back and said that it could be strenuous, and that height played a factor.

When asked if the operators have the necessary information at hand to perform their tasks, operators mentioned that the main information channels are clear including a daily control board, displays and paper that comes with the frames. They mentioned that it is not difficult to know what to do after some time at the station and they can always ask or solve problems together if they are not sure. They mentioned that the cooperation between the stations works well enough but the distance between stations can be a possible obstacle sometimes. They also said that the workload between the stations is quite equal, sometimes the person with the task of mounting the ball bearings need to walk quite far to prepare finished products or get new components from the warehouse.

This can pose a problem and be a bit difficult when the drawer assembly station is in full operation. The biggest obstacles they mentioned in their work are a constant noise level from a riveting machine/pneumatic cylinders and heat from the paint line oven. Noise levels at the riveting machine measured over a minute, resulted in an average noise level of 73.3dB when operating, with occasional higher pitch noises. The noise level by the pneumatic cylinders at the bearing mounting station was an average of 71.9dB. Both noise levels are within the acceptable values for daily noise exposure level at 85 [dB] from AFS (2005:16).

When asked about hindrances and possible problems in their work operators stated that they sometimes experience a lack of material in the buffers and that those drawer frames are not in the same order as the production planning list says that they should be manufactured. Furthermore, they mentioned that it could have been better with more space for ball bearings as it is an annoyance as you must move a lot of things to access when refilling with a forklift. An error that can occur is that the sensors on the pneumatic machine do not work properly and you must do the step several times. A similar problem was mentioned regarding the riveting machine where it stops working and technicians need to be called.

5.3 Analysis of production flows

In this chapter, results from several production analysis methods are conveyed based on the evaluation of the 7 flows that Lindskog et al. (2016) presents. Results in this chapter start by looking at production functions, different material flows and operator processes. Together with the mapping of the current state analysis which results in specifications of requirements for the project.

5.3.1 Flowchart and operation balance analysis

Following analysis is based on data from a time study that was completed by looking at videos that a production designer provided over the different workflows. The process task time and relations for the assembly of drawer units are seen in figure 23 where important material buffers are placed out as yellow triangles. The flowchart shows the task time at each station and for further analysis, this time is multiplied by the number of boxes to calculate processing time with exceptions for “Place sticker and cardboard” and “packaging machine” processes as these are not dependent on the number of boxes. The quality control after the automatic riveting (blue) is not always performed which shortens the cycle time significantly for box assembly.

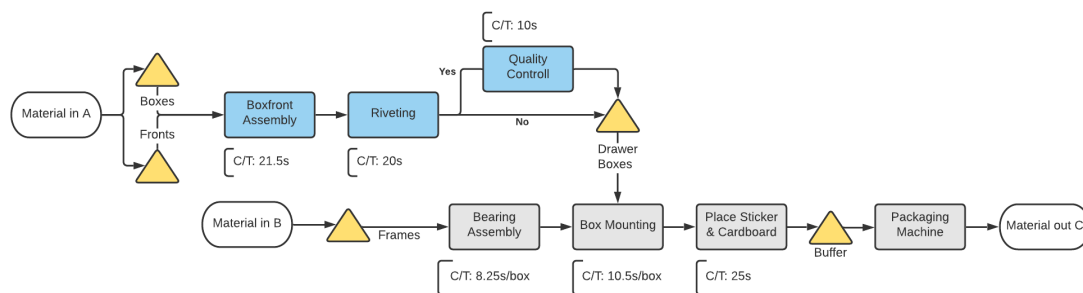


Figure 23. Flowchart over drawer assembly

Processing times are seen in Figure 24 where “Box” is the blue operations and “Frame” is grey operations. The box assembly line has a processing time of 51.5 s/drawer with quality control and 41.5 s/drawer otherwise. The station has a minimum cycle time of 21.5s/drawer because the bottleneck (*Box front assembly* = 21.5s) and with quality control a minimum cycle time of 31.5s/drawer (*Box front assembly* + *Quality control* = 31.5s). The cycle time for the “Box front assembly” changes if the operator is waiting for the automatic riveting station to finish before starting the assembly of a new front. The frame assembly line has a processing time of 18.75 s/drawer box + 25 s as the process “Place sticker and cardboard” does not depend on the number of boxes. Occasionally if only one operator works at the frame assembly station the processing time will become the cycle time.

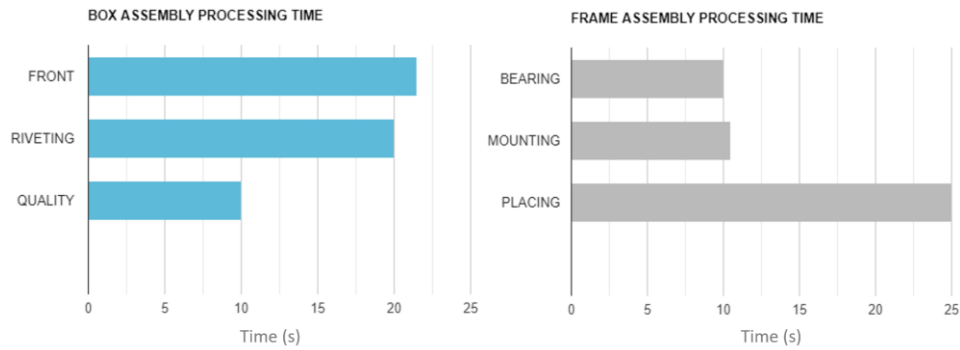


Figure 24. Processing time for box and frame assembly (drawer station)

The “Box mounting” and “Sticker and cardboard” tasks (placing) are separated in the figure 24 but in current state these processes are performed together on the line. The minimum cycle time for 2 operators on the entire drawer assembly station would be derived from the bottleneck of the system. The calculated theoretical cycle time for the box mounting station would be: $(Box\ Mounting * Number\ of\ boxes) + Placement\ of\ sticker\ and\ cardboard$. For the bearing assembly station, the calculated theoretical cycle time would be $(Bearing\ mounting * Number\ of\ boxes)$. In current state most of this idle time is utilized as the workers have different tasks to perform on the other stations when they get the chance. One important aspect to consider is that the manual assembly brings uncertainty to the cycle times for different operations. In table 3 the cycle times for the drawer stations are shown, these times are established from one video for the assembly of a drawer with 3 boxes. The calculations for the cycle times for drawers are done with the assumption that there is a linear correlation that depends on the number of boxes.

Table 3. Cycle time for the drawer frame stations based on videos from Modul System HH in seconds(s).

Nr. of boxes	Cycle time: Bearing mounting	Cycle time: Box mounting	Drawer station cycle time:
1	10.25	35.5	35.5
2	20.5	46	46
3	30.75	56.5	56,5
4	43	67	67
5	51.25	77.5	77,5
6	61.5	88	88

Figure 25 depicts the estimated correlation between the drawer stations cycle time and the number of boxes from table 3. The experienced idle time between the stations seen in the figure is utilized for other smaller tasks in current state. This makes it difficult to balance the line at different production capacity levels as there are many other tasks other than assembly that needs to be performed that is not included.

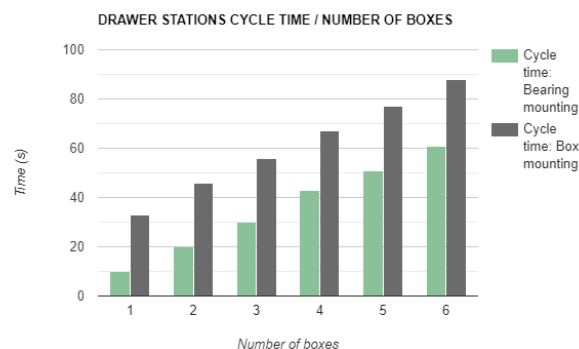


Figure 25. Difference in cycle time dependent on the number of boxes (drawer station)

To complement the data from the videos that was provided, some measurements were performed on drawers with three boxes at one of the study visits, table 4. These gave insight into the differences in cycle times that are dependent on the individual operators method. The largest difference was seen on the task “Placement of sticker/ cardboard” when measured in the factory, the task took 12.5s, half of the measured time from the provided video at 25 seconds. This means that the imbalances in figure 26 would be smaller but still relevant as the possibility still exists that the task does take 25s or longer. The bearing mounting stations cycle time result is fairly equal to the measurements from the video.

Table 4. Cycle time for the drawer frame stations measured at the factory in Mullsjö based on observation in seconds(s).

Nr. of boxes	Cycle time: Bearing mounting	Cycle time: Box mounting	Cycle time: Only sticker/ cardboard
3	33s	40.6s	12.5s

At the visit, the cycle time for the box assembly station was also performed. The measurement was done from the time the operator grabbed a box and stopped until the button for the automatic riveting machine was pressed. Table 5 shows of four of these measurements, it resulted in the the mean cycle time of the station being 16s, which is 5.5 seconds faster than in the video of the station.

Table 5. Measurements for the box front assembly in Mullsjö based on observation in seconds(s).

Measurement	1	2	3	4	Mean
Cycle time: Box front assembly	19s	15s	16s	14s	16s

5.3.2 Raw material & component flow

The material flows to the assembly stations are replenished by the warehouse workers, these operators are connected to the production planner that controls the components and material need. Components and material have two main entry point shown as A & B in figure 26. The material flow from A focuses on smaller components and necessities for production as well as inner boxes made in the factory. These components are mainly transported by a combination of forklifts and manual transport to their respective stations. From my discussions and observations, twelve main material flows connected to production were localised. There are possibly several smaller material flows that went unnoticed.

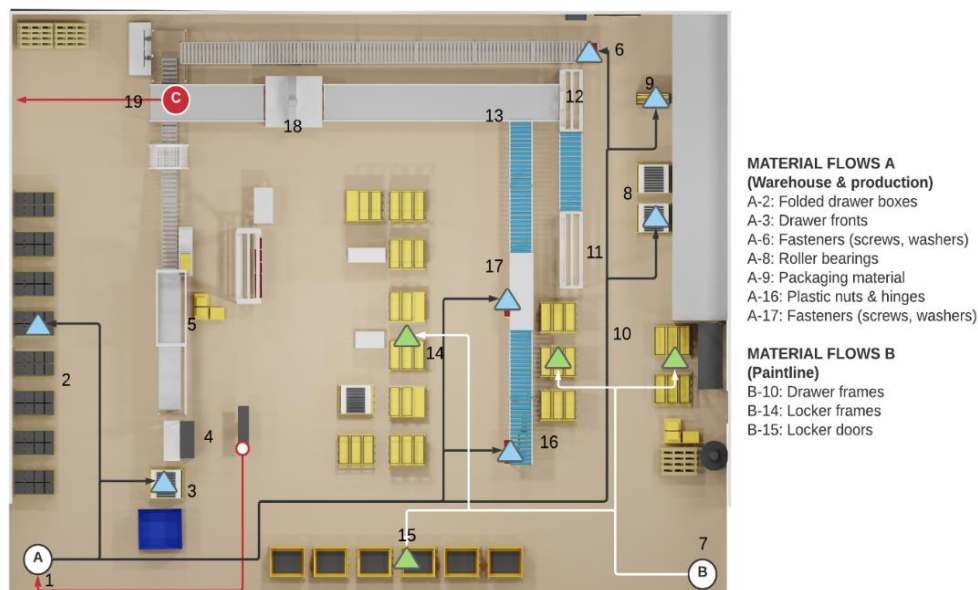


Figure 26. Material flows in current state with descriptions

Material flows from B or the “*Paint line*” supplies larger welded and painted components like frames and doors. Material from this station is planned a week ahead with the focus on minimizing possible shortcomings for customer orders and filling up safety stock to refill levels. The production of drawer boxes directly matches the material flow of frames from the paint line. The production planning for different products and variants are done in batches that are dependent on the demand for certain variants. An interview with the production planner showed that there sometimes could be synchronization problems at the stations. This is partly because of the possibility that the welding of cages in the other end of the factory is done quicker than inhouse box production for drawers. This can create delays or stops, but the production planner does not consider this to be a major problem in the current state.

Another mention is that components from the paint line can fall behind in planning. This can generate synchronization problems and material shortages in production. This problem relates to colour changes in the paint line as they set up the paint line to covers a week's demand for components. Säfsten and Aresu (2000) mentions that low disturbance sensitivity is an important technical assembly property. In current state the stations combat sensitivity problems with quite large material buffers which could be considered an inventory waste when production runs smoothly.

5.3.3 Hierarchical task analysis

HTA for station one (drawer boxes) is seen in figure 27. The assembly is a sub-assembly for the drawers that are assembled in station four. The goal for the operator is the assembling of a box that meets the quality control performed last on this station. I simplified the station to consist of four major tasks that are further divided into seven sub-tasks that are necessary to assemble a drawer. The blue stations have been classified as value-adding and the yellow stations as necessary but not value-adding, possible wastes have not been noted here.

Firstly the front is assembled by getting a box and front from different material storages, there is a small display that displays the next box to be assembled from the production planning system. It tells the dimensions of the box and the front but there is still a need for operators to verify that they have the right component. There are signs above the material storages that tells the variants apart. The next step is the mounting of bearing rails that connects with the ones mounted in the drawer frames. These bearings click into place and the positioning is quite straightforward as there are premade holes in the boxes. The almost finished drawer box is then placed in an automatic riveting machine that required user input to start. While the machine works the worker can start working on the next box or wait and perform the final quality control before it is sent to the drawer assembly station.

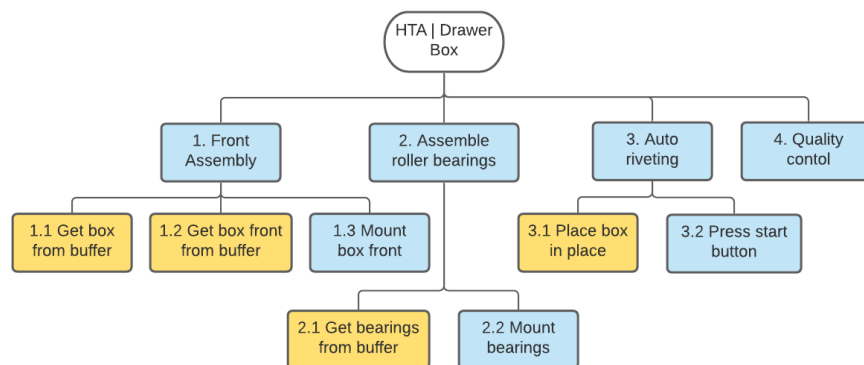


Figure 27. HTA for drawer box assembly

The assembly of drawers is done on station four and the goal for the worker is to create a finished drawer for the warehouse that meets the quality demands. There are three main tasks consisting of ten sub-steps, seen in figure 28. Operators get the frames from the paint line frame storage and start by lifting them to a pneumatic controlled machine that shows where the bearing rails for drawers should be placed. These are placed in place with a click and the drawers are manually moved forward to the next station. The

number of operators varies between one and two. A worker gets the drawer boxes from station one and screws on a handle for the box. And proceeds to mount the boxes in the order that they come from the conveyor. When all the drawer boxes are mounted the worker performs quality control for each box before the next step begins. The third step is to send the drawer forward on the conveyer connecting the station to the automatic packaging machine. Firstly cardboard protection is applied, the drawer is folded down onto the conveyor and lastly, a sticker is placed giving warehouse personal information about the product.

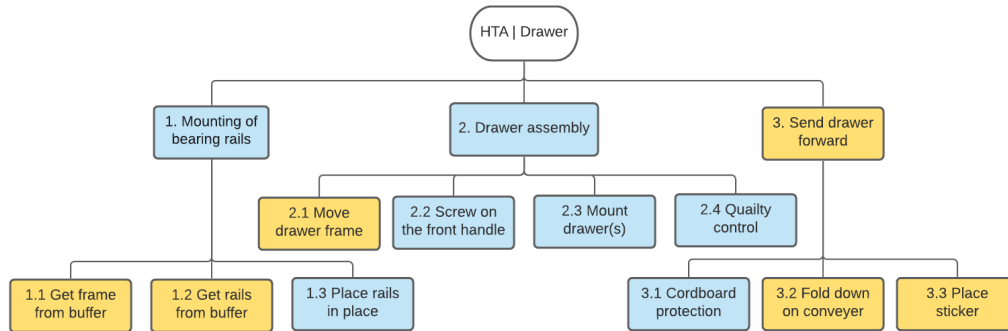


Figure 28. HTA for drawer assembly

The assembly of lockers is done on station four and the goal for the worker is to create a finished locker. The process is divided into 3 main tasks with 16 sub-tasks, the first station prepares the locker frame for the door assembly by installing plastic hex nuts, hinges, and dampeners, figure 29. The locker is then moved to the next station for door assembly and sometimes the workers do this in smaller batches. The doors are hooked on the hinges and fastened with screws, then the worker assembles the locking mechanism with a washer and bolt. The keys are placed inside the locker, and it is sent forward where cardboard protection & sticker is applied before it is sent to be packaged.

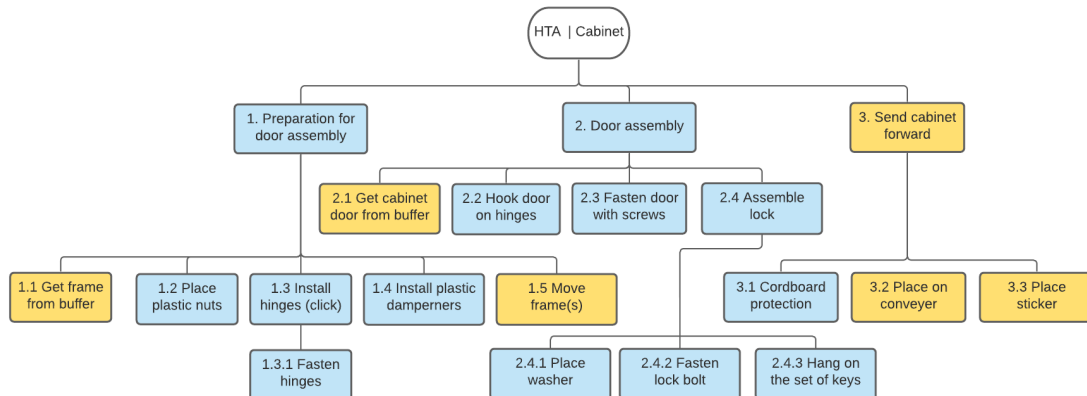


Figure 29. HTA for cabinet assembly

5.3.4 Link Analysis

Figure 30 shows the processing steps for each station in a visual representation of the different processing steps needed in the assembly process. The process uses the steps from the HTA analysis above to show where the task is done. The figure also shows how a worker travels in-between the process steps. The many steps for different stations are colour-coded and steps without worker processing are left blank. The red dots symbolize automated movements or operations, and the white dot is the final step where lockers and draws are marked for shipment or storage. Station 2 (purple) is included but will not have impact on developed concepts as it will be moved elsewhere.

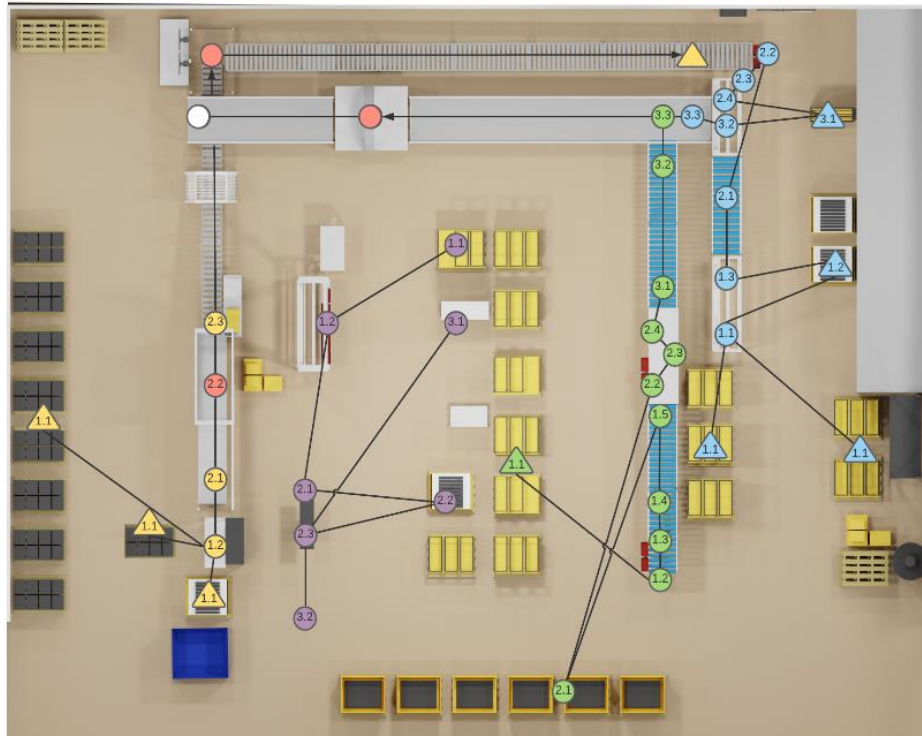


Figure 30. Link analysis for analysing current process flows

Regarding assembly processes, there is a good separation of flows in the current production system for different products. As shown in the figure nearly all tasks can be done without the intersection of each other. There are some intersections though, stations three (green) and four (blue) share the same conveyor belt before packaging which could create buffers and thereby possible idle time. Products from these stations are packaged in the same machine and have a dependency for a worker to process packaged goods fast to not waste time waiting. On the other hand, by having two stations use the same conveyor they do not have to use any extra space.

In figure 30, workers from station 1 (yellow) must get drawer boxes from the buffer, which is located several meters away, in the current state this movement is not as severe as the picture shows as boxes needed for the day are moved closer to the station at (1.2). The same applies for station four (blue) at step 1.2 where workers have a smaller buffer at a time close at hand thus preventing wasted movement. Station three (green) has one outlying process step which is (2.1) where the workers need to move back and forth to the locker door storage for every locker. This is mainly because of the current layout of material buffers; in development, the locker doors could be moved to closer proximity to the door mounting station (2.2).

5.3.5 Proximity valuation chart

In figure 31 desirable proximity is noted with the codes A, E, I O or U which is a scale from "absolutely necessary" to "not desirable". The connections are derived from stations 1,2 and 4 being the assembly of drawers and lockers, the different material flow in/outputs are also noted (A, B & C). The necessary and important relations have operations with connecting material or worker movements.

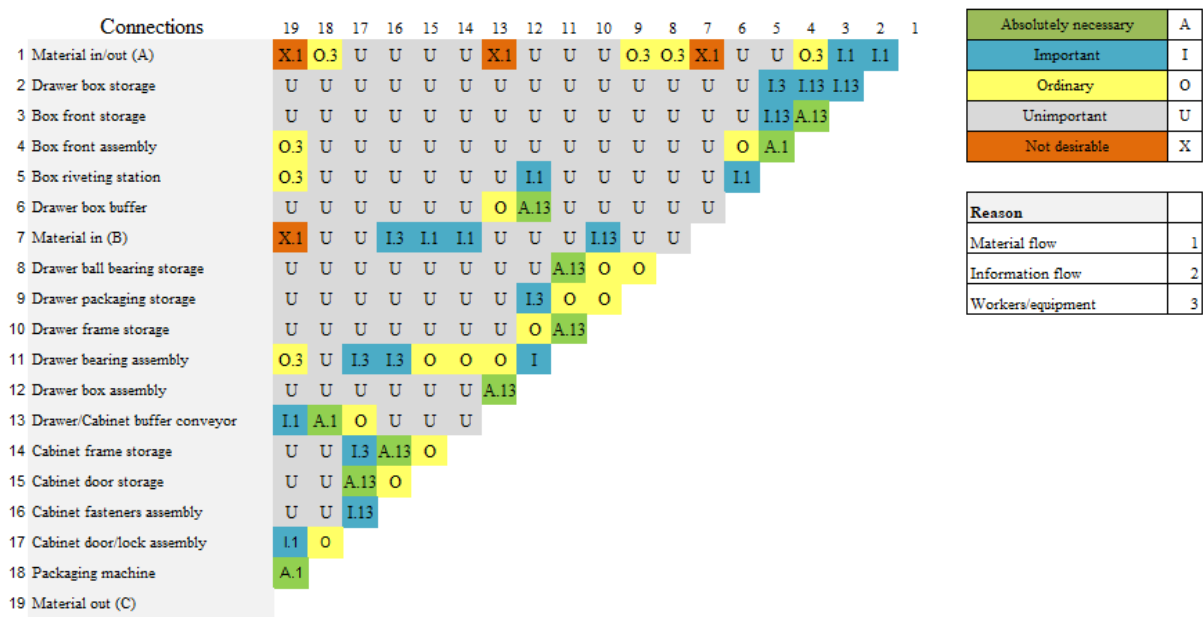


Figure 31. Proximity valuation chart results with descriptions

The connection between the box front storage and assembly station (3-4) is set to A as it minimizes unnecessary movement, allows for fast readjustments and station visibility. For the assembly of drawer boxes, the remaining connections are set as important or ordinary as there are current procedures in place to minimize waste between these stations. Operators move material closer to the assembly station (4) based on the production planning for the day which could be improved but shows that the closeness need is not absolutely necessary, therefore these stations are set to “I”. The drawer frame and bearing storage are set as “A” to the bearing assembly station (8/10-11) to minimize waste and not increase the workload. This is important as there exist some capacity problems when only one worker is present at the station. The connection between the drawer box conveyor and drawer box mounting station (6-12) is also “A” in case the buffer runs out of boxes and shorten the task time as this station is a bottleneck in the current state. The drawer/locker buffer conveyor has necessary connections to the packaging machine and material out connections (13-18-19) to lower the material transport distance. To avoid intersection material flows some of the stations are set to “X” which will allow for more efficient material refills and transport to the warehouse.

5.3.6 Relationship analysis

In figure 32 the relations from the closeness need analysis are mapped out, the connections between the functions and their importance are shown by different line thicknesses. In the figure, the necessary connections are shown by double lines, important connections are single lines. The analysis shows that there are possibilities for improvement regarding unnecessary movement and transport of material, with the connection between box riveting and the box mounting station (5-12/6) being the most apparent. The processes closest to the paint line (7) have many connections between themselves as the workers move between the stations. In the current state, there is no dedicated personnel working at the locker assembly (16-17) because of lower annual demand. This results in the locker assembly having lower priority and workers working here when they experience idle times.

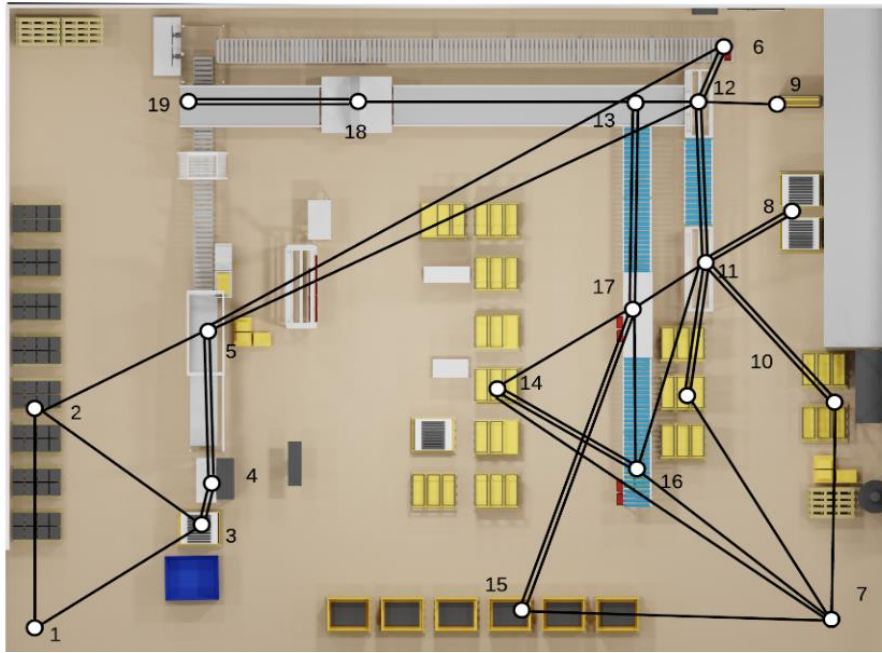


Figure 32. Relationship analysis over important and necessary connections

Figure 33 shows the ordinary connections; these connections are important for everyday operational function, but their closeness need is secondary. Often are these ordinary relationships are connected to workers or equipment and are important as workers move between them quite often during tasks. In the figure, there are a connection between (4/5-19) as the worker at the box assembly takes care of preparations for storage at station 19 when the workers have idle time. They are helped by workers at station 11 which creates a need for operators to travel across the station, creating movement waste. Between (12-18) there is a connection as operators from the box mounting station changes the plastic in the packaging machine from a small buffer of plastic rolls.

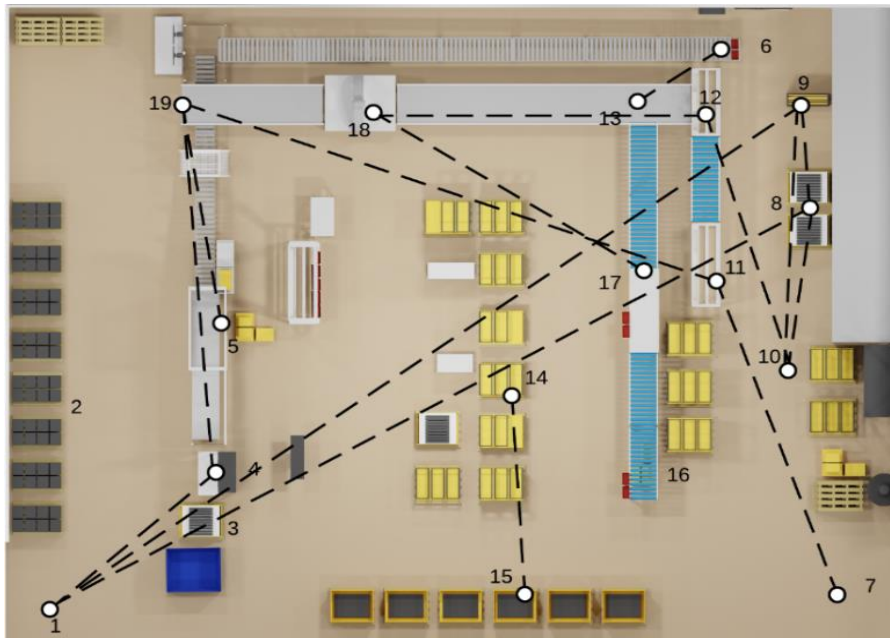


Figure 33. Relationship analysis over ordinary connections needed for operational function

5.4 Summary of layout, ergonomic and flow problems in current state

The current problems mainly concern flexibility aspects in the event of possible changes in capacity regarding personnel and product variation changes. Overall, the assembly processes at the stations in the current state are performed in a flow-oriented manner. Problematic areas and wastes described by operators or found by analysis methods show that some of the largest hindrances for workers at a high capacity could rely on large distances and smaller tasks. These ordinary everyday tasks that the operators are performing simultaneously with the assembling of products create idle time in production which could create imbalances, flexibility problems and capacity losses. From the performed material flow analysis several optimization areas could be identified.

- There are optimization possibilities regarding material flow due to long material transport and some intersecting material flows. Some connections between stations and placing of material results in unnecessary movement of operators which increases processing time.
- There could be a better placement of material buffer to create easier refills, closer proximity to stations and there is not a clear separation of personnel and warehouse trucks.
- There are some synchronization problems with other functions in the factory which could result in production stops and higher production sensitivity which in turn could contribute to larger material buffers.
- There are some unbalances in assembly processing that fluctuates between different products resulting in waiting. There are possibilities to alter processes to further balance production flow and minimize waste.
- The current layout does not have easily implemented possibilities for future expansion and its total area could become significantly smaller by taking production relations into account.
- There are some stations where workers need to repetitively use manual handling for loading and unloading of products in twisted and inclined lifting postures.

6. Future state mapping

This chapter revolves around the evaluation of the assembly stations based on the different analysis results and provides alternatives for the elimination of determined wastes. Solution proposals from theory are also discussed to formulate possible operational and tactical improvements for the future state of production.

6.1 Production development strategy

An interviewed product manager describes that the production development process is not directly part of the company's core business as the product development process in the company has a higher internal priority. Even though it is not the core focus the company says that they put a lot of effort into working with production development and the people who work in it. The company currently has no ambition to become a fully developed Lean production company but instead uses Lean production methods in their production development strategy. The methods that are used focus on benefits the production goals regarding low tied-up capital, increased flexibility, and minimization of waste. One of the main reasons for these Lean principles are used is that the production has too many items to be able to have all items in stock, which means that they must be good at being able to quickly produce or order materials and products, which they say benefits from Lean principles.

They have noticed that in their factory in Mullsjö it becomes very expensive when there is too much manual work. They place great emphasis on being able to develop efficient production systems, constantly working to remove "simple steps", steps that are described as a lot of work and a little refinement and that these operations are a constant problem. They are driving the business towards getting so many finished products and components in from subcontractors and instead focusing on final assembly and quality assurance. This could be applied to ready-made bags with fasteners and products with components pre-assembled from suppliers. The reason is that they want to maintain a high quality, but they want to get rid of some of the costs that are difficult to justify. For elements in production that are difficult to get pre-assembled the company invests a lot of effort into automation e.g.

6.2 Determination of requirements

Results from the brainstorming workshop with production development personnel is seen in figure 34. The results are categorized into three main areas from the "project spiral" methodology that Bohgard et al. (2015) summarizes: production requirements-, functional-, and work environmental. These areas will be the foundation for the design specification and concept development.

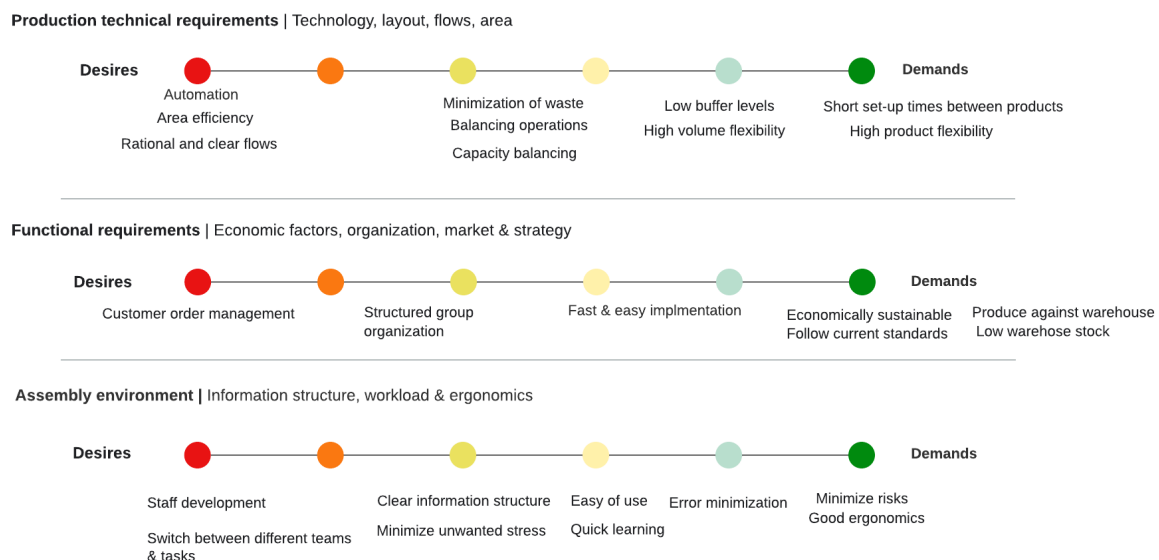


Figure 34. Results from the determination of requirements workshop

6.2.1 Production technical requirements

From the workshop, these technical requirements mainly surround the need for flexibility and fast lead times with the added importance of short changeover times between products and low buffer levels. Some demands that are not as important but still relevant for the development of a new layout is the minimization of waste and the balancing of operations/ capacity. From the company's strategic planning some desires were also brought up regarding possible automation, small station area and rational flows. For this project, the processes and flows for the drawer assembly is the focus when optimizing the value stream, the station is important as the drawers are included in the standard product range and have a high yearly demand. The lockers are secondary, and the extra-long boxes are meant to be moved away if they cannot be incorporated into the new layout. All these products are thought to not change that much soon, but the process flows could change as new products are introduced further on.

To combat the unbalances in assembly processing time seen in the results from the time study, the company could apply principles for assembly line balancing. Boysen et al. (2007) describes that an ALB problem is part of the optimization part of the production and involves assigning assembly tasks among stations in such a way that each station takes equal time. In the current state, the box mounting station for drawers is the bottleneck for the system, mainly because of the added task of fastening the drawer fronts and placing stickers and cardboard protection. To minimize the unbalance of this task they could investigate automating the sticker and cardboard step or give the task of fastening drawer fronts with a screw to another worker. A possible solution could be that the layout enables the box assembly station to be closer to the box mounting station so the workers can cooperate easier.

Furthermore, experimenting with a parallel structure after the bearing assembly could improve the throughput of the station but lower utilization. Jonsson & Mattsson (2016) say that you should plan for higher capacity at stations later in the production chain to minimize disturbances when balancing production. This is because effects of variation, unpredictably in production and manual work sends disturbances down the production line which can create temporary waiting waste, especially in assembly line structures. One problem with this idea would be possible over capacity because the assembly system in current state can keep up with the customer demand. The production planner mentioned that the process could be capacity could be somewhat improved so that the warehouse safety levels are kept all year around. For future state this means that the development of a new system could still utilize existing equipment and production planning but maybe increase the capacity a bit where needed.

Further, Womack & Jones presents the importance of the generation of smooth flows by optimizing value adding steps, balancing production and to rethink work practices to eliminate waste. The current station flows seem to have their dedicated supply lanes but there are some flows intersecting with production flows and material flows which could possibly be optimized. Philips mentions that the layout should opt for straight flows and Lindskog et al. (2016) say that the factory layout should be planned in a way that enables material flows and prevents intersecting flows. The flow analysis showed that there are some changes that some of the material flows move through several turns and some process/worker flows move across the entire station which results in unnecessary transport/movements. Placement of buffers could be arranged so that more frequently used material would be placed closer to the stations, so the workers do not have to turn around or walk short distances.

6.2.2 Functional requirements

The current production against warehouse is an important requirement to consider as this is the core of the company's logistic strategy in focus for any new production solution. There is one desire that could become more relevant in the future. As more special orders come in, there might appear a need for a more customer-oriented production management with fast production planning and lead times for special orders. If this would be the case Garza-Reyes et al. (2012) describe that continuous process flow is important in lean systems as it helps to reduce throughput times, improve quality, minimize operational costs, and shorten delivery times. For the current production strategy: produce against the

warehouse, there could be productivity improvement potential by working towards the generation of smoother flows. By optimizing value-adding steps, further balancing production and rethink some work practices they could eliminate waste in the form of buffers, movement, transport, and idle time.

The company uses scheduled push production that fluctuate based on inventory levels with a batch-oriented planning. One important aspect to consider is the lowering of disturbances, because of existing synchronization problems with other functions. The company could start measuring which parts that are most frequently out of sync and increase the buffer level to compensate. These synchronization problems in the factory would have to be fixed to solve potential production stops and lower the production sensitivity as this could contribute to large material buffers. The paint line seems to be the cause of the synchronisation problem because of many different products and a weekly production planning. One possible route would be for the company to investigate the possibility of pull structures with supermarkets which MudaMasters (n.d.) say could result in a higher flexibility. Another important functional requirement is to aim for an efficient implementation that would minimize production losses in the set-up time for the new system. Any developed concepts should be economically sustainable and be able to follow current operational standards. A new concept should also be possibly operated by the currently active organisational steering method.

6.2.3 Assembly environment

Hitchcock et al. (2004) argue that it is essential that ergonomic aspects are communicated in the development to benefit from the integrated ergonomic contribution of minimising risks and optimising performance. As stated in theory, workers should have control of planning and decision-making within their area. In the current state, the workload is described as good and the operators feel that they can convey their opinion, the most important improvement in this area would be the inclusion of the operators in the further development of the station.

There exist some problematic tasks in current state that are performed in twisted and elevated positions or with heavier lifting and repetitive tasks. Possible improvements for an optimal work environment could be the minimization of monotone and repetitive tasks where self-control and possibilities for more variation in tasks. The repetitiveness is already to some degree combated with work rotations, but the manual handling should be improved to not pose risks for operators with lower physical ability. Possible lifting aid finished drawers could be introduced of the packaging machine conveyor. This would possibly result in longer task time which would have to be compensated, possibly by closer proximity.

Håkansson et al. (2017) describe that low perceived control over work could result in stress reactions. Workers in the current state said that they already have the possibility for social interaction and good communication. The rearrangement of stations needs to take the information and communication channels into account, current state is improved upon so that the distance between connected stations is minimized. The disturbance created by the machines that sometimes do not function properly could also be looked at as operators said that these points could be a hindrance when operating at high capacity.

6.3 Design specification

The design specifications from the mapping of future state and problem analysis is summarized in appendix 8. These requirements act as the foundation for the design and concept development in the ideation phase and covers production requirements-, functional-, and work environmental aspects. In 6 selected requirements have been summarized that are possible to evaluate and compare the layout concepts against. These focus more on functional demands and possibilities for improved flexibility, flows and integration with company's logistics strategy. The possibility for fast readjustments was chosen as the most important demand and the remaining design evaluation as seen in table 6.

Table 6. Design specification developed for evaluation of layout alternatives with weighted values

Requirements	Weight
Allow fast readjustment (Product flexibility)	10
Allow capacity changes (Volume and worker flexibility)	9
Offer fast cycle times (Inventory & waiting waste)	8
Low manual material handling (Motion waste)	6
Structured flow between connections (Transport waste)	7
Surface-efficient layout (Future expansion)	5
Economically sustainable initial cost (Cost and time savings)	8
Integration with company's logistics strategy (Push strategy, batch-oriented production)	9
Easily reconfigurable to match new products (Modularity and reusability)	5
Good social proximity and communication (Allows for efficient rotation of staff)	7

7. Ideation and concept development

The results from the ideation development phase are presented in this chapter. It shows how the usage of idea generation and concept development tools in combination with block layouts and relationship diagrams was used to create four main concepts.

7.1 Brainstorming & Mind mapping

The ideas were categorized into three main areas important for the conceptual layout: “Production structure, Layout & equipment, and work environment” with sub-categories derived from the literary overview. The results from the ideation brainstorming session resulted in a mind map surrounding possible betterments and their effects on production and the company’s future state, appendix 7.

Regarding production structure, three main areas are considered for the development: *parallel*, *line* and *flow group* structures. These were chosen as they represent the tested and heavily used systems that would be possibly good fits for the current state of Modul System HHs production planning. A parallel line structure could increase flexibility and decrease the disturbance sensitivity because of the increased capacity and routing possibilities. These structures strengths are balanced by a more complicated planning, a more expensive set-up and lowering of worker utilization at current product demand. The current production structure is a line-oriented flow group that offers fast lead times and possibilities for standardized work. The current line layout offers good effectivity, but a more dominant flow group structure could pose better modularity and product flexibility. A flow group structure would also pose a greater possibility for user involvement and worker decisions and self-control than a standardized line structure. More flexibility could pose a greater demand on material planning and handling as there could arise a need for a more JIT and pull structure to not build up large buffers.

Layout and equipment summarize some of the ideas for increased visualization surrounding material flows, modularity, and possible automation. The material flow in the current state could be assisted by minimized waste and on flows both to and from the station. Smaller shelves/supermarkets could pose faster finding of components like drawer fronts or boxes. But could be used for frames to move towards customer-oriented production if this becomes the case in a future state. For the moment, when the production is batch-oriented this could result in wasted material handling when the smaller buffers run out. The production could focus more on visibility and support. By using clear signalling like colour coding, visual support surrounding buffer levels or displays. These ideas could pose a possibility for decreased idle time and uncertainty by operators together with instructions. Modularity could be achieved by the usage of standardized modules that are easily reconfigurable or by offering movement for current process stations with wheels.

Ideation surrounding the work environment is divided into *physical* and *cognitive* as these were the most prevalent after observation and discussions with operators. Any organisational change initiatives were not included as the context focused more on flows and processes. At some stations, lifting is done away from the body with libs in rotated and/or extended positions. For these stations, a reintroduction to lifting aid, help with transport and minimization of carrying could help. Even new shelves with more material in one place at good height would be a possible improvement to minimize work positions in inclined positions. Generally, ergonomic aid like rubber mats and components in ergonomic reach distance will be important aspects to consider in the development. Regarding cognitive ergonomics, information panels, better displays and visual elements would help with unwanted stressors, offer good usability, and minimize errors even though the employees said the current ones are sufficient.

7.2 Block layout development based on connections

In this stage of the project, the current equipment on the stations was used in the development of the layouts. The following concepts are based on different production structures singular/parallel and different layout shapes. There are U, L and T shaped layouts to try to evaluate different alternatives. The mapped outflows in some figures use the colours from the link analysis: (Blue = drawers, Green = lockers and Orange = boxes). The numbers in the relationship diagrams are reused from the closeness need analysis of the current state, connections are presented again in figure 35. The developed block layouts used the estimated existing area needs for different functions seen in appendix 5.

Connections

1 Material in/out (A)	8 Drawer ball bearing storage	14 Cabinet frame storage
2 Drawer box storage	9 Drawer packaging storage	15 Cabinet door storage
3 Box front storage	10 Drawer frame storage	16 Cabinet fasteners assembly
4 Box front assembly	11 Drawer bearing assembly	17 Cabinet door/lock assembly
5 Box riveting station	12 Drawer box assembly	18 Packaging machine
6 Drawer box buffer	13 Drawer/Cabinet buffer conveyor	19 Material out (C)
7 Material in (B)		

Figure 35. Clarification of the connections and their numbers

7.2.1 Concept 1: Parallel U-shape concept

Based on the smaller imbalances in the production flow, the parallel concept was developed to minimize idle time and have the possibility for alteration of personnel and capacity. The relationship diagram for the concept is centred around the important connections between the drawer station (10-11-12) where the surrounding stations are placed around the parallel line, see figure 36. A more detailed block layout based on the relationship diagram is also seen in figure 36. The concept uses a U-shaped drawer assembly structure in the centre which allows operators to move between the stations quickly. The parallel structure aims to increase the possibilities for communication by having operators in proximity of each other which could be important due to a possibly more complicated production planning. When needed, the structure would be able to handle a larger capacity while keeping low cycle times.

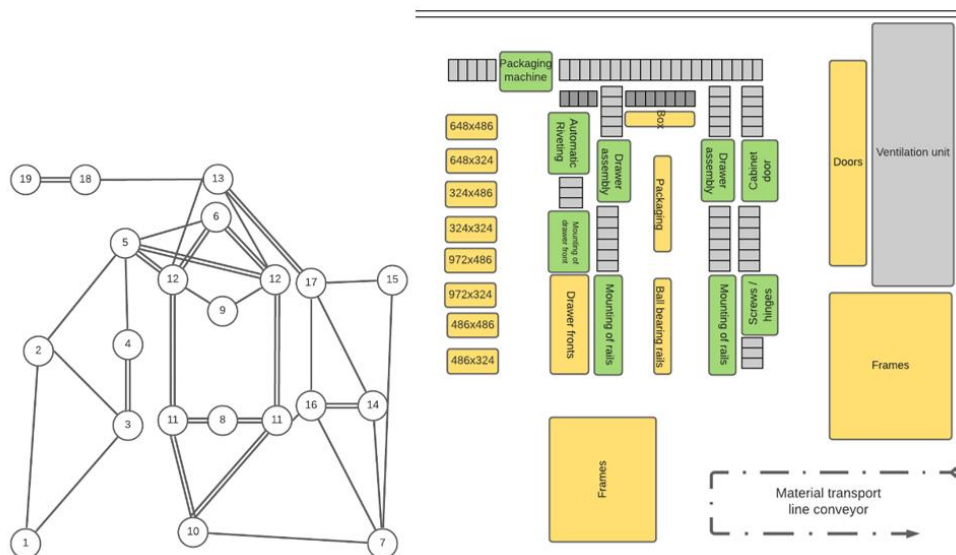


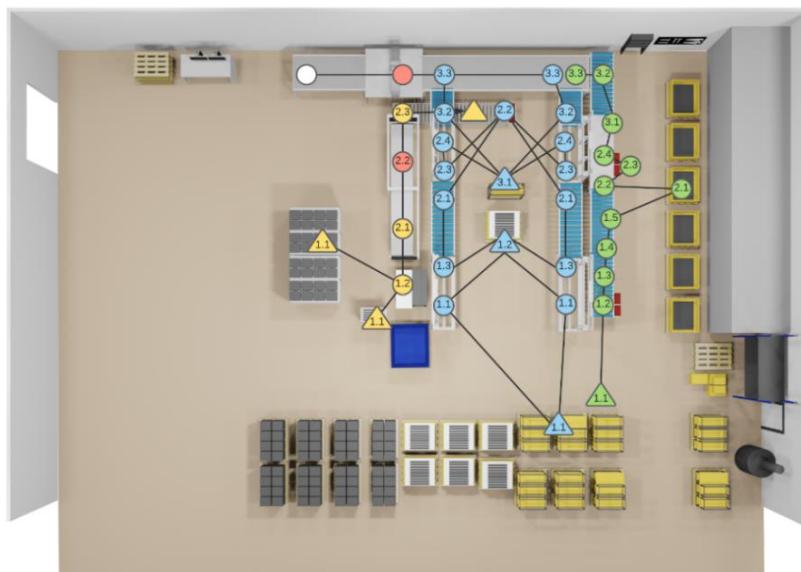
Figure 36. Relationship diagram and its conceptual block layout for concept 1

To combat difficult production planning, the concept has designated areas for shelves/ supermarkets to reduce changeover times and allow for smaller production series to increase product flexibility. In the further development of the block layout, a possibility to store different drawer boxes and fronts in shelves near the box assembly station was implemented, seen in the centre of the 3D model in figure 37. This solution could help minimize unnecessary movement in the case of more customer-oriented production planning. In the current state with the batch-oriented refill strategy, there would have to be larger shelves as they have large volumes of the same products. The idea is that the placement of material could be arranged so that is based on important connections, by placing more frequently used material closer in shelves the assembly workers do not have to stop their work to change out the material. These shelves would be manually loaded, either by workers at the station during idle time or by warehouse/material refilling personnel. An important aspect to consider is that the current demand levels of this layout structure could pose a risk for unutilized equipment and workers and the box assembly station could have to be expanded to provide boxes for two stations. If this is the case, the layout can remove the leftmost drawer assembly station or have it idle while keeping the old layout structure.



Figure 37. Flows of concept 1 for singular and parallel production structure

Figure 38 depicts a link diagram for the conceptual station. The parallel structure does increase the number of flows and will have an impact on material refills as the capacity could increase. The material buffer below the station could help with reducing longer transports to the warehouse for workers at the station. Overall, the process flows follow the current state with some rearrangement of material buffers and stations which lowers material/worker transport. One outlier regarding process flow is the step (blue 1.1) where the drawer frames have moved away to a central material buffer.



7.2.2 Concept 2: Serial L/T-shape

On the contrary, to the parallel concept, the serial concept uses the current line structure as its foundation. The difference from the current state is the placement of stations, these follow a flow-oriented placement based on material flows, this time an L-shaped structure was used to incorporate the locker station and box assembly station into the layout, figure 39. The idea is to have the box assembly station close to the drawer assembly as the operators can move faster between the stations and make for easier operator capacity changes. Jonsson & Mattsson (2016) describes those straight flows are usually best utilized in high volumes of standardized products. In this case, the lengths of the different stations are quite short and will not have a large impact on the station's flexibility, but it could possibly pose some difficulties with production modularity and readjustment in comparison to modular flow group structures.

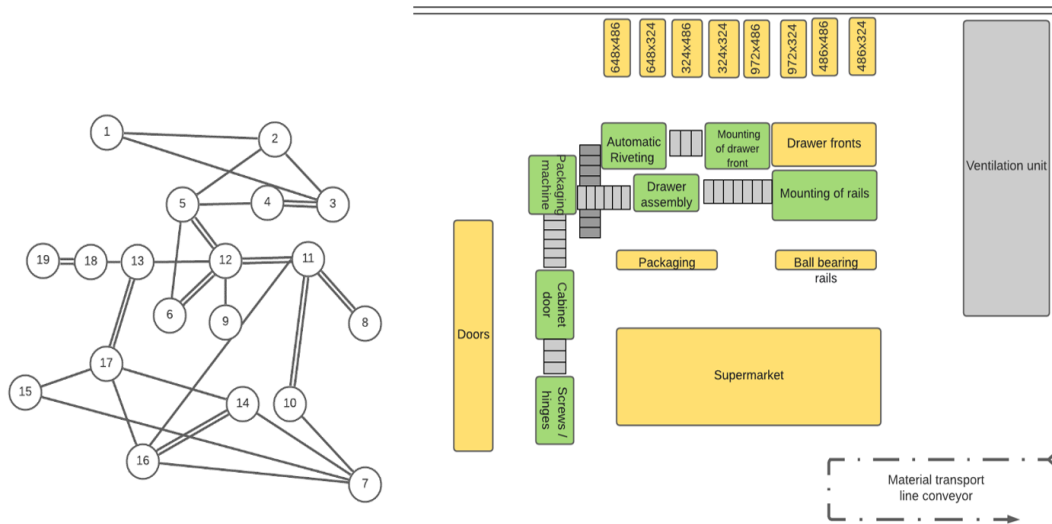


Figure 39. Relationship diagram and its conceptual block layout for concept 2

This concept is designed around the current state production planning, it has a large material buffer for frames in the proximity of the material transport line. It does not use any shelves or other storage solutions and instead uses the current way of storing components for large buffers. In further development from the block layout, the concept had to be turned into what could resemble a T-shaped layout because of the automatic riveting machines current design. In the first block layout, the company would have reconfigured or bought a new machine which could be avoided with some tweaks. A more complete look of this concept can be seen in figure 40 where the main flows are mapped out. One problem with the design for further development is the very short box buffer following the automatic riveting machine. This would have to be fixed, production planners at the company said that a length of roughly four meters is preferred. The distance from the bearing and locker assembly station becomes unnecessarily long which would result in unnecessary movement.

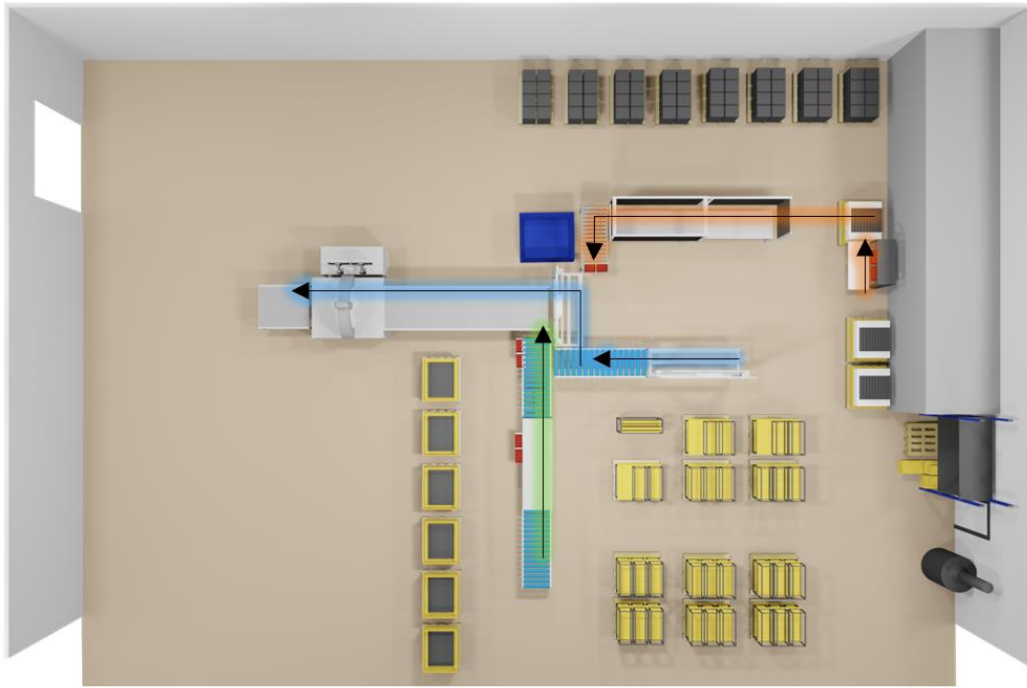


Figure 40. Flows of concept 2

Figure 41 depicts the different links from current state analysis on the concept, the links for the separate stations are structured in a flow-oriented manner. There does exist some unnecessary operator movements, e.g., from the box assembly stations material buffer along the top wall to the drawer front station (yellow 1.1-1.2). When production switches from drawers to lockers, operators need to walk from the drawer to the locker station. In the current state, this transport would realistically not affect the overall productivity of the station, but it could be improved. This relation could be of importance if there will be smaller batches and more switches between drawers and lockers in the future.

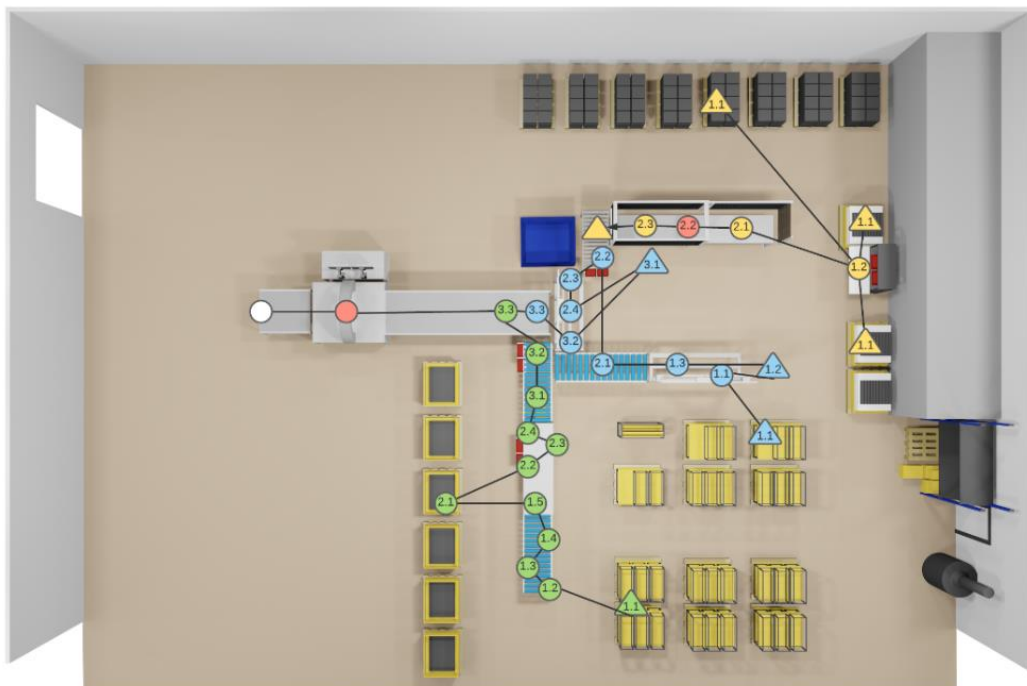


Figure 41. Link analysis for evaluation of concept 2

7.2.3 Concept 3: Flow group T-shape

The development process for this concept can be seen in the relationship diagram and block layout in figure 42. The last concept is meant to follow a more flow group-oriented structure, it takes inspiration from both the current state and concept 2 in the placement of stations. The concept shares the placement of the box assembly station with concept 2 (orange arrow) but the connection between the drawer and locker stations is better considered. The box assembly has the possibility for a larger box buffer and more room for using full-sized EU-pallets with components within the U-shaped area.

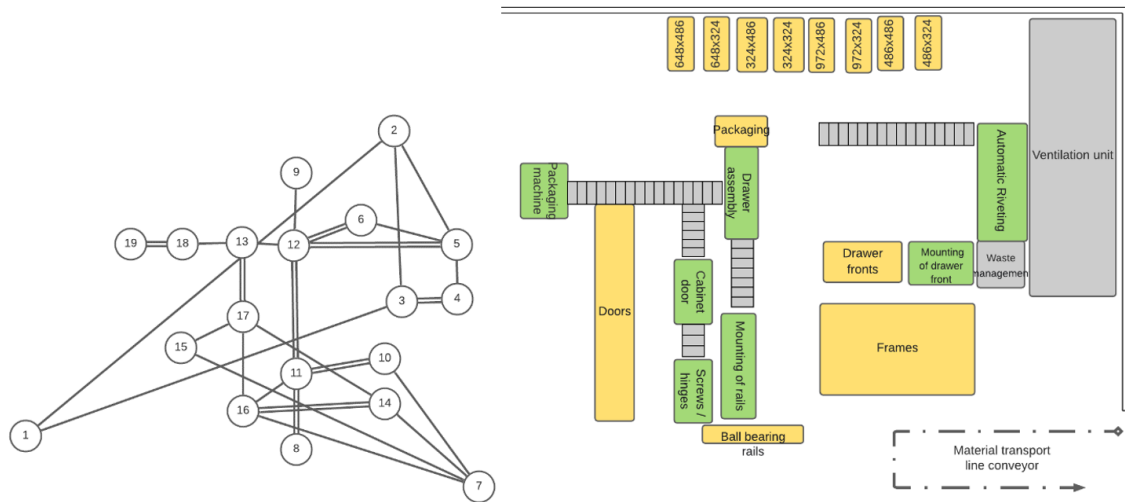


Figure 42. Relationship diagram and its conceptual block layout for concept 3

The main flow for the concept is seen in figure 43, the most important drawer flow is L shaped (Blue) where the locker line follows alongside as it does in its current state. The T-shape in the name for this concept comes from the placement of the box assembly (orange) to the right of the drawer mounting station. The main idea for the box flows is that the operator working here can easily assist the workers at the other stations. Based on the flow analysis, this placement also makes it easier to balance the production as the bottleneck station “Box mounting” can get help with the fastening of drawer fronts.

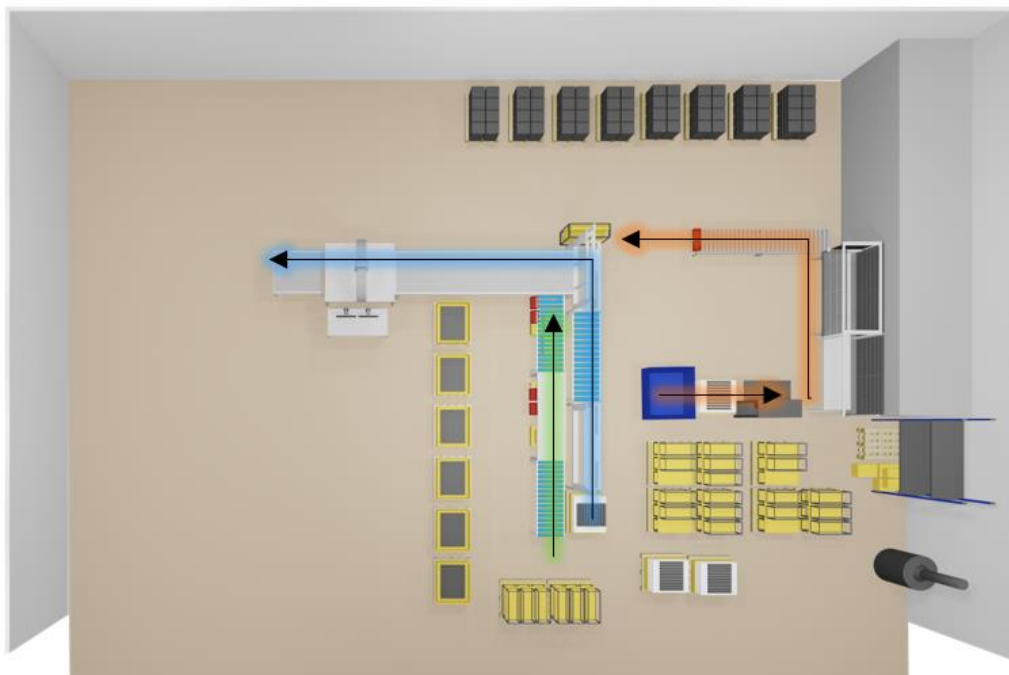


Figure 43. Flows of concept 3

The layout is also designed for flexibility regarding operator capacity because of the closeness needs between the stations. Overall, this concept is flow-oriented where the biggest changes are the shortening of the locker station and movement of the box assembly. This enables for storage of boxes alongside the top wall. Frames for both drawers and lockers in the same area and have the locker doors are placed near the locker line, which lowers manual handling. From the link analysis in figure 44 there exist two outlying processes that could be further improved, the material flow from the inner boxes to the front assembly (yellow 1.1-1.2) and the turn for workers to get boxes (blue 2.2-2.3). These problems arise as the boxes from the automatic riveting machine go via a transport conveyer to the box assembly station which intersects with material flow from the box buffer along the top wall. The workers need to turn to get a box is a waste that would have to be further developed.

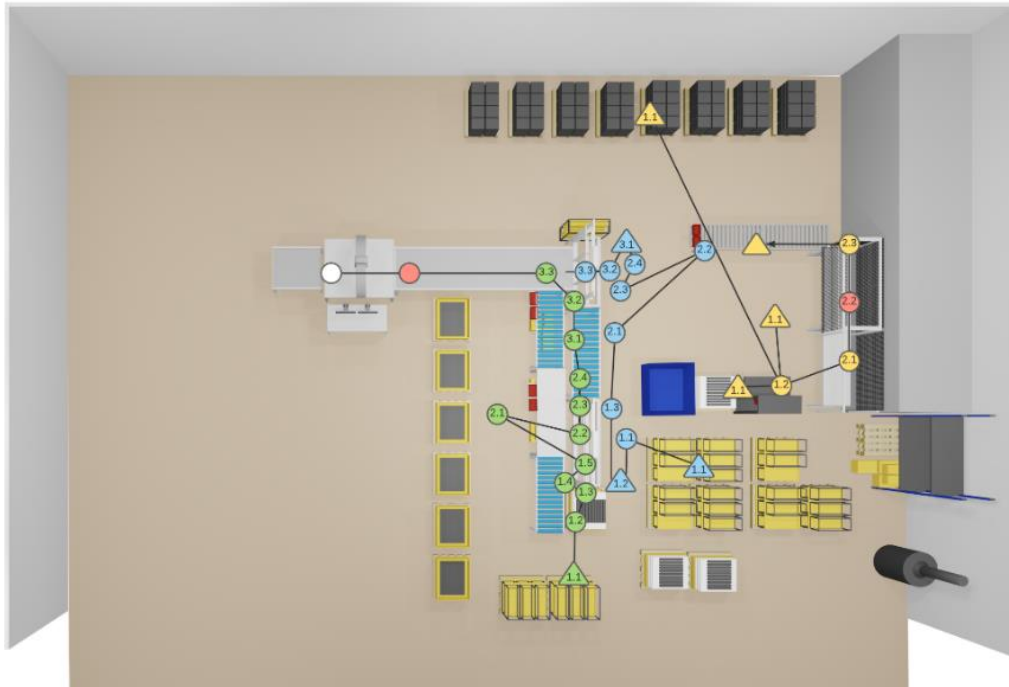


Figure 44. Link analysis for evaluation of concept 3

7.3 Evaluation and choice of concept

Figure 45 depicts the evaluation of the three concepts, the highest score at any given requirement was E or *effective*, to gain an A or *perfect* rating would be difficult for these conceptual systems as they have not been through a detailed development phase. The results from the evaluation showed that the Flow oriented T shaped layout fared best against the other concepts when compared against the set-up requirements. No concept had any ratings of U and X and some solutions were given an I for *interesting* rating for possible further evaluation in further development. The evaluations are based on discussions and comparisons with each other and the current state. Many of the requirements were difficult to judge fairly in an early state so even though one concept one the evaluation, ideas from the others will be used in the development of the final one.

Project	Date	Resp
Master's thesis Moduls System HH AB	2021-04-22	Oskar Abrahamsson

Requirements	Weight	Parallell U	Serial L	Flow T	
Allow fast readjustment (Product flexibility)	10	E/30	O/10	I/20	A = Perfect (4) E = Effective(3) I = Interesting(2) O = Ordinary(1) U = Insignificant (0) X = Not desirable(-1)
Allow capacity changes (Volume and worker flexibility)	9	I/18	I/18	E/27	
Offer fast cycle times (Inventory & waiting waste)	8	O/8	I/16	O/8	
Low manual material handling (Motion waste)	6	E/18	O/6	I/12	
Structured flow between connections (Transport waste)	7	O/7	I/14	E/21	
Surface-efficient layout (Future expansion)	5	E/15	O/5	E/15	
Economically sustainable initial cost (Cost)	8	O/8	O/8	O/8	
Integration with company's logistics strategy (Push strategy, batch oriented production)	9	E/27	I/18	E/27	
Easily reconfigurable to match new products (Modularity and reusability)	5	I/10	O/5	O/5	
Good social proximity and communication (Allows for efficient rotation of staff)	7	I/14	I/14	E/21	
Sum		155	114	179	
Results		2	3	1	

Figure 45. Evaluation and choice of concept

As seen in the figure above, the third concept called “Flow T” got the highest score of the three compared concepts. Based on the flow-oriented T-shaped layout, the concept was further evaluated by a group discussion that followed the presentation of the ideas to the company. To include their perspectives into the detailed development results from an ideation workshop that the personnel at the company provided was also incorporated into the design, see appendix #. This layout proposal from the company’s production designers was also T-shaped. From my understanding, the provided concepts main design idea was to create a more continuous flow from the paint line to the drawer station by moving the drawer station closer to the paint line, possibly lowering buffer sizes and the manual handling of frames. The evaluation and choice of concept phase ended with a combination of their idea and the winning concept seen in figure 46 where some of the shortcomings were fixed. In figure 46, the automatic riveting machine was accidentally mirrored which needed to be changed in the detailed development.



Figure 46. Further developed layout based on evaluation winner/ concept from company

8. Detailed design of the production system

In the detailed production layout planning ideas from the future state mapping and ideation have been incorporated into the development of the highest-rated concept. In this chapter, the final conceptual layout is described and evaluated against the current state.

8. 1 Assembly station layout and connections

Figure 47 shows a view over the proposed final layout, and some new details and components that are seen later in this chapter. The warehouse connection is located to the left and outgoing goods is stored in a reserved area by the gate. On the floor, there are ergonomic working mats placed out at the stations as the workers mentioned strain in their feet. In the bottom right, the paint line is seen, in this new layout, it is near both the drawer and locker line. The layout total surface area has been made considerably smaller which allows for the component storage for the stations to move closer.

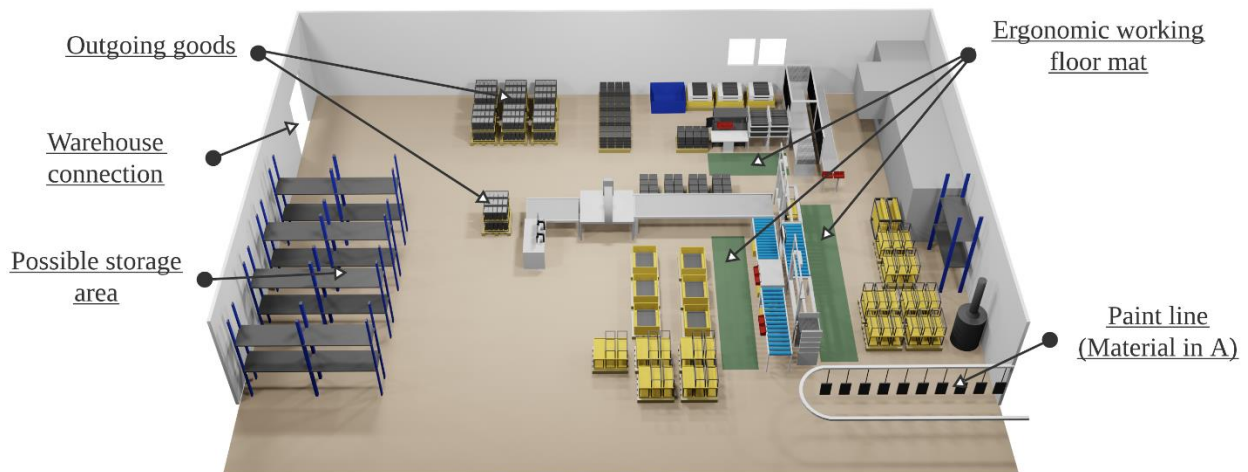


Figure 47. View over the proposed final layout, and some new details and components

Operators mentioned that the distance between stations could be a hindrance in the current state both for flows and communication. By the description that Wang et.al., presents this could be considered a bottleneck from a sensitivity-based perspective. By taking the described hindrances from operators into consideration, many smaller operations and hindrances that affect the overall system throughput could be changed. In the proposed layout seen in figure 48 the placement of stations is based on needed proximity, this could improve the flexibility and cooperation between functions.

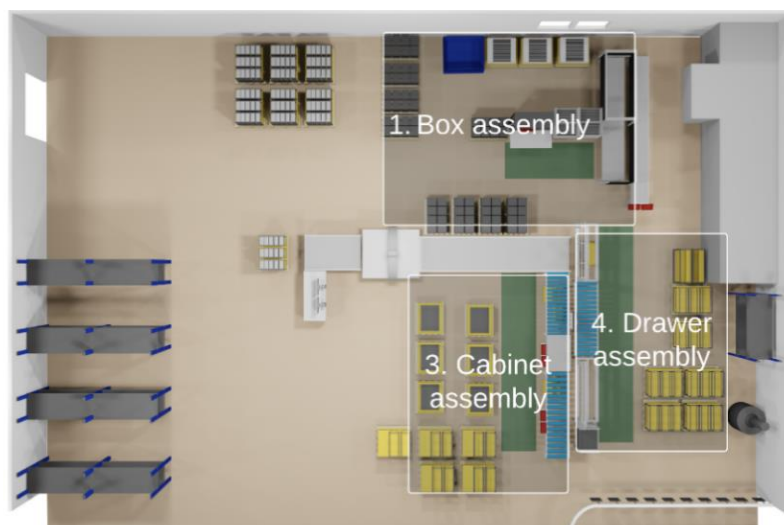


Figure 48. New assembly station layout with station 1.3 & 4

The increased closeness also lowers unwanted movement and enables better balance as the operators can aid each other with tasks from bottlenecks as describes from a *performance in processing* (PIP) perspective. By focuses on the real-time performance of the system, the station with the highest utilization ratio is considered as the bottleneck, in the current state, this is the mounting of drawer boxes station. In the proposed layout the worker from the box assembly station could walk over and aid with the fastening of drawer fronts from the riveting machine, in figure 49 this would be the movement from station (1-4). Station 2 (Long boxes) is not included in the final concept but could be placed where the pallet racks stand as seen in appendix 11 if needed, this area could be used for special orders.

A relations comparison between new and current layout is seen in the figure, many of the important and necessary connections flows have been shortened, seen also in appendix 12. One central aspect is that recourses have been arranged with the material flow as the foundation. The assembly of drawer boxes has been moved closer to the box mounting station. Preparation of products before being sent to the warehouse has a closer distance to the bearing assembly station to lower unnecessarily movement. The process flows and many other changes were implemented by giving importance to relations in the layout from closeness needs and operator feedback. A new layout based on connections could according to Philips (1997), help optimize flow, minimize manual handling, shorten cycle times.

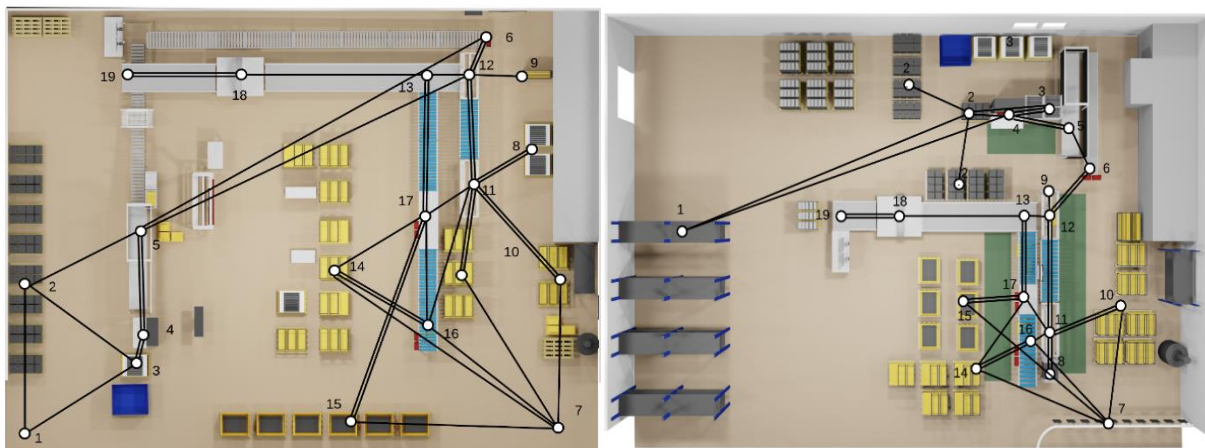


Figure 49. Comparison between connections from current state and new layout

Figure 50 shows a comparison between the link analysis over the developed concept and the current state. The drawer and locker stations process flows are kept from the current state but have been shortened to make room for the box assembly at the top. Both lines still have room for smaller buffers and are now closer to the paint line to possibly incorporate a more continuous flow. The drawer station has been moved down so it is placed back-to-back with the locker station, which lowers wasted movement. A larger version of the new layout's flows is seen in appendix 13.

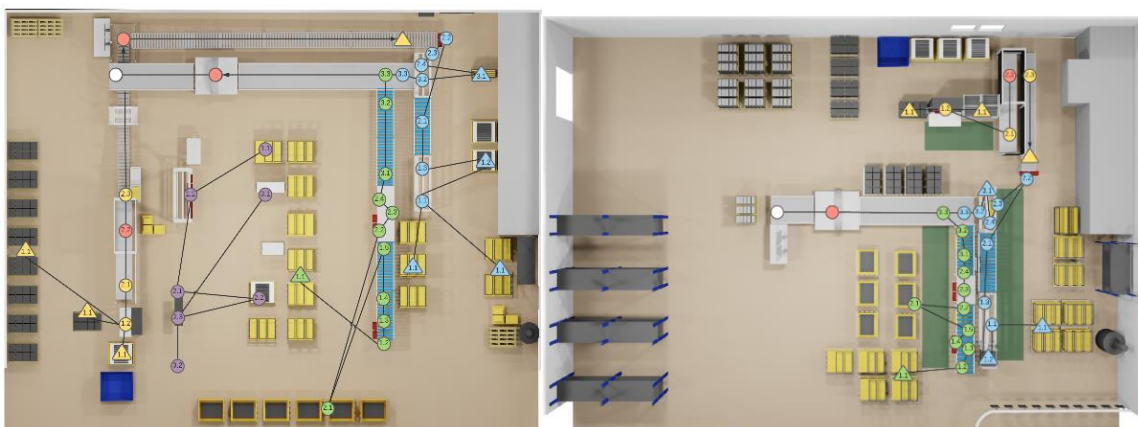


Figure 50. Comparison between process flows from current state and new layout

The developed layout tries to follow what Lindskog et al. (2016) emphasises, the design incorporates short direct transport and a material flow-oriented layout where material buffers have been rearranged to be closer to workers. It incorporates some smaller two-bin supermarkets systems from concept 1 (Parallel) that should lower unnecessary walking/ carrying for station workers and increase product mix flexibility and possibly ease of use/ visibility. These have been placed at the box assembly station and the bearing assembly station for different bearings and drawer fronts. The idea comes with the added task of refilling these smaller buffers, by using a refill/ two-bin system it would be quite easy for material handling personnel to recognise when material buffers are running low.

8.2 Changes to workstations and material buffers

Figure 51 shows the *drawer assembly* station that has moved into closer proximity to the paint line seen to the left. The line structure has been kept but there are new details trying to optimize process flow like displays and buffers. To the left of the bearing assembly station, a small buffer at working height has been implemented. Workers at the station described that having to turn around was a hindrance and this could be a possible solution. By having the components closer and in reach distance, unnecessary movement is lowered when getting bearings from the material buffer. This buffer is located behind the worker in the current state. Another implemented idea is the fixed cardboard protection buffer under the box assembly station (right) possibly lowering the cycle time of the station and thereby helps balance the processing time for the current state bottleneck station. Boxes from the automatic riveting machine come in from the right as in the current state. One difference is that there is an opening between which allows for movement between this station and the box assembly. The area designated for frames have been made smaller which could become a problem at low operator capacity, the idea is that the possibility for a shorter cycle time should balance this possible problem.

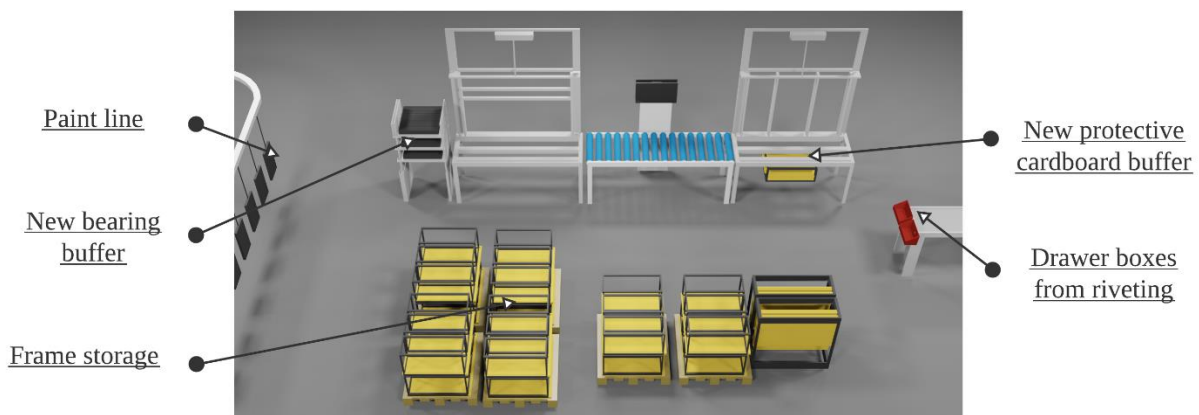


Figure 51. Changes and description of the drawer assembly station

Figure 52 shows the *locker assembly* this station keeps the layout from the current state, with the main difference being a shortening of the whole station. It also has an added information display and changed in the placement of the material buffers. The stations lower priority enabled me to make it shorter in favour of the flows-oriented layout. The process flow for the locker line stays the same but the locker frames and doors material buffer placement has been switched, this decision is based on the link analysis from the current state that showed unnecessary material transport and worker movement when getting doors.

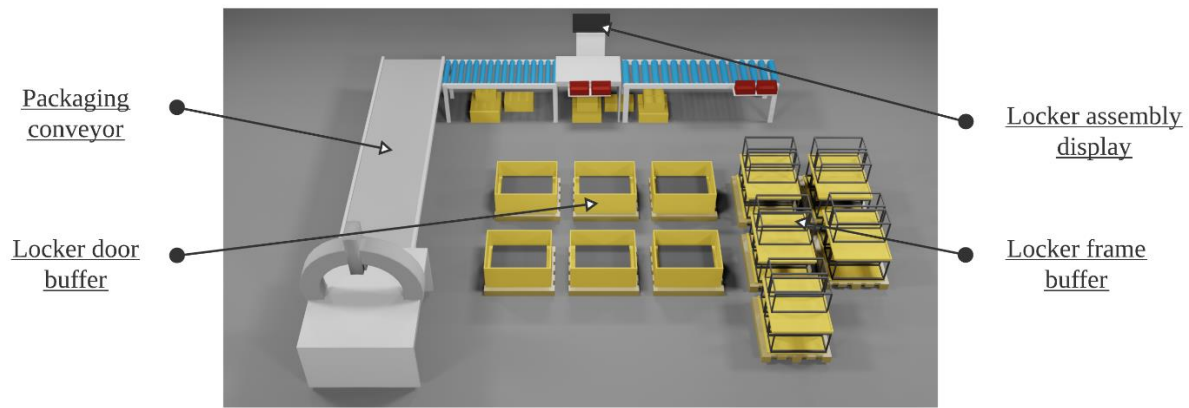


Figure 52. Changes and description of the locker assembly station

The last station *box assembly* is seen in figure 53, the redesigned station layout is developed to be placed near the drawer station along the top wall. The main assembly table in the middle has inner boxes to the left and drawer fronts in a small two-bin supermarket system to the right, and with just a turn the worker can access the automatic riveting machine to the right. The station incorporates the material storage for boxes in an L-shape which gives good proximity for different boxes to the front assembly table. The whole EU pallet is meant to be brought forward and placed next to the table according to production planning. If buffers are running low, there is room to the left of the station for components. The front panels are stored behind the table along the wall and material personnel can therefore refill the front buffer from the back and not disturb process flows. The area also has the waste management container along the top wall which is meant to be moved with a manual pallet truck.

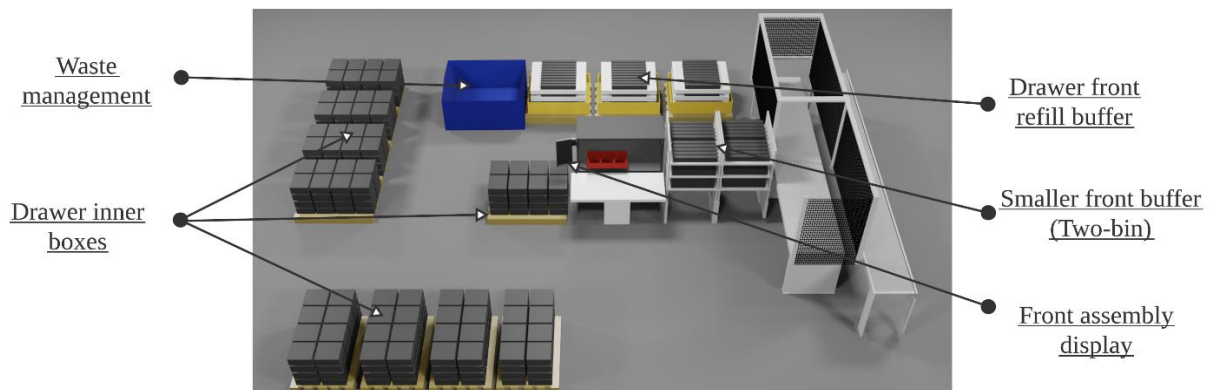


Figure 53. Changes and description of the drawer box assembly station

In all the conceptual systems there are incorporated information displays mounted on the stations. There is one between the drawer/locker lines and one to the left of the box assembly station. These displays main function would be to give workers information surrounding the production planning and overall station goals. A conceptual information panel is seen in appendix 14, it focuses on production planning, the article numbers are listed in the order that they should be assembled for lockers/drawers or boxes. The panel could also incorporate production information like the number of units made or planned and possible KPIs (Key performance indicators) like the station's efficiency or quality output. This system could help with flexibility by providing the needed information at a fast glance and help with future development projects as goals could be set up and the progress towards them shown to the workers.

9. Discussion

This chapter evaluates the results from the report from the theoretical viewpoint, the evaluation focuses on future development and the impact of changes in the current layout. It answers the main research questions and finishes with some recommendations for future development.

9.1 Analysis of results

The theoretical framework has been of great importance for the objective of the project of using theory together with user participation to find effectivity deficiencies and strain in production. Throughout the project most identified, problems have been connected to production balance, flow, or equipment. But without user involvement which theory states is of great importance, I would have missed many of the disruptions and stressors that exist for the employees and thereby perhaps made the wrong decisions in development. They also mentioned which material flows and processes worked well and what they thought could be improved, they told me about difficulties in accessing material stocks and buffers.

By discussion with both managers, production technicians and employees a clearer image of the current state could be obtained which help me to find the relevant theory to help with development. Throughout the project, some uncertainties appeared regarding the future state which made it difficult to estimate the company's upcoming needs in production. The most important aspects gathered from the development personnel and management would be high product flexibility, low cycle times and possibilities for the alteration of production personnel. Finding the theory that would incorporate these aspects with the current logistics strategy of a scheduled push against refill levels was a challenge. Increased flexibility demands and possibilities for operator capacity changes made it difficult to balance production by not knowing how many workers would be present. Because of these limitations, a larger focus was put on the layout itself, workstations, important connections, information/ closeness needs.

9.2 Relevance of the work to the user, company, and society

The project itself does focus on development and therefore there is no clear relevance of the layout results for most people outside of the company. However, the combination of an efficient layout based on connection and closeness needs together with the psychosocial work environment could increase motivation and reduce strain for workers. Existing flows are shortened which could decrease cycle time, the closeness need enables people to cooperate and communicate better. Flexibility does depend on a large variety of factors; in this project, I have talked with people on different levels in the organisation. I conclude that the individuals and their prerequisites seem to be one of the most important aspects for increased flexibility.

9.3 Project's contribution to sustainability in production

The overall flows are important but have many limitations in an existing system. In a manual assembly where there exists a lot of uncertainties and many different variants, enabling self-control and providing the right information at the stations will be the priority for future projects. If implemented broadly, these sociotechnical aspects as the theory mentions have a positive impact on economic sustainability through increased performance by a more effective assembly, shorter cycle times and higher product and process flexibility. Remember to include both positive technical and social assembly station properties that Säfsten & Aresu, (2000) presents in the development. Standardized systems, modularity, balanced flows with low disturbance sensitivity works best if the system is easy to use, have great visibility and incorporates a good information system. Possible results from these factors could help create a flexible and efficient station that takes human limitations, interactions, and motivations into account.

9.4 Answering the research questions

- Are there production balance losses and wastes in the current station's layout planning?

The current layout is functioning well and is flow-oriented, the workers have good knowledge of how to perform several of the stations and move between stations quickly. Found production losses mainly arise as several stations have connections and personnel flows between them but are far apart. There are some unnecessarily long material transports and material buffers that could be moved closer to their assembly stations and be placed within reach of the operators. Operators also mentioned that some material buffers are harder to refill as they must move away from other buffers first. Some components, mainly the material buffers for frames could be made clearer by FIFO lanes or visual support, operators mentioned that it sometimes can take unnecessary time to find the correct components article number. How could the assembly station layout be developed to help streamline the production?

According to Philips (1997) the most important aspects in optimizing layouts are material handling, cycle time, eliminating storage queues, and lowering non-value-added operations. Many of these concerns were considered in the final concept, which is based on connections, closeness requirements, and process flows. Take closeness requirements into account in future development but remember to consult with operators and try to discover solutions for buffer placement to enable flow and proximity of stations to eliminate unnecessary transport and operator movement. Talapatra et al. (2019) argue that a company must manage the production line well and distribute the workload over different workstations to obtain the maximum production line performance or efficiency. The proposed layout could aid with the development towards more flexibility and efficiency in production by focusing on the hindrances the operators are facing.

- How can the working environment be developed to promote social sustainability?

Operators could be involved in the implementation of new solutions to ensure that ergonomic factors and challenges are well communicated. According to Bohgard et al. (2015), it is critical in the creation of work processes to consider employees' working circumstances. This is to minimize interactions in the environment that create alarm reactions. The corporation should maintain their effective communication throughout the organization, as well as provide opportunities for people to change their work environment and tasks. Reduce potential ergonomic or cognitive impediments an important component of the development process. This relates to what Abrahamsson & Johansson (2013) say an organization with a good psychosocial work environment function better, is easier to develop, and provides better opportunities for flexibility and cooperation. Furthermore, some changes to material buffers could be made to limit inclined or twisted working postures and help avoid keeping joints in the outer position. There also exists some lifts that are straining with the most prevalent being the unloading of packaged drawers/lockers of the packaging conveyor.

9.5. Recommendations

Use the results from the flow analysis and conducted interviews to understand the hindrances that operators are facing, the results from the flow analysis to understand what can be improved. Philips (1997) describes, the company should try to implement a continuous, ongoing improvement for the production process and plant layout, as it is essential to achieving a competitive advantage. The company does not want to become a strict “Lean production” company but could make usage of the idea of *Pursuing Perfection*. There is no end to the process of continuous improvement, the “peruse perfection attitude” should start with a policy or vision of the ideal process. The generation of *smooth flows* is also important, start by improving the process bottleneck, currently being the drawer box mounting station. But remember sensitivity-based bottlenecks which also play an important role. When this step is done, try to improve upon the results from this project or find new solutions to the problems summarized in 5.4 (Summary of layout, ergonomic and flow problems in current state) which shows both technical and social improvement possibilities. The future state analysis gives a good insight into the different demands that was identified by talking to different people in the organisation and could be of help to identify goals.

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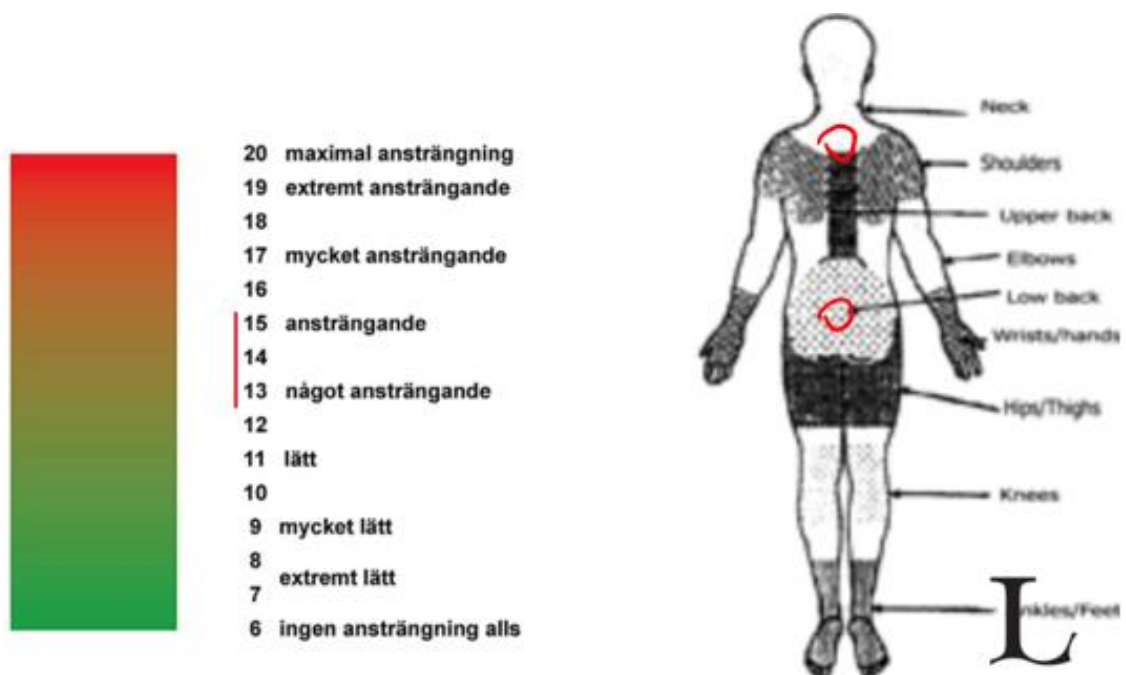
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11 Appendixes

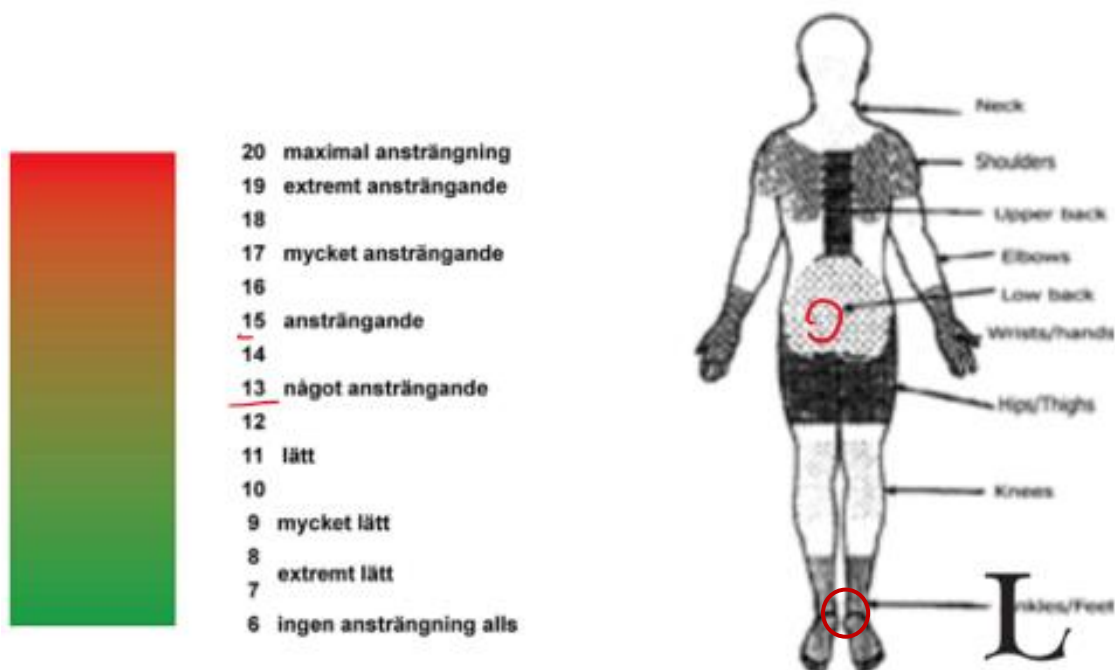
Appendix 1. Interview questions for operators regarding the current burdens and problems.

- What do your usual tasks look like?
 - Can you control the way of working, self-control regarding work distribution and way of working?
 - Do you feel any strain, if so where on the body, which stations?
 - Do you feel stress surges in your work, which stations, tasks?
 - Is the workload manageable? Is there a possibility of recovery?
- What do you think about the work environment and the design of the stations today?
 - What disruptions are there in the work?
 - What should be improved?
 - What should not be changed?
 - Physical: There are repetitive movements, poor posture, one-sidedness, or heavy lifting
 - Cognitive: Do the systems used work well? Are they easy to understand?
 - Is the workload of the stations well distributed?
 - What could be changed?
- How does communication take place?
 - Is the necessary info easily accessible?
 - Are there instructions in place?
 - Do you always know what to do, who do you ask if you do not know?
 - How well does the control and cooperation at the station work?

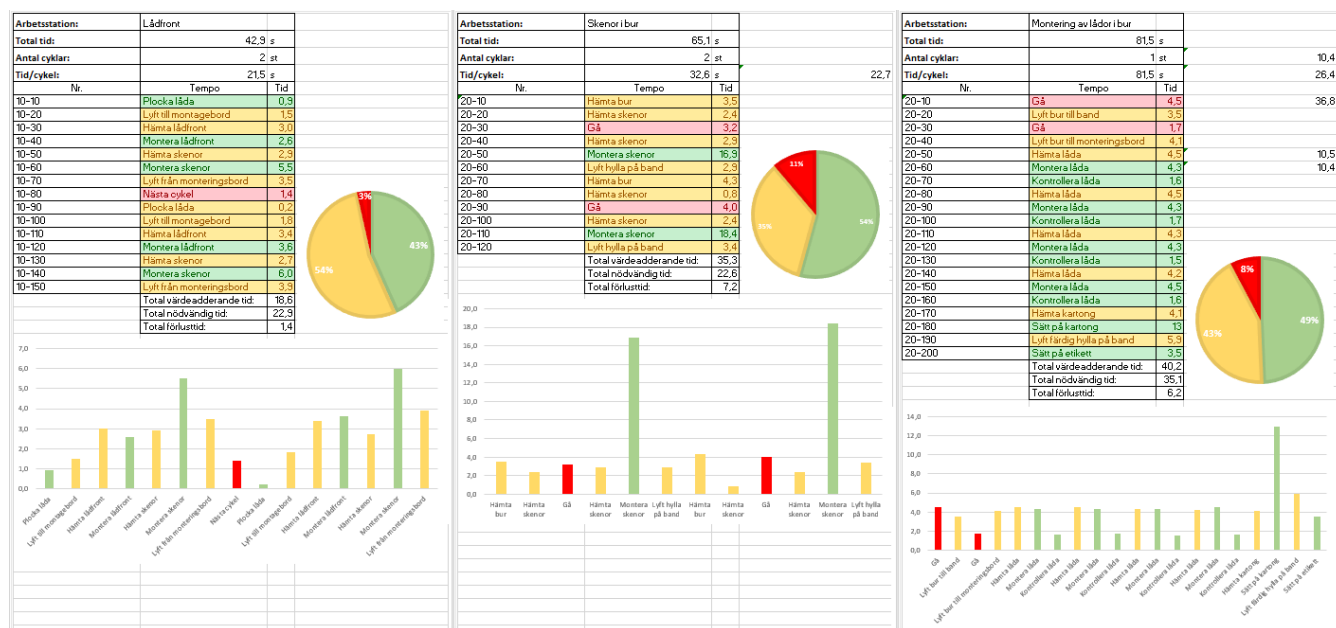
Appendix 2. Subjective ergonomic evaluation using Borgs RPE-scale and body map for unloading of drawers/lockers onto pallets for warehouse



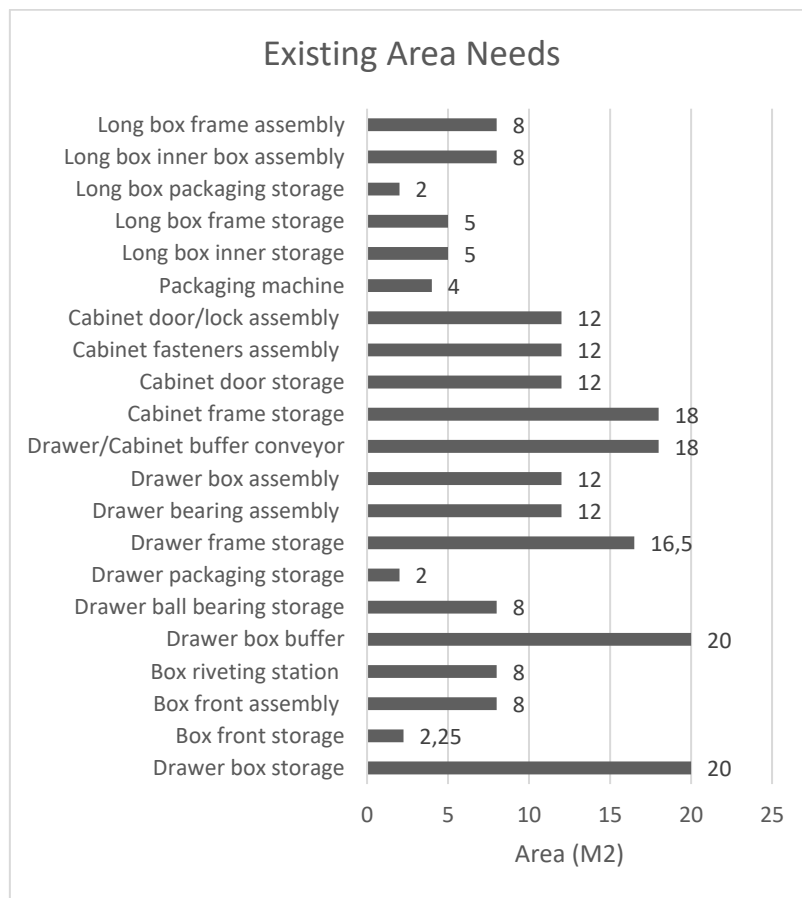
Appendix 3. Subjective ergonomic evaluation using Borgs RPE-scale and body map for the drawers assembly station.



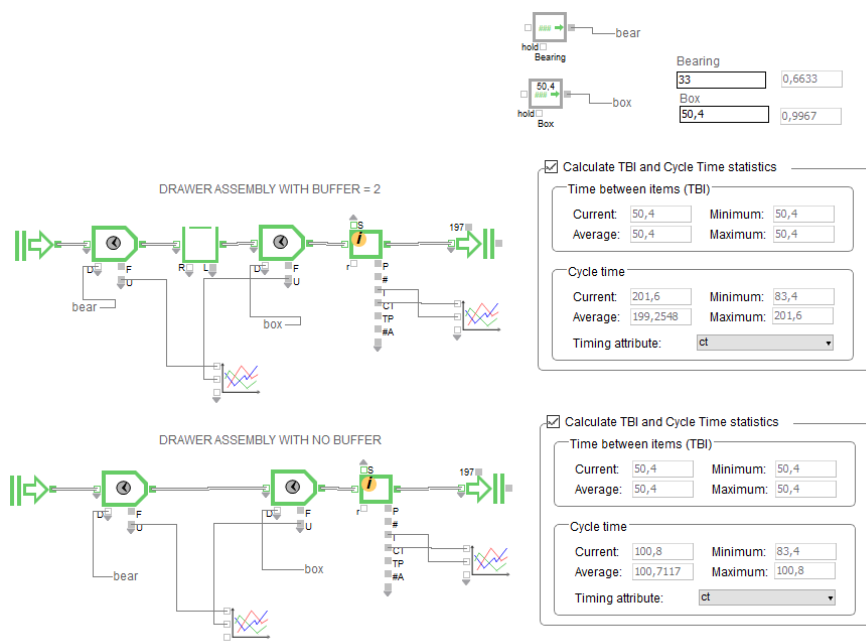
Appendix 4. Time study data from Modul System HH AB



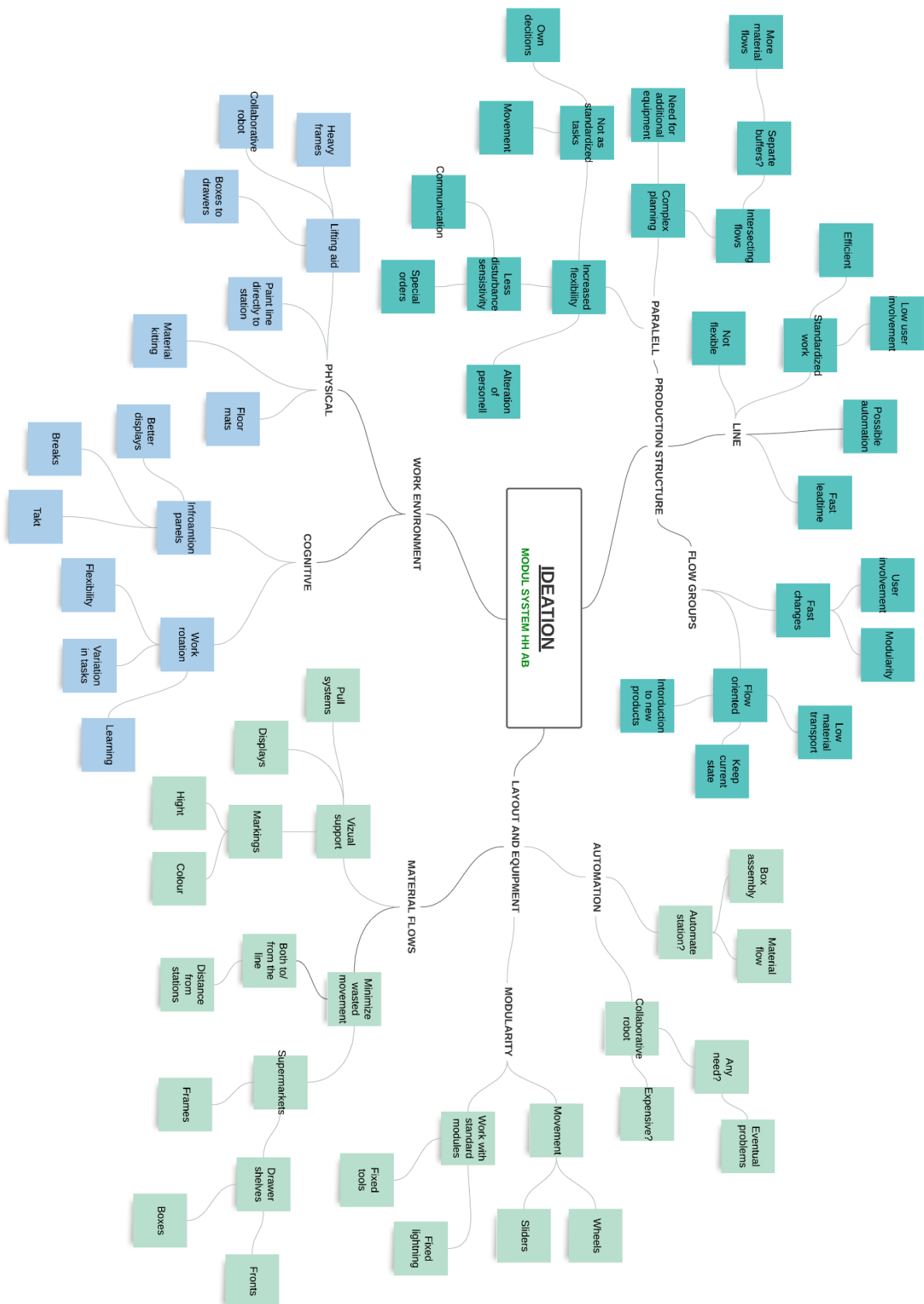
Appendix 5. Estimated existing area needs for different functions in current state



Appendix 6. Time simulation in ExtendSIM for the drawer station



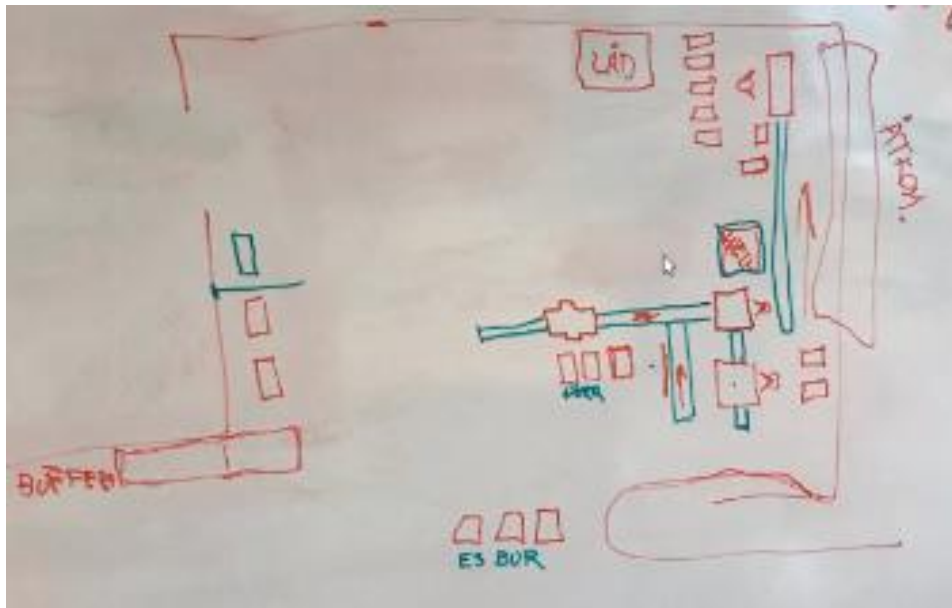
Appendix 7. Resulting mindmap from the brainstorming session



Appendix 8. Specification of requirements for the three main areas

Production requirements Technology, layout, flows	Allow fast readjustment between products	D
	Allow smooth capacity changes	D
	Offer fast lead times & Balanced proceses	D
	Lower manual material handling	D
	Strucutred flow between important connections	D
	Surface-efficient layout from closeness needs	D
	Allow for the possibility of automation	W
Functional demands Finance, organization, strategy	Economically sustainable initial cost	D
	Integration with company's logistics strategy	D
	Easily reconfigurable to match new products	D
	Allow for fast implementation	W
	Enable future customer order processing	W
Assembly environment Information structure, workload & ergonomics	Good usability and minimization of errors	D
	Minimize risks and provide good ergonomics	D
	Allow for efficient rotation of staff	D
	Good social proximity and communication	D
	Allow for sharing of equipment and personnel	D
	Offer clear information channels	W
	Allow for versatile work content & learning	W

Appendix 9. Block layout from production development personell at Modul System HH AB

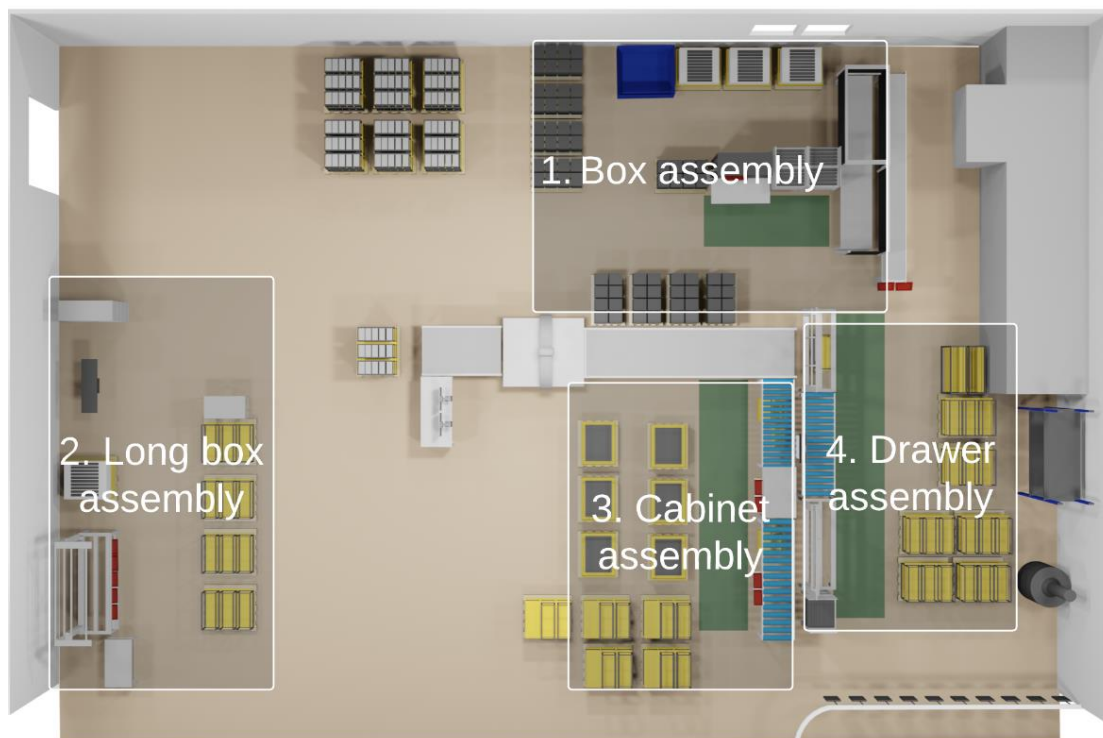


Appendix 10. Detailed production layout planning, Philips (1997)

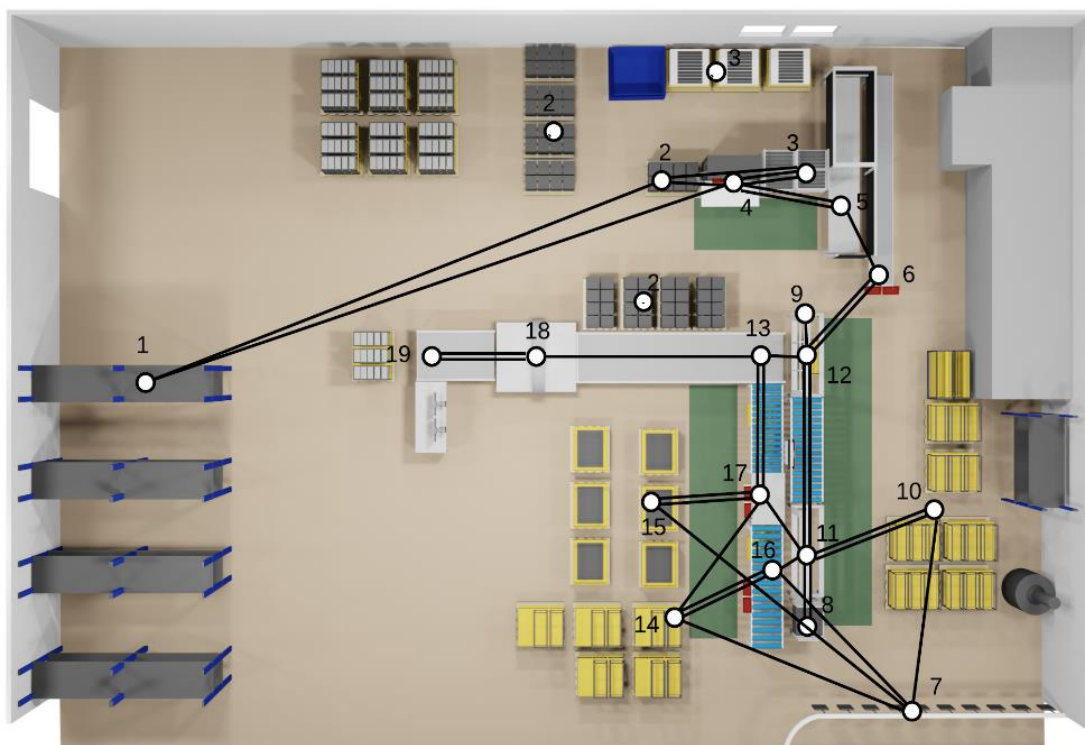
There are a number of questions that have to be answered during the detail layout phase:

- How will materials be delivered and taken away from the detail area and where will the pickup/set down points be placed?
- Are all materials within easy reach of the operators? Have we taken ergonomics and human factors into account? Are people working with or against gravity?
- Will special lifting or rotating equipment be needed?
- Has all necessary equipment been specified and regarded? Chairs, tables, boxes etc.
- Do we need a second floor arrangement?
- How will power, water, compressed air, telecommunication, computer communication be distributed to and within the detail area? Is there enough flexibility?
- How are return flows arranged? Activities that probably will expand must be placed where expansion is possible. How is scrap handled? Where are containers placed?
- Is there any wasted walking, reaches or other unnecessary movements?
- Has the layout contributed to low idle time? Is there enough slack time?
- Can an operator perform additional tasks?
- Can equipment be served and maintained properly? Can equipment be installed and moved in an acceptable way?
- Are no value adding material handling pickups, travels and set downs minimized?
- Are queue space or additional storage space needed? Is there enough room for adjustments?

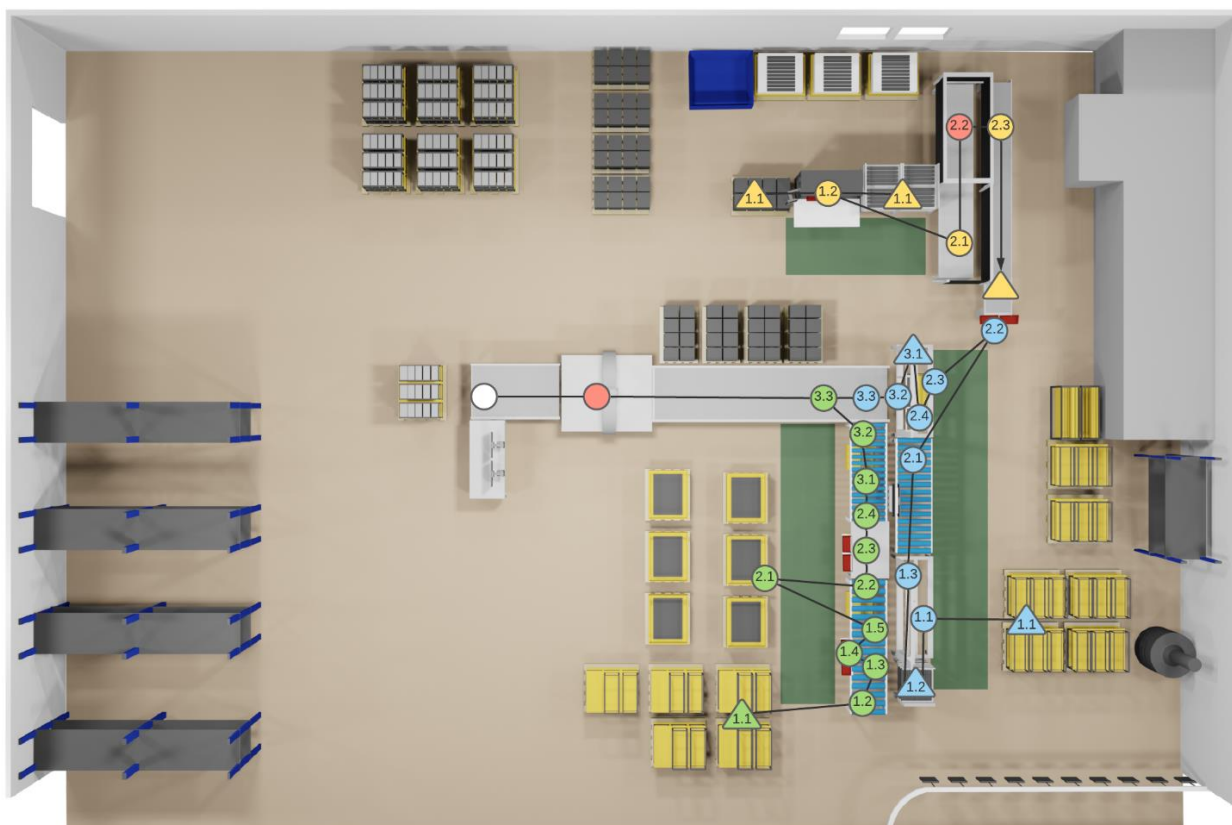
Appendix 11. New conceptual layout including long box assembly if this would be needed



Appendix 12. New conceptual layout's important & necessary relationships



Appendix 13. New conceptual layout's process flows



Appendix 14. Concept for information panels at the drawer/locker station

