TAMPEREEN
AMMATTIKORKEAKOULU

Design of an assembling line

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Bachelor’s thesis
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Mechanical and Production Engineering
Machine Automation

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
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YLIRÖNNI, RAMI:

Design of an assembly line

Bachelor's thesis 42 pages, appendices 3 pages
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The purpose of this bachelor’s thesis was to make a scheme for an assembly line of a new product, which the commissioned company could use. The objective of this thesis was to design working methods and equipment used in the assembly, inspection measurements for the products’ components, testing of the finished products, the required inventories and three layout options for the assembly line.

In the theory part of this thesis explored the systematic layout planning and other layout planning tools, and different layout types. Inventories, and planning management were also covered.

The work started by examining the product and its components. The assembling of the product was planned together with the representative of the company, and the suitable working methods and equipment were considered. As the incoming components are to be inspected prior to the assembly, the necessary measurements and the suitable measuring tools were defined. The necessary equipment and inventories were described and three layout options were made using AutoCad software.

In conclusion, the commissioned company received the plan for an assembly line of a new product. The design includes the required tools, equipment and working methods, and the layout options made. The confidential material has been removed from the public report.

Key words: assembly, layout, inventories

TIIVISTELMÄ

Tampereen ammattikorkeakoulu
Kone- ja tuotantotekniikka
Kone- ja laiteautomaatio

YLIRÖNNI, RAMI:
Kokoonpanolinjaston suunnittelu

Opinnäytetyö 42 sivua, joista liitteitä 3 sivua
Toukokuu 2016

Opinnäytetyön tarkoituksena oli tehdä suunnitelma uuden tuotteen kokoonpanolinjastosta, jota työn tilannut yritys voisi hyödyntää tulevaisuudessa. Työn tavoitteena oli suunnitella kokoonpanossa käytettävät työmenetelmät ja laitteet, tuotteen osille tehtävät tarkastusmittaukset, tuotteille tehtävä testaus, tarvittavat varastot sekä tehdä kolme layout-vaihtoehtoa kokoonpanolinjastolle.

Työn teoriaosuudessa käsiteltiin systemaattista layout-suunnittelua ja muita layout-suunnittelun työkaluja sekä käytiin lävitse eri layout-tyypit. Lisäksi teoriaosuudessa kerrottiin varastoista, niiden suunnittelusta ja hallinnasta.

Työ aloitettiin tutustumalla valmistettavaan tuotteeseen ja sen osiin. Kokoonpanoa suunniteltiin yhdessä yrityksen edustajien kanssa ja pohdittiin soveltuvia työmenetelmiä ja laitteita. Koska saapuville tuotteiden osille halutaan tehdä tarkastusmittaukset ennen kokoonpanoa, määriteltiin tarvittavat mittaukset sekä niihin soveltuvat mittavälineet. Komponenteille ja valmiille tuotteille suunniteltiin niille soveltuvat varastot. Kun tarvittavat laitteet ja varastot oli määritelty, tehtiin kokoonpanolinjastolle kolme layout-vaihtoehtoa AutoCad-ohjelmistolla.

Opinnäytetyön tuloksena työn tilannut yritys sai suunnitelman uuden tuotteen kokoonpanolinjastosta. Suunnitelmassa on kerrottu kokoonpanossa tarvittavat työvälineet, apulaitteet ja työmenetelmät sekä esitelty tehdyt layout-vaihtoehdot. Julkisesta raportista on poistettu luottamuksellinen aineisto.

Asiasanat: kokoonpano, layout, varastot

CONTENTS

ABBREVIATIONS

DRP	Distribution requirements planning
EOQ	Economic order quantity
JIT	Just in time
MRP	Manufacturing requirements planning
MRPII	Manufacturing resource planning
SLP	Systematic Layout Planning
WIP	Work in process

1 INTRODUCTION

The objective of this bachelor´s thesis was to design an assembly line for a new product, which could be used by the commissioned company. Designing an assembly line includes planning the assembly process, defining the inventories for the components and finished products, and making layout options for the assembly line. The necessary equipment for the assembly has also been described.

In the first chapter of the theory part has been focused on systematic layout planning and other layout planning tools. Different layout types has been presented. The other chapter in the theory section is about inventories and inventory management.

At first, the product was assembled and disassembled few times to understand the operation of it. This helped to define the working methods and equipment needed for the assembly.

The assembly process of the product includes inspection measurements of arriving components, the actual assembly and the testing of the finished product. For these work phases has been defined the required working methods and equipment. About the inventories has been told the storing methods and discussed the inventory management.

Layout options in this thesis are based on the flow chart, selected equipment and on the space requirement chart. The layout options were drawn by using AutoCad-software. The options are presented in chapter six and a comparison has been made of them.

2 LAYOUT PLANNING THEORY

Layout is a well-established term which means the placement of components of the production system in the production facilities. The components are machines, devices, inventories and passageways. (Haverila, Uusi-Rauva, Kouri, Miettinen, 2005, 475.) By minimizing the movement of personnel and material between the components, a system's efficiency and productivity can be increased and material handling costs decreased (Heragu, 2008, 3-4).

2.1 Systematic layout planning

One of the most used layout planning methods is Systematic Layout Planning (SLP), which was developed in the 1960s. One of the main reason SLP is still widely used is that its simple step-by-step approach to facility design. It contains four phases:

- Phase 1- Determination of the location of the area where departments are to be laid out
- Phase 2- Establishing the general overall layout
- Phase 3- Establishing detailed layout plans
- Phase 4- Installing the selected layout. (Heragu, 2008, 68.)

Phase 1 includes decisions of where departments are located. For example, which building or which part of the building one area is located. (Heragu, 2008, 68.)

Phase 2 involves analysis of the material flow between departments, determining which departments need to be close to each other, defining the required space of one department and balancing it with the space available. Safety and budget constrains has to be also taken into consideration. By using this information, a few overall layout plans can be generated. The plans are then evaluated and a layout is selected based on cost and non-cost considerations. (Heragu, 2008, 68.)

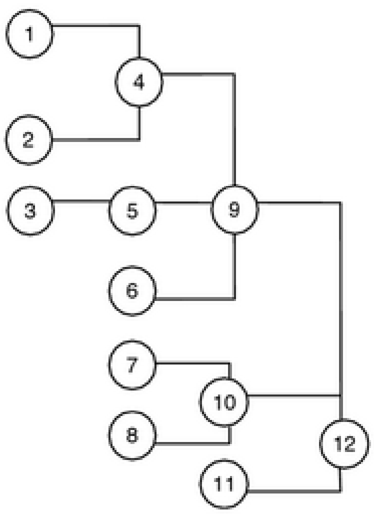
Phase 3 focus on the details of the layout, like exact location of each specific machine, auxiliary equipment and supporting services. Supporting services includes, among other things, rest-rooms, cleaning rooms and inspection stations. Generating detailed layouts follows the same procedure as generating the overall layout in phase 2. (Heragu, 2008, 68.)

In phase 4 the final layout is prepared. Drawings of the final layout have to be very detailed, as they are used when planning the move to the new facilities. Funds and time for the moving process need to be also determined. The actual move and relocation of the machines and services takes also place in the phase 4. (Heragu, 2008, 68.)

2.2 Product analysis

Product analysis can provide important information about the products, which is essential when generating layouts. Products define processes and equipment needed, material-handling methods, the arrangement of auxiliary equipment and service departments. Types of product and volume of production determines the selected layout. (Heragu, 2008, 13)

For better understanding of the product and material flows of the factory, different charts and diagrams may be used. Bill of materials shows which components and subassemblies are needed for one product. It can be used with an assembly chart that tells us how each component and subassembly is assembled when making the final product. Figure 2 shows a bill of materials and assembly chart of a computer device. One device is made up of three subassemblies and each of them is made up of their own components and subassemblies. (Heragu, 2008, 13, 15)

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12 Computer Device
  11    Keyboard Assembly (Purchased)
  10    Color Video Display Device
     8    Video Panel (Purchased)
     7    Circuit Board
   9    Main CPU Unit
     6    Power Supply Kit (Purchased)
     5    PC Board Assembly
       3        Main PC Board (Purchased)
     4    Disk Drive Unit
       2        DVD Drive
       1        Hard Drive
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FIGURE 2. Assembly chart and bill of materials of a computer device (Heragu, 2008, 15)

2.3 Equipment selection

Effective use of production, service and auxiliary equipment is important for functional manufacturing process. When making a layout plan, one must know the quantity and type of required equipment. One must at first clear out what kind of manufacturing processes are used in production and find the matching equipment for those processes. Production equipment is normally categorized based on their function. Equipment types may be lathes, horizontal milling machines, vertical milling machines, planers and shaping machines. (Heragu, 2008, 18, 19, 20)

Quantity of the machines can be defined based on the production volume. Some processes may need supporting services like heating or drying and this has to be also considered when thinking the quantity of the equipment. The type of production equipment defines the type and quantity of service and auxiliary equipment. The amount of equipment can be reduced when using machines that are capable of performing a variety of operations but they are typically more expensive. (Heragu, 2008, 20)

2.4 Space requirement and availability

To determinate the space for each department one has to understand the interaction between departments and the flow between machines. When defining the space requirements for each department and machine, the designer has to take into consideration the space needed for loading and unloading of parts, a buffer storage for incoming material and work in process (WIP), and shelves for storage of machine accessories and tools. The operator of the machine has to also have enough space for movements. (Heragu, 2008, 31)

One way to calculate the space requirements is simply add 1 or 2 meters to the length and width of each machine and workstation, or multiplying the area of the workstation by 2 or 3. According to Heragu (2008, 31) the preferred method is to calculate the required spaces for the workstations, auxiliary equipment, operators, incoming material and WIPs and then add them, to define the total space required. Figure 3 shows an example of production requirement sheet. At first the floor space of a machine is calculated and then the required space for auxiliary area, operator and material are added to it. The auxiliary area can be defined by measuring the area or by calculating approximately it as percentage of space required by production machines. Then the subtotal area is multiplied by the total space factor (column 11) to make room for material handling, maintenance operations, WIPs and for anticipated growth of production volume in the near future. The result is total required space of each machine, which is then multiplied by number of the machines. The last columns show the total of the required space per machine type. (Heragu, 2008, 31)

Department name (1)	Work center name (2)	Work center code (3)	Length (ft) (4)	Width (ft) (5)	Area (ft^2) (6)	Auxiliary area (ft^2) (7)	Operator space (ft^2) (8)	Material space (ft^2) (9)	Subtotal (ft^2) (10)	Allowance (%) (11)	Total space per machine (ft^2) (12)	Number of machines (13)	Total space per machine type (ft^2) (14)
General machining	Vertical milling	1202	15	15	225	70	30	50	375	150	570	2	1140
	Planer	2005L	25	5	125	40	20	40	225	125	290	1	290
	Punch press	3058	10	10	100	30	20	20	170	140	240	2	480
	Injection molding	6078	20	10	200	60	50	100	410	150	615	3	1845
Otoscope cell	NC-machine	9087	20	8	160	50	30	30	270	125	340	2	680
	Lathe	1212	15	8	120	40	20	30	210	150	315	1	315
	Autochucker	2056	5	5	25	10	5	5	45	125	60	1	60

FIGURE 3. Production space requirement sheet (Heragu, 2008, 32)

2.5 Flow analysis

The flow analysis defines the path one part takes through the plant and assists the designer to find the most efficient arrangement of machines, facilities, workstations and departments. The purpose of the flow analysis is to minimize the distance travelled and costs of production. By improving the product flow, the profitability of the manufacturing process will increase. (Stephens & Meyers, 2013)

The flow process chart illustrates the steps one product goes thorough during the manufacturing process. Figure 4 shows a flow process chart. The moving distances, the time each operation takes, ASME chart symbols, operation and department identification, number of pieces and how they are moved are listed in the chart. Under the process chart is a partially completed summary table, to which the total amount of the operations, time and distances are listed. For the factory designer the flow process chart is a tool to improve the process efficiency. It allows to find a non-value-adding activities like inspections, delays and transportations. Some activities may also be combined to one. After making improvements to the process, the changes may then be documented in a new flow process chart. (Heragu, 2008, 42)

Subject Charted TB03100 Face Panel Chart No. 112XAG
Drawing No. ______ Part No. ______ Chart of Method Present
Chart Begins Receiving Charted By N.L.
Chart Ends Steel Dept. Date Feb. 5/90
Sheet 1 of 1

Dist. (ft)	Time	Chart Symbol	Oper ID	Dept ID	M/C ID	# of pieces	How moved	Process Description
	.02	1 ▼	A1	S&R		100	Truck	Received material 0.022 wcs (51" x 102")
220	.02	1 ➧	H2	MF1		100	Forklift	To crane bay area
		2 ▼		WIP1		100		Stored temporarily
20	.02	2 ➧	H2	MF1		100	Conveyor	To hydra shear
	.01	1 ●	M1	MF1	HS1	100		Cut to length (front panel)
50	.02	3 ➧	H3	MF2	13G 142	95	Forklift	To machine #13G (100 ton press) or Komatsu (machine 142) or to HYMAC 101 (7" & over neck)
	.01	2 ●	M2	MF2	101	95		Necking operation (punch hole)
160	.03	4 ➧	H3	MF2		95	Forklift	To machine # 136
	.03	3 ●	M2	MF2	136	95		Punch holes
240	.01	5 ➧	H1	MF3		95	Forklift	To machine #155 or machine #104 or machine #111
	.05	4 ●	M2	MF3	155	95		Braking operation
260	.01	6 ➧	H1	WIP2		94	AGV	To marshalling area
		3 ▼		S&R		94		Temporary storage
150	.01	7 ➧	H3	WIP3		94	AGV	To steel dept.

Summary

Event	Total	Time	Distance
● Operations	4		
■ Inspections	–	–	–
➧ Transportations	8		(min.) 1100 ft.
▼ Storages	3		
▶ Delays			

FIGURE 4. A flow process chart (Heragu, 2008, 43)

Next a flow diagram based on the flow chart can be made. A flow diagram is shown in figure 5. The flow diagram shows the operation symbols and the sequence of the operations. The process starts from receiving the parts and ends to the shipping of the products. The operations between receiving and shipping, like drilling and milling, are illustrated by their own boxes and transportations are illustrated by arrows. The flow diagram helps the designer to perceive the material flow and see if there is any unnecessary movements in the process. (Heragu, 2008, 43)

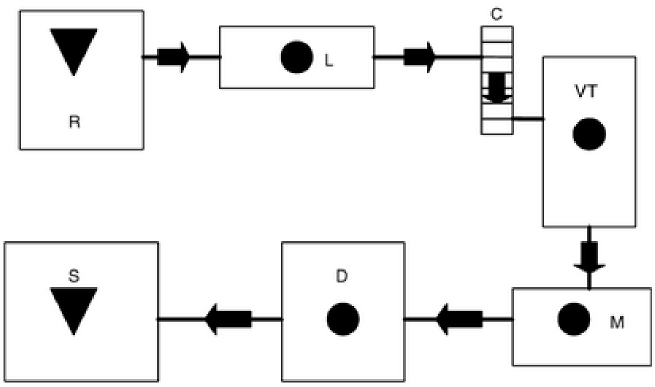

FIGURE 5. A flow diagram (Heragu, 2008, 44)

2.6 Layout design goals

The main goal of layout design is to make the material flows more efficient by minimizing the transportation times and distances. Definite material flows clarify the production control. According to Haverila et al. (2005, 482) the features of good layout are the following:

- Material flows are clear
- Layout is easily and flexibly changeable
- The need to transfer the material is low
- Distances are short
- Operations that require special skills are focused to one place
- Receiving and distributing the material is efficient
- Communication is made easy
- The special needs of different manufacturing stages are taken into consideration
- All the space is used efficiently
- Work safety has been taken into consideration

When making a layout plan, the possibility for future expansions and changes has to be taken into consideration. If the production volume or product type changes, the layout has to be possible to change. Especially the difficultly movable machines and devices has to be located so, that they don’t harm future changes.

2.7 Layout types

Layouts can be separated to groups based on the flow and disposition of the machines (Haverila et al, 2005, 475). Layouts may be separated to five groups:

- Product layout
- Process layout
- Fixed position layout
- Cell layout
- Hybrid layout

2.7.1 Product layout

Product layout, or assembly-line layout, is a layout type where machines and workstations are placed in the order, which is the same as the sequence in the operations of the manufacturing process. Product layout is focused to manufacture a specific product or product group. The workflow is straightforward and mechanical conveyors may be used between the operations. (Haverila et al, 2005, 475)

High production volume is essential for the product layout because of the high construction costs. If the production volume is high enough the costs of one product will decrease. Product layout tolerates failures poorly and even small failure can decrease the productivity of the entire assembly line. (Haverila et al, 2005, 475)

Production series are often long, because the setting time for a new product is high. Assembly line is able to manufacture also faulty products, which makes the quality control very important. Distinct work process makes the production management easy and it may be controlled as one unit. (Haverila et al, 2005, 475)

2.7.2 Process layout

In process layout the machines and workstations are organized in groups based on the operation they perform. For example, all the milling machines are in one department and all the drills are in another one. A typical process layout is illustrated in figure 6. (Heragu, 2008, 40)

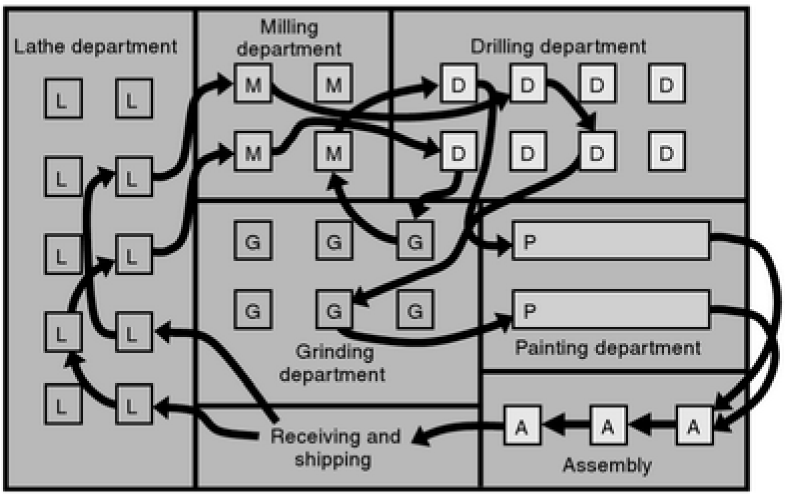

FIGURE 6. A process layout (Heragu, 2008, 40)

The amount and the type of the products may vary a lot and process layout is able to flexibly manufacture different products. Variety of manufacturing processes makes the material handling operations difficult to automatize. Intermediate storages are needed and distances between workstations may be long so the material handling costs are high in process layout. (Haverila et al., 2005, 476)

Compared to product layout, implementation of process layout is cheaper and easier. Process layout is more flexible but it has many disadvantages, such as decreasing of the productivity and the load rate. Production management is also more complicate and it is mostly arranging the works to a queue. (Haverila et al., 2005, 476)

2.7.3 Fixed position layout

Fixed position layout is used for manufacturing big and expensive products that are difficult and expensive to move, such as ships and aircraft. The process and equipment for making the product are brought where the product is located. There is no costs of moving the product and chances for damaging the product during the transportation are minimized. However, moving the equipment to and from the work area is expensive. The utilization of the equipment is poor as the equipment has to stay in the work area until the product is ready. (Heragu, 2008, 41)

2.7.4 Cell layout

Cell layout is composed of groups of independent machines and workstations. A cell is specialized to a specific product or function. Material flows are explicit and there is no intermediate storages. The setting times are short and the cell is able to very flexibly manufacture products which it is designed for. Executing consecutive manufacturing stages in the same area makes the quality control easier. (Haverila et al., 2005, 477)

Compared to the product layout, the cell layout is more flexible but less efficient. The load rates of the cell layout may vary and they are lower than in the product layouts. Production control is simpler than in the process layout, because it has to focus on only one product or process. Responding to changes in load rate and product range is not as good as in process layout. (Haverila et al., 2005, 477)

2.7.5 Hybrid layout

Many companies use combination of the layout types. When a company increases its production volume or amount of products it may find that none of the layout types meets its requirements. For some stages of the production the product layout is the best option and for some the fixed position layout. Then the hybrid layout is a good choice. In figure 7 is a sample of a hybrid layout. (Heragu, 2008, 41)

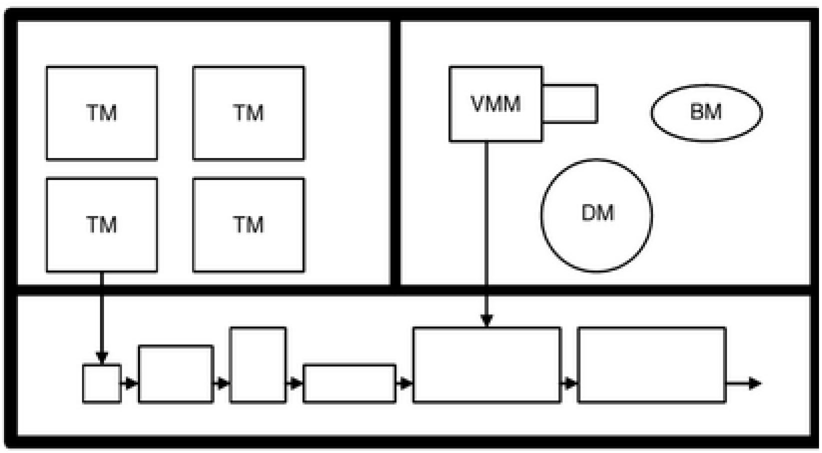

FIGURE 7. A hybrid layout (Heragu, 2008, 42)

3 INVENTORIES THEORY

Inventories are a significant expense for companies but product and material inventories are essential to almost every company. Inventories secure companies' ability to deliver products and connect different manufacturing processes together. A great amount of capital is usually tied-up to inventories and material handling causes expenses. The product may also become outdated in the inventory which increases the risks of the inventories. (Haverila et al., 2005, 445)

Inventories can be divided to six groups based on their function and from what they are result of:

- Securing the delivery capacity.
- Controlling the seasonal variation.
- Connecting the manufacturing processes.
- Inventories result from large batch sizes.
- Inventories result from transports.
- Inventories kept for in reserve of errors in manufacturing process. (Haverila et al., 2005, 446)

Manufacturing time of the product is usually longer than the delivery time that customers demand. In that case the buffer inventories are used for securing the delivery capacity. Buffers may be finished products or raw materials. The size of the buffer inventories can be decreased by using the sales information and with good production scheduling. A short throughput time and a flexible manufacturing process decreases the need for buffer inventories. (Haverila et al., 2005, 446)

Seasonal variations can be balanced by storing products. To make it possible, the inventory costs have to be low. This approach is used particularly when the flexible use of the production capacity is too expensive. The production capacity may then be designed on the basis of the average sales (Haverila et al., 2005, 446)

Because different phases in manufacturing process take different amount of time, the intermediate inventories are used to store unfinished products between the operations. Products are often moved in batches between workstations, in which case the batches grow the intermediate inventories. Intermediate inventories are the greater the more there are different phases in manufacturing process. The amount of different product types and the distances between workstations affect also to the size of the intermediate inventories. Intermediate inventories increase the throughput time, tie up capital and increase the number of defects in quality. (Haverila et al., 2005, 446)

Long set up times and high set up costs increase the batch size and the large batch size causes larger intermediate inventories. Growth of the batch size in one phase usually leads to growth of batch sizes in the whole process, which extends the throughput time and increases the amount of work in progress. To reduce the batch sizes without affecting to the cost efficiency, the set up times have to be shortened. (Haverila et al., 2005, 447)

Transports cause the need for storage. Creating transport batches, packing, loading, and unloading lead to unnecessary inventories and to increased throughput time. The situation is particularly challenging when the product goes to subcontractor during the manufacturing process. Moving the product back and forth should be avoided as far as possible. (Haverila et al., 2005, 447)

Errors of operation and manufacturing are often covered up by extra inventories. In case of an error, extensive malfunctions and delivery capacity problems can be avoided by using inventories. However, this type of action prevents developing the manufacturing process, because problems and their reasons are not solved. This type of inventories should be removed and problems that caused them should be fixed. (Haverila et al., 2005, 447)

3.1 Planning Inventories

A company’s inventories have to be large enough to ensure delivery reliability and level of service, but the amount of the capital tied up in inventories should be minimized. Planning the inventory levels of end product storages is based on sales predictions. Size of the end product stores should be designed so that the desired level of service can be reached when the sales are high. During the low sales, products may be manufactured to the inventories. (Haverila et al., 2005, 449)

Raw material stores sizing may be based on the derived demand which is calculated from the sales of the finished product. The derived demand is often used when defining inventory levels of materials that are expensive or have a long time of delivery. Acquisition and storing of materials that have short time of delivery is usually based on inventory levels that are empirically defined. (Haverila et al., 2005, 450)

3.2 Inventory management

The purpose of inventory management is to define how much inventory is needed to ensure delivery reliability despite of variations in sales forecast, customer demand and supplier's deliveries. To achieve this, the information about the inventory has to be timely, accurate, consistent and reliable. The advantages of good inventory management are better customer service, better efficiency of purchasing and production, smaller inventory investment and increased revenue. (Viale & Carrigan, 1996, 3)

Inventory management is essential in production management. The information about amount of one specific product or raw material is used, when defining delivery times and production batch sizes. Acquisition of material is also based on the balance of inventory. Poor inventory management usually causes notable additional costs. (Haverila et al., 2005, 450)

3.3 Inventory management models

3.3.1 Push inventory management models

Inventory management models can be categorized to push and pull models. In the push models, the production and ordering of raw materials are scheduled in advance of customer's demand. Production batches are planned beforehand and they are pushed through the manufacturing process to the final customer. Push model is widely used but it requires clear manufacturing process, good quality control and disciplined operation. Executing a push model in complex production chains have been proved difficult. Plans made in advance don’t always match to the reality and production may not be able to operate according to the plan. This causes problems which lead to larger inventories. (Haverila et al., 2005, 422)

The best known push models are economic order quantity (EOQ), manufacturing requirements planning (MRP), manufacturing resource planning (MRPII) and distribution requirements planning (DRP). The economic order quantity model is used for calculating when and how much to order parts. The EOQ calculation is used to predict the future consumption of the parts based on past demand patterns. The equation gives the exact number of ordered parts, and by using that and the annual demand of the product, the reorder point may be calculated. The EOQ relies on assumptions that don’t meet reality, like constant and known demand rate, invariable transportation costs and purchasing prices and the amount of available capital is limitless. Because the EOQ gives the exact number and is simple to use, it is widely used model. (Bloomberg, LeMay, Hanna, 2002, 149)

The manufacturing resource planning is a computer based medium term production planning tool. It is used to define the amount of the needed parts to manufacture one product. This information is used when converting the demand of the products to the demand of the parts. Based on the medium term production plan, the MRP also describes when the parts are needed. The MRP system contains the information of the connection between the parts and finished products and the amount of the parts in the inventory. When the medium term demand of the finished products is entered to the MRP systems, it defines the demand of the parts. The demand of the parts is then compared to inventory balance and the ordered amount and ordering date of the parts is then decided. (Hollier & Cooke, 1991, 151)

Because the MRP takes in the account only the demand of the parts, the MRPII and DRP systems add manufacturing capacity and requirements of outbound movements to it. The MRPII considers production scheduling, labor needs and inventory budget. Using the MRPII successfully leads to fewer inventory shortages and stockouts, which improves customer service and makes the system more tolerate to demand changes. It also decreases the inventory levels and costs. DRP focuses on the flow of the finished products and it makes the handling of the inventories more flexible. (Bloomberg et al., 2002, 164)

3.3.2 Pull inventory management models

In pull models, the production is based on the immediate demand. In the manufacturing chain the demand for the product is coming from the end towards the beginning. Pull models are usually implemented by using small inventories as buffers. Parts and products are pulled from the inventories only by the amount that is needed to respond to the demand. Pull management is fit to parts whose consumption is relatively constant, because otherwise building the buffers would be difficult. Pull models require short throughput time and good quality control because problems in one phase of the process may stop the whole process quickly. (Haverila et al., 2005, 422)

According to Bloomberg, LeMay and Hanna (2002, 148) the most widely used pull inventory models are Just-in-time (JIT) and Kanban. JIT system is an inventory management system which is based on restocking the inventories only if it is empty. JIT is also a production development method which aims to improve manufacturing quality, flexibility and productivity by reducing waste and involving people (Bloomberg et al., 2002, 165). In functioning JIT system all parts are being delivered just in time to right place. High quality and reliability of the parts are essential in JIT manufacturing and inventory management. In an ideal JIT inventory management system all the inventories are in busy use and there is no long term inventories that raise costs. This requires regular shipments from the suppliers. (Hollier & Cooke, 1991, 152)

The best known JIT production and inventory management model is Kanban. Kanban system uses visible signals, usually cards, to indicate the need for more parts. The needed amount of parts are taken from the previous workstations or inventories. When the parts are transported to the next workstation, the previous workstation needs parts from the earlier phases of the manufacturing chain and the production order is moving to the beginning of the chain and to the suppliers. The orders are placed by using Kanban cards. No parts should be produced without a Kanban card. (Hollier & Cooke, 1991, 153)

Kanban system can significantly reduce the need for large inventories. Unlike push models, it is not based on sales forecast but the status of the workstation. The produced parts are made to replace the parts that have been taken from the workstation or inventory. This ensures that each part will be used. (Hollier & Cooke, 1991, 153)

3.4 ABC-analysis

ABC-analysis is an analyzing method which aims at separating the significant matters from the non-significant. It can be used as a tool when analyzing the material inventories, planning inventory management methods and finding targets for development in material handling. In ABC-analysis the items in the inventory are classified based on their annual consumption. Items which have the highest annual consumption belong to the A-class and items with the lowest annual consumption to the C-class. (Haverila et al., 2005, 457)

Items can be classified to two (A and B) or three classes (A, B, and C). Class boundaries are usually placed as percentage of the amount of items. For example class A may include 15%, class B 30% and class C 55% of the items. When planning the inventory control methods the most attentive method should be used to the items in the class A as their consumption is the highest. Inventory levels of items in the class C may be controlled with rougher methods. (Haverila et al., 2005, 457)

4 ASSEMBLY

4.1 Inspection measurements

The assembly of the product is a process which includes inspection measurements when the parts arrive, the actual assembly and testing of the assembled product. Inspection measurements are made to ensure the quality of the parts and so ensure the functionality and reliability of the finished product. At first when the production starts, every critical component is inspected. After the quality of the parts has been found high the amount of inspections may be decreased.

The most important component of the product is the component 1. All the inspections are made to secure the movements of the component 1. The measured dimensions are:

- The outer diameter of the component 1
- The inner diameter of the bore going thru the component 1
- The outer diameter of the component 2
- The inner diameter of the component 3
- The inner diameter of the component 4

Measuring devices for the inspections have to be accurate enough to make sure the dimensions of the components are correct. However, measuring is a non-value adding activity, so the time used for the inspection measurements should be reduced to the minimum. Using high accuracy coordinate measuring machines to measure every component would make the inspection process too heavy and time consuming, so routine inspections should be made by using manual measuring devices. Elementary inspections may be done with micrometers and three point internal micrometers.

Micrometers (picture 1) can be used to measure the outside diameters of the components 1 and 2. These dimensions vary between 20 mm and 230 mm depending on the size of the product, so a few micrometers with different ranges are needed. In the figure 8 is shown accuracies and ranges of Mitutoyo micrometers. The smallest micrometers have an accuracy of ±1µm and the largest ±4µm. The smallest dimension tolerance is ±0,02 mm, so the micrometers are accurate enough. A digital display helps the user to read the measurement result and decreases the measuring error.

PICTURE 1. A Micrometer (Mitutoyo Micrometer catalog)

SPECIFICATIONS

Metric With ratchet stop

Range	Resolution	Order No.	Accuracy
0 - 25mm	0.001mm	**293-230-30 / 293-240-30***	±1µm
25 - 50mm	0.001mm	**293-231-30 / 293-241-30***	±1µm
50 - 75mm	0.001mm	**293-232-30 / 293-242-30***	±1µm
75 - 100mm	0.001mm	**293-233-30 / 293-243-30***	±2µm
100 - 125mm	0.001mm	**293-250-10**	±2µm
125 - 150mm	0.001mm	**293-251-10**	±2µm
150 - 175mm	0.001mm	**293-252-10**	±3µm
175 - 200mm	0.001mm	**293-253-10**	±3µm
200 - 225mm	0.001mm	**293-254-10**	±3µm
225 - 250mm	0.001mm	**293-255-10**	±4µm
250 - 275mm	0.001mm	**293-256-10**	±4µm
275 - 300mm	0.001mm	**293-257-10**	±4µm

*without SPC data output

FIGURE 8. Accuracies and ranges of Mitutoyo micrometers (Mitutoyo Micrometer catalog)

Inside diameters of the wear sleeve, inner cylinder and piston may be inspected with a three point micrometer (picture 2). These dimensions vary between 20 mm and 230 mm, so a few different sizes of three point micrometers are also needed. Mitutoyo three point micrometers' measuring ranges and accuracies are shown in the figure 9.

PICTURE 2. A three point micrometer (Mitutoyo Inside Measurement catalog)

SPECIFICATIONS

Metric ▭ with TiN coated contact points

Range	Accuracy	Order Code Individual	Order Code Main Body Assembly
6-8	±2μm	468-161	04AZB106
8-10		468-162	
10-12		468-163	
12-16		468-164	04AZB107
16-20		468-165	
20-25	±3μm	468-166	04AZB108
25-30		468-167	
30-40		468-168	
40-50		468-169	
50-63		468-170	04AZB109
62-75		468-171	
75-88		468-172	
87-100		468-173	
100-125	±5μm	468-174	04AZB110
125-150		468-175	
150-175		468-176	
175-200		468-177	
200-225		468-178	
225-250		468-179	
250-275		468-180	
275-300		468-181	

FIGURE 9. Accuracies and ranges of Mitutoyo three point micrometers (Mitutoyo Inside Measurement catalog)

Threads of the component 5 have to be inspected also. Threads are critical part of the product, so their functionality has to be confirmed. The easiest way to test them is by using thread gages. All inspections should be made before storing components to the inventory.

5 INVENTORIES

5.1 Component inventory

A component inventory is needed to store the parts that come from subcontractors. To make the inventory management more efficient, components should be stored to Kardex storing unit. Using Kardex storing unit saves floor space as the components can be stored on different levels vertically. Components may be sorted to the levels based on their size, so that all the parts needed for one product can be find from one level. This would make the collection of the parts faster but it may be not be possible to fit all parts to one level. Other option is that all the same parts are on the same level of the Kardex.

According to representative of a subcontractor the batch size of arriving components should be approximately 25-50 pieces. The time between placing of an order for components to subcontractor and arrival of the components is approximately four weeks.

5.2 Inventory of finished products

Inventory of finished products is a result from the need to store the products before shipping them to the customers, and it contains the assembled and tested products. After a product is found functioning it can be stored. They should be stored based on their size to help the inventory management and packing. The inventory of finished products should be located next to the packing and shipping area.

5.3 Inventory management

5.3.1 Products sales data

To plan the inventory sizes, the amount of products being sold has to be known. In this thesis is used sales data of the products to estimate the needed inventory levels. In the table 1 is shown the type and amount of sold products during a period of time.

TABLE 1. Sold products

Product type	The percentage of sold products (%)
Product type 1	49,3 %
Product type 2	14,3 %
Product type 3	13,6 %
Product type 4	12,9 %
Product type 5	2,6 %
Product type 6	2,4 %
Product type 7	1,1 %
Product type 8	0,5 %
Product type 9	0,4 %
Product type 10	0,4 %
Product type 11	0,4 %
Product type 12	0,3 %
Product type 13	0,3 %
Product type 14	0,3 %
Product type 15	0,3 %
Product type 16	0,3 %
Product type 17	0,1 %
Product type 18	0,1 %
Product type 19	0,1 %
Product type 20	0,1 %
Product type 21	0,1 %
Total	100 %

There is total of 21 different types of products which have been sold during that period of time. From the table can be read that there is few product types which sales combined covers 90% of all product sales.

5.3.2 ABC-analysis

Products can be classified to three categories based on their sales during the time period presented in previous chapter. In table 2 is illustrated the three categories by colors. Class A is marked in red, class B in yellow and class C in green.

TABLE 2. ABC-analysis

Product type	**The percentage of sold products (%)**
Product 1	49,3 %
Product 2	14,3 %
Product 3	13,6 %
Product 4	12,9 %
Product 5	2,6 %
Product 6	2,4 %
Product 7	1,1 %
Product 8	0,5 %
Product 9	0,4 %
Product 10	0,4 %
Product 11	0,4 %
Product 12	0,3 %
Product 13	0,3 %
Product 14	0,3 %
Product 15	0,3 %
Product 16	0,3 %
Product 17	0,1 %
Product 18	0,1 %
Product 19	0,1 %
Product 20	0,1 %
Product 21	0,1 %
Total	100 %

Because there is one item which sales was almost 50% of all sold products, it is the only item that belongs to the class A. Because the consumption of the item is so high, there has to be very accurate way to control the inventory level of this type of products.

Class B includes the next three product types. These three types made combined approximately 40% of the sales during the time period. The amount of work used for inventory control of these products doesn't have to be as high as the products in class A.

The rest of the product types belong to class C. These 17 types made 10% of the sales during the time period. Because of the lack of consumption of these types of products, the inventory control method doesn't have to be as exacting as the other classes.

6 LAYOUT PLANNING

6.1 Flow chart

The Flow chart of the assembly process is presented in the figure 9. It has been used to determinate the arrangements of the workstations and inventories. The flow chart shows which workstations has to be next to each other to make the material flow fluent and to minimize the travelling distances.

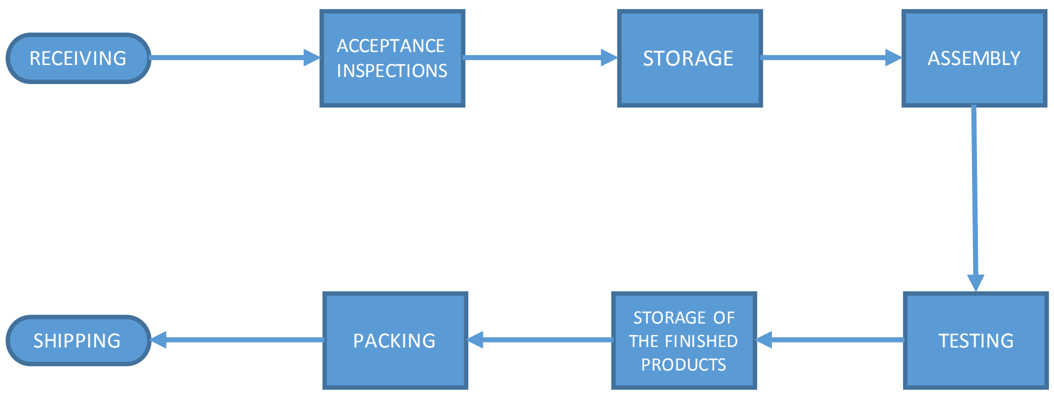

FIGURE 9. Flow chart of the assembly process

The inspection measurements should be made before storing the parts. This prevents the substandard products ending up to the component inventory. Inspection measurement workstation should be close to the storage in order to shorten the moving distance of the parts.

To make the assembly process efficient and flexible, the distance between the assembly workstation and the component storage has to be short. This makes the assembly time shorter when worker doesn’t have to move far to collect the parts needed. After the assembly the products are brought to the test bench, where their functioning is tested.

When the products are tested they are moved to the storage of the finished products. The last phases of the flow chart are packing and shipping products to the customers.

6.2 Equipment selection

Required equipment for the assembly line are measuring equipment, an assembly press and a test bench. Measuring equipment includes measuring tools and a work surface. Micrometers and three point micrometers can be stored to a tool container close to the measuring table. The table should be large enough so there is enough space to perform the inspections.

At the assembly and testing workstations has to be working surfaces. At the assembly workstation placing the O-rings and seating rings require working space. Installing the component 2 involves space also. Tools are needed to attach the product to the press and to the testing bench.

To lift the assembled products and heavy components safely and efficiently there should be a lifting device. A bridge crane which operating range covers the most of the work area would be an optimal choice. It could be used for lifting heavy components to the inventories, and to the assembly and test benches. A single jib crane may be used at the assembling or testing to prevent waiting if the bridge crane is in use. The easiest way to attach the product to the lifting device is to use lifting magnet.

A coordinate measuring machine may be used to measure some of the components that need more accurate inspections. If the coordinate measuring machine is going to be used to measure even the biggest components, the measuring range has to be large enough. Especially, measuring the inner diameter of the component 3 requires large loading height of the coordinate measuring machine. For the smaller components, a coordinate measuring machine with smaller loading height and measuring range is more suitable. In picture 4 is a Mitutoyo Crysta-Plus M7106 coordinate measuring machine which loading height is big enough for the most of the components.

PICTURE 4. Mitutoyo Crysta-Plus M7106 (Mitutoyo CMM catalogue)

6.3 Space requirements of the workstations

Space requirements of each workstation is defined using space requirement table, which was presented in chapter 4.4. The space requirement sheet for the assembly line is presented in the table 3 is. In the table the assembly process is divided to acceptance measurements, component inventory, assembly bench and test bench. The meaning of the columns has been explained in chapter 4.4.

TABLE 3. Space requirement table for the assembly line

Stage of operation	Workstation	Width (m)	Length (m)	Area (m²)	Auxiliary equipment area (m²)	Material space (m²)	Subtotal (m²)	Allowance (%)	Number of workstations	Total space requirement for the workstation (m²)
Reception	Measuring table	2,00	2,00	4,00	2,00	2,00	8,00	1,5	1	12,00
Component inventory	Kardex	4,28	1,47	6,29	1,00	1,00	8,29	1,5	1	12,43
	Storage of component 3	3,70	1,20	4,44	1,00	1,00	6,44	1,5	1	9,66
Assembly	Assembly bench	1,06	0,93	0,99	2,00	2,00	4,99	1,5	2	14,96
Testing	Test bench	2,00	2,00	4,00	1,00	2,00	7,00	1,5	1	10,50

Acceptance measurements include the measuring table which has to be large enough to contain the measured components and to have enough space to complete the measurements. There has to be also enough space for the WIP and for the storing of the measuring tools at the measuring workstation. There has to be also enough space for the movements of the worker and material.

Component inventory includes the inventory of component 3 and the Kardex storing unit, which contains the other components. Auxiliary equipment area is for material handling equipment. At the front of the component inventory has to be enough space to put components to the storage and collect them for the assembly.

Assembly workstation includes two assembly benches, a tool cabinet for the assembly equipment and enough room for the WIP. Around the assembly benches has to be enough space for worker to move and for material handling.

There has to be enough space around the test bench to handle the products and for the WIP. Tools for the testing should to be stored close to test bench.

6.4 Layout options

Based on the flow chart, equipment selection and space requirement table, three layout options were designed. The assembly line was meant to be placed to an industrial hall which floor plan is presented in the figure 10. As can be seen from the floor plan drawing, the building is divided to three halls. From these three halls the layout options were decided to place to hall C. This leaves the additional two halls for other uses.

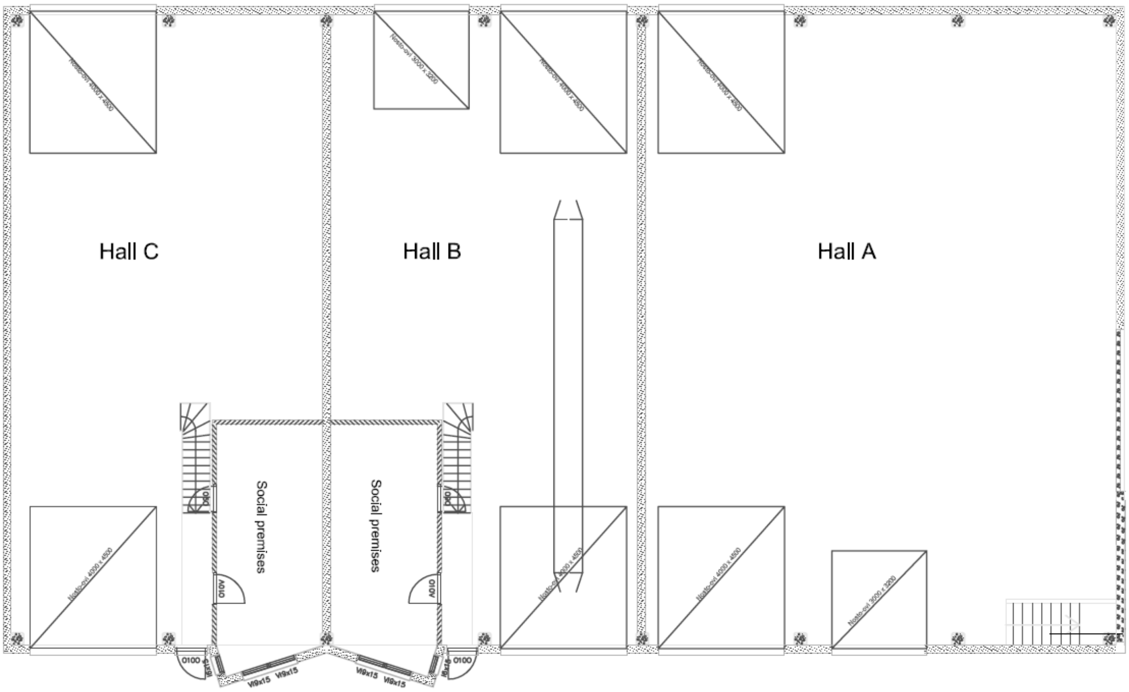

FIGURE 10. The plan drawing of the building

The floor plan drawing of the hall C can be seen in the figure 11. There is level gear doors in the both ends of the hall and social premises in one corner. The front of the level gear doors should be left free to make the handling of incoming and outgoing material easier.

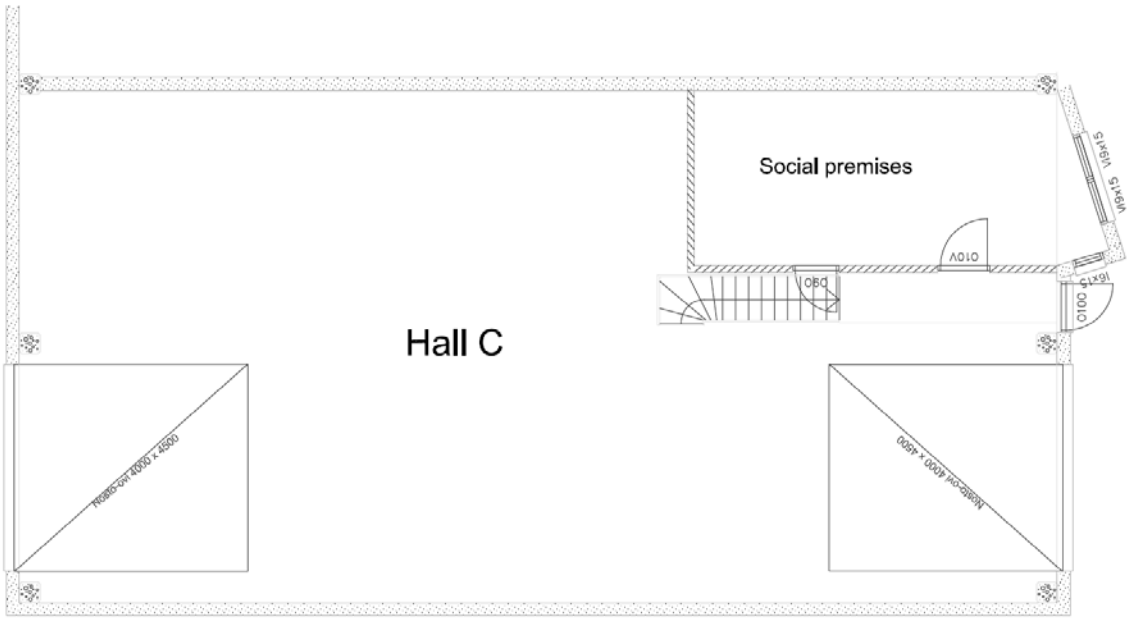

FIGURE 11. The plan drawing of the hall C

Layout options were made by using AutoCad-software. The workstations and the required areas for them are drawn in the layout drawings. The intended material flow is marked as arrows.

6.4.1 Layout option 1

Layout option 1 for the assembly line is presented in the figure 12. In this option the components are intended to bring in from the door on the southern side of the building. The acceptance inspections and the component inventory are placed on the same wall. The assembly workstation is placed in the middle of the hall. The test bench is on the opposite wall of the acceptance inspections, next to the social premises. The rest of the side and the end of the hall next to the door are meant for the inventory of finished products and packing area.

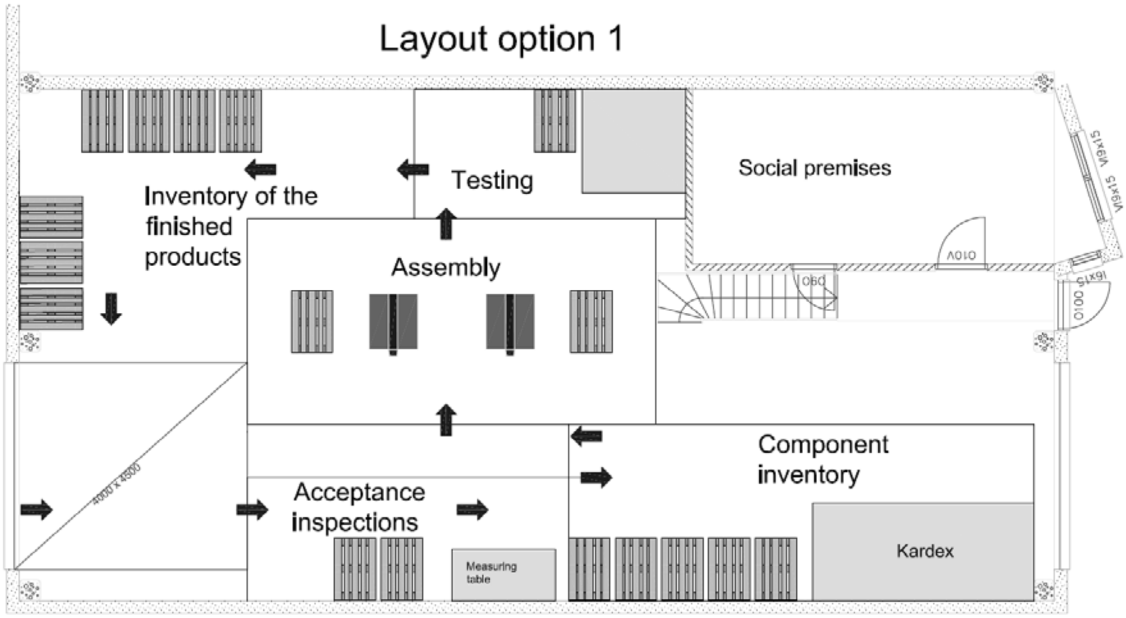

FIGURE 12. Layout option 1

The material flow in this option goes around the hall as incoming and outgoing material goes through the same door. This leaves the other door unused and the space in front of it can be utilized. Placing the component inventory front of the unused door is good way to use all the floor space efficiently, but in this case it increases the distance between the component inventory and the assembly workstation.

6.4.2 Layout option 2

In the layout option 2 (figure 13) the incoming and outgoing material is going through the door on the northern end of the hall. This leaves the door in the other end of the hall unused and the front of it can be utilized. Components that has to be inspected go to measuring workstation, which is in the middle of the hall. Other components can be put straight to the component inventory. This layout option also gives possibility to store the arrived components temporarily next to the finished products.

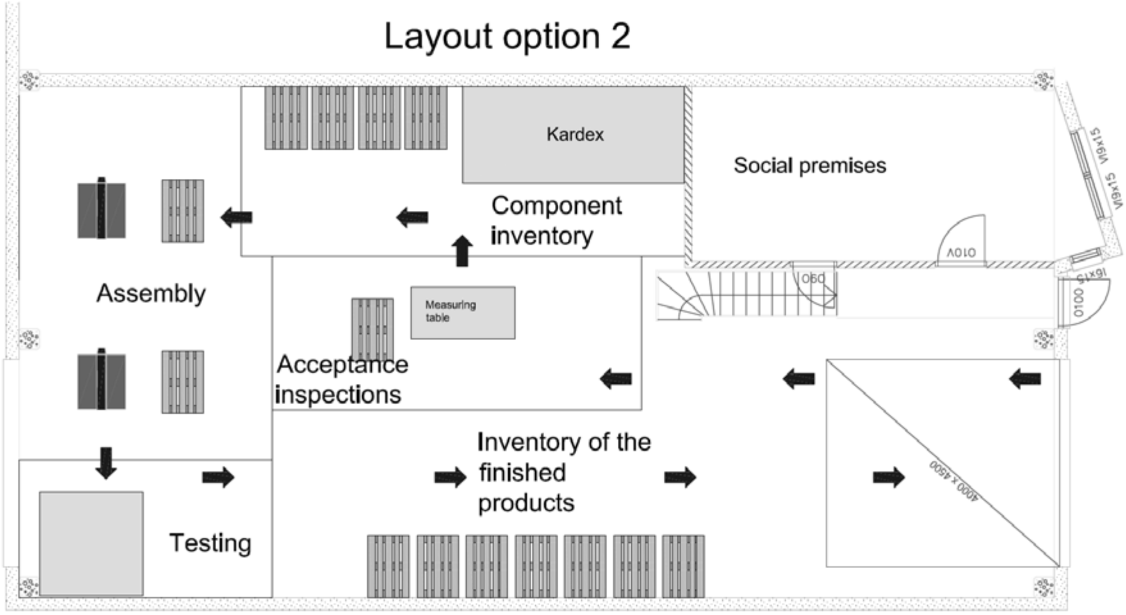

FIGURE 13. Layout option 2

The component inventory is on the wall next to the social premises. The assembly area is located next to the component inventory and the testing area is at the other corner in the southern end of the hall. As the testing area is relatively small, the most of the eastern wall of the hall can be used for the inventory of the finished products.

This option leaves enough space for each workstation. Because the incoming and outgoing material goes through the same door, the material flow in this option goes around the hall. This increases the travelling distance that the material has to move but it also makes the floor space better utilized, as the front of the other door doesn’t have to be open.

6.4.3 Layout option 3

In the layout option 3 (figure 14) the incoming material goes from the door in the southern end of the hall and outgoing through the door in the northern end. Acceptance inspections are located next to the door of the incoming material. Component inventory is on the western side of the hall and the assembly workstation is in the middle of the hall. Testing and inventory of finished products are on the opposite side of the component inventory.

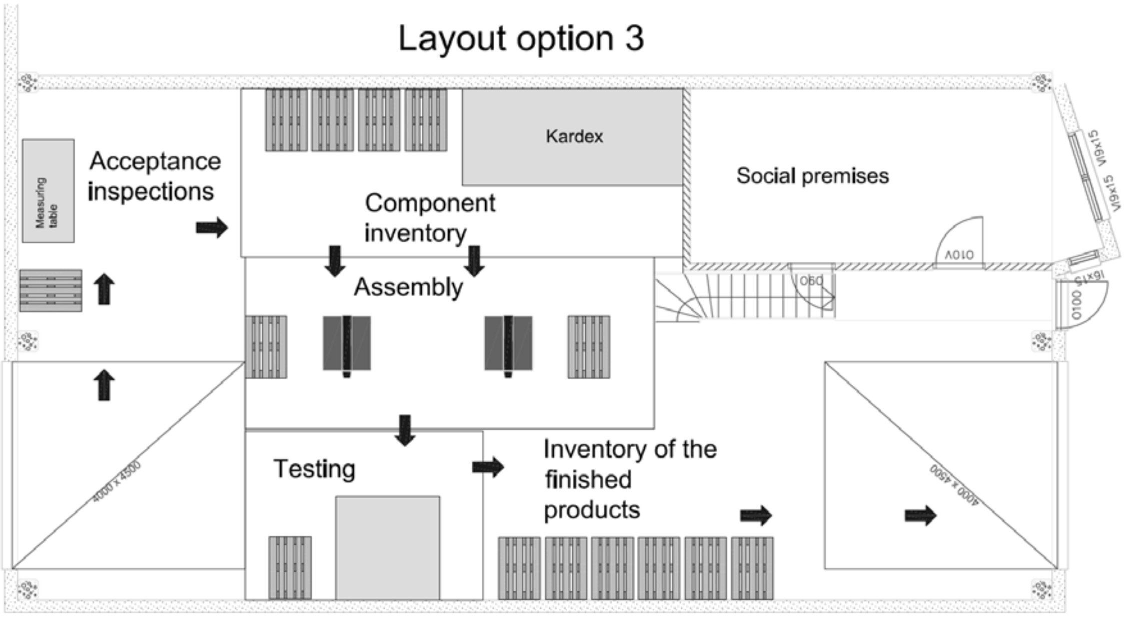

FIGURE 14. Layout option 3

The material flow in this option is simpler than in the options one and two, as the material goes through the hall. The traveling distance of the material is shorter than in the first two options and the need for moving the material is decreased. Because the doors in both ends of the hall are used free space has to be left in front of them.

6.5 Evaluation of the layout options

Table 3 was made to compare the layout options. The layouts were evaluated based on layout design goals introduced in chapter 4.6. From them, five goals were chosen and modified to make them more suitable for this case. Each layout were rated on a grading scale 1-5. Each criterion was given a weight based on the importance of the criterion.

TABLE 3. Layout evaluation table

Evaluation criteria	**Weight**	**Layout 1**	**Layout 2**	**Layout 3**
Efficiency of material flow	25 %	3	4	5
Distances between workstations	25 %	4	4	5
Efficiency of receiving and distributing the material	20 %	2	5	4
Use of space	15 %	4	4	3
Changeability of the layout	15 %	3	3	3
Total	100 %	3,2	4,1	4,2

As can be seen from the table, the layout option 1 has the lowest total rate and options 2 and 3 have almost the same rate. The efficiency of the material flow and the distance between workstations were the most important criteria. In layouts 1 and 2 the material flow goes around the hall as the incoming and outgoing material goes through the same door. This makes the efficiency of the material flow less efficient compared to layout 3 where the material flow goes through the hall. In the layout option 1 the location of the component inventory causes back and forth movement of the material which also reduces the rate of this criteria. The distances between the workstations are almost the same in every option.

Option 2 has the best rate in the efficiency of receiving and distributing the material criteria, because if necessary, there is space to store the incoming components temporarily before inspection measurements. In the layout 1 the location of the component inventory brings down the rate of this criterion too. The use of space is good in layout options 1 and 2, as the front of the doors are used more efficiently.

7 DISCUSSIONS

The objective of this thesis was to determine the requirements for the assembly line. The needed equipment and tools had to be determined as well as the working methods for the assembly. Layout options for the assembly line were also required.

The inspection measurements were decided to make for the component 1 and components which affects to its movements. The most suitable measuring tools for the inspections were micrometers and three point micrometers. The amount of the inspections made should be considered thoroughly, as the quality of the components has to be high but an excessive measuring is not reasonable. The amount of measurements may be reduced by inspecting only few components of incoming batch. This requires good quality control from subcontractors.

The most efficient way to assemble the product would be pressing. It would require the design of suitable press and the acquisition of it. The features of the press depend on if the pressing is wanted to do vertically or horizontally. The other required device acquisitions are the test bench, lifting equipment and a Kardex storing unit.

The required number of employees in the assembly line is two workers. The assembly time of a hammer is short but other operations, like the inspection measurements and testing, take time and require another worker. Working alone is also prohibited for safety reasons. For these two workers should be trained two substitutes.

While discussing the results of the thesis with the representatives of the commissioned company, the need for the painting of the hammers came out. The painting can be done before the assembly or the whole hammer can be painted at once after the assembly. Adding a painting line to the assembly line requires changes to the layout options. Taking down the social premises would provide enough space for the painting line but the locations of the other workstations have to also be changed so that the material flow would be efficient. These changes are not presented in this thesis.

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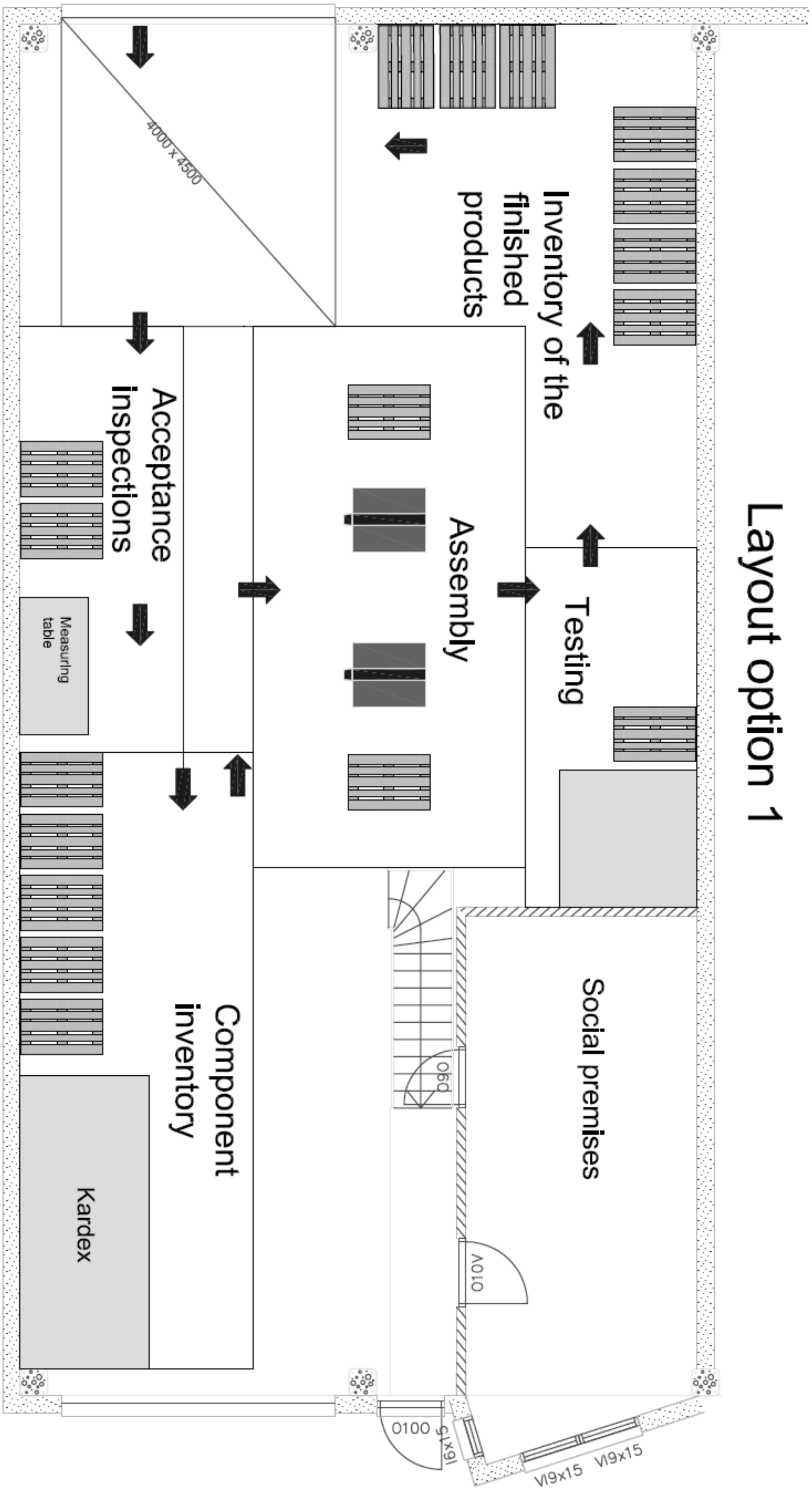
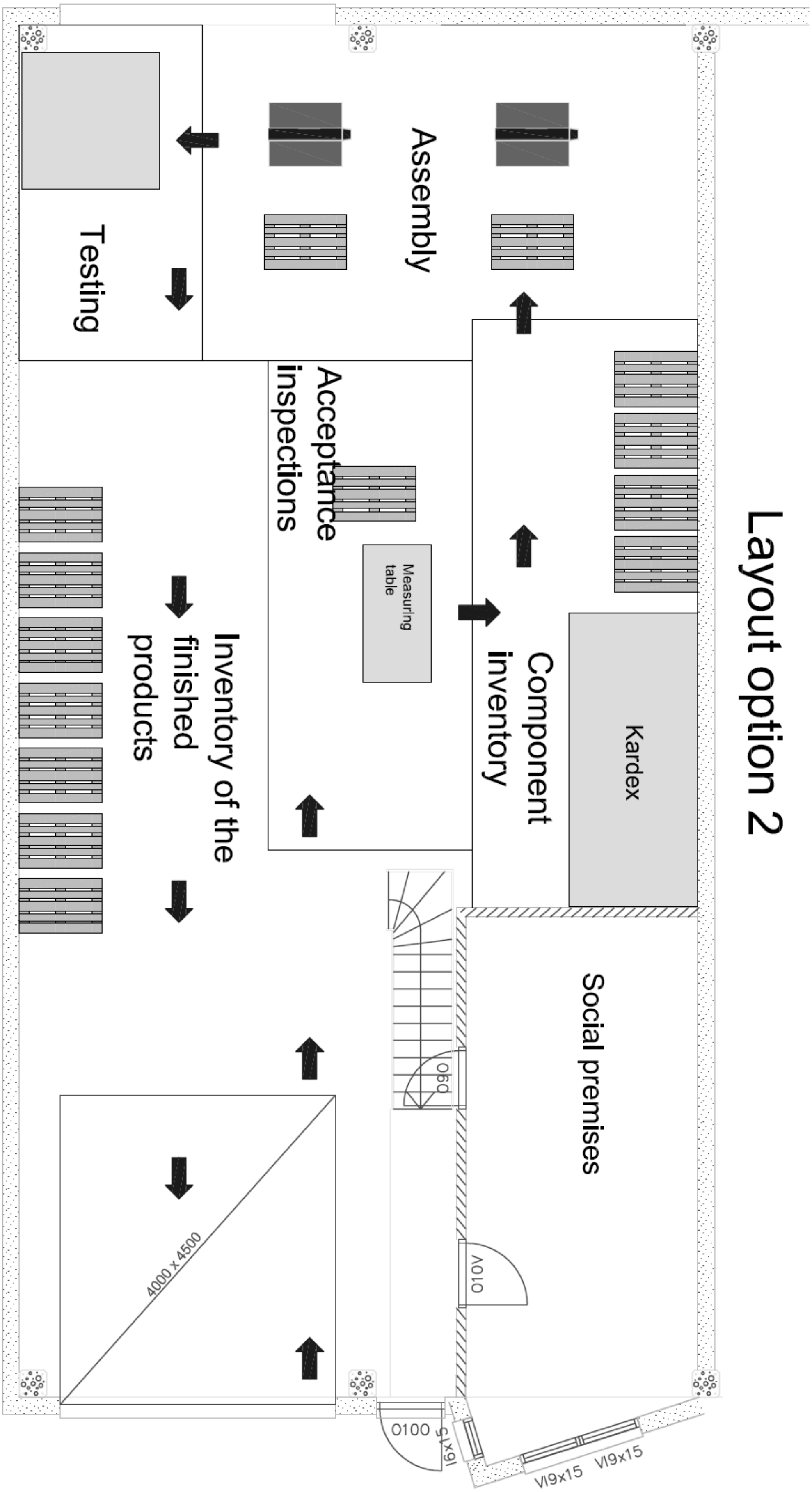
APPENDICES

Appendix 1. Layout option 1



Appendix 2. Layout option 2



Appendix 3. Layout option 3