Layout planning for production of welding machines

Zietsman, J

29044392

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Executive summary

Industrial Engineering knowledge can be applied to businesses that operate ineffectively in order to save time, money, space, energy and other resources. The knowledge gained during the study of Facility Planning Layout Design can be used to improve a company which is currently operating at a subpar level. By gathering the necessary information, investigating alternative techniques and conducting appropriate calculations, the layout of the company can be improved in a way that will allow for better utilisation of resources.

Contents

List of figures

List of tables

Introduction & Background

Company ABC manufactures welding machines that are predominantly used in the mining industry. They specialise in manufacturing inverter welding machines as well as producing welding consumables. Their machines have a unique design which makes the machines a market leader in the South African mining industry. They supply both light and heavy duty industries in South Africa. The factory is based in Strijdom Park, Randburg.

The factory manufactures, distributes and repairs machines. *Company ABC* originated when Coulson Engineering CC bought out Reef Electrical (Pty) Ltd. In 1981 premises in Strijdom Park, Randburg, were acquired and the company was opened in 1981. The premises were originally a storage facility and had built-in equipment such as an overhead crane which was used to move equipment between the top and bottom level of the facility.

The company produced and maintained welding equipment for the mining industry. A policy of make-to-order was used. Therefore, only once a customer placed an order, would the manufacture of the machine begin. After a few years, welding consumables were made available for sale. The facility had to accommodate this expansion by making more storage space available for these consumables. The reception area was adjusted to allow for the consumables to be displayed.

Project Aim

The aim of this project is to help *Company ABC* with the following:

- Assist in planning future expansion and how this can be best accommodated
- Improve the flexibility of the facility in terms of responding to demand or changes in methods
- Improve material flow in the system by identifying possible bottlenecks or future bottlenecks
- Identify areas where costs can be reduced
- Improve the safety in terms of how equipment or materials being handled, how the facility is laid out and improving safety standards to allow for a safer working environment
- Improve the space utilisation of the facility to make space for future expansion to create a more functional facility
- Improve the current productivity by identifying areas where a different method can be used, allowing for better results
- Rearrange activities or storage facilities to reduce pilferage. Copper wire has frequently been stolen and sold to scrap yards, indicating the necessity for a new facility layout
- Improve worker morale by applying best practices from ergonomic - and material handling principles that would create a more worker friendly environment. This could include looking at the specific requirements for each workstation
- Improve the material handling in terms of how materials are being handled, moved and stored in the facility
- Identify possible areas where housekeeping can be better applied and maintained
- Identify possible areas that can improve their efficiency in terms of workers, equipment and space and allow for better maintenance in the facility

Project Scope

The first step would be to gather more information about the company and to take measurements of all areas of interest as well as all the obstacles. Calculations regarding the optimal facility plan will then be done and alternatives will be generated. Equipment, procedures and safety guidelines will be given for each alternative before deciding on the optimal layout. Possible alternative methods for calculating optimal layouts will be investigated and results will be compared. The scope does not however include a practical implementation.

Literature Review

Facilities' planning is used in many different sectors to help design a functional and more effective facility. Facility planners have recently had to consider global markets, since it has such a huge impact on possible facility expansion. If an organisation is not able to expand when needed, demand will not be met, customer satisfaction decreased as will profits.

According to Ghrayeb (2002), facilities planning allows for a facility to improve its competitiveness. Tools such as simulation can be used to identify bottlenecks in the process and find a suitable solution to improve material flow. When a manufacturing facility does not make use of facility planning, they may encounter problems such as inconsistent material flow, unsuitable assigning of work to workers, out-dated equipment and inefficient layouts. Techniques such as line balancing can be used to determine the correct amount of workstations.
Ghrayeb (2002) has stated that the following strategies can be used to eliminate scrap during the manufacturing process:

- Employee certification
- Mistake proofing
- Preventive/Predictive maintenance practices
- Autonomous maintenance (cleaning, lubrication, minor adjustments)
- Better processes/operation documentation with emphasis on quality concerns
- Better quality materials
- Better machines
- Looser tolerances
- Automation
- Quality at source

As explained by the National Productivity Council of India (2005), facility planning is a method of adding value to a facility. Strategically designing a facility is very important as facilities last for decades and therefore need to accommodate any growth of the products and processes. If the facility is planned properly, it increases the competitive advantage of the facility. Advantages that are described include:

• Operate At Low Cost

• Provide Fast Delivery

• Accommodate Frequent New Products

• Produce Many Varied Products

• Produce High or Low Volume Products

• Produce at the Highest Quality Level

• Provide Unique Services or Features

When designing a facility, factors to consider include available space, proximities of departments and constraints. It is important to split the facility up into different departments so that the project becomes more manageable and easier to analyse.

The National Productivity Council of India (2005) divides facilities planning into separate levels. The five levels that exist include:

• Global (Site Location): transport costs, labour costs and labour skills

• Supra (Site Planning): size and location of facility

• Macro (Building Layout): the physical structure of the facility

• Micro (Workcell/Department Layout): location of equipment and stations

• Sub-Micro (Workstation Design): layout of workstations. Information is required about the product and processes to determine how to assign work

Neustro Consulting Ltd (2011) describes lean as a philosophy of eliminating non-valued added activities, or waste. Lean manufacturing is one of the current methods employed in factories in order to increase effectiveness. Facility planning can be used to implement lean in factories. Lean is becoming a popular trend in the planning of facilities. Costs are reduced as unnecessary materials are decreased. Lean focuses at minimising all factors within the factory. Continuous improvement is encouraged so that processes are continually improved and waste eliminated. Lean manufacturing allows for a certain level of flexibility, as there is a constant level of change.

Just-in-time (JIT) is a management philosophy that focuses on eliminating waste whilst improving the manufacturing process, as described by SergeyTokarev(2010). The idea behind JIT is that all materials are only available when required. This reduces inventories and therefore costs, since materials do not lie around waiting to be used. In factories the focus is usually on planning and schedules, making use of maximum capacity. JIT focuses on controlling the elements within the manufacturing system, allowing for a more flexible

system that can easily adapt to changes. JIT is having the right things, in the right place at the right time.

Advantages of JIT include:

- Low inventory levels
- Small batches of raw materials delivered
- Economical machine setups
- Flexible manufacturing system that quickly adapts to changing market conditions
- Improving product quality
- Preventative maintenance
- Continuous improvements
- Reduced costs

Implementation of various philosophies has not taken place in many factories. This is due to the fact that it is a complete change in how things are done. Many companies consider this too much effort to change. The difficulties in changing to another management philosophy outweigh the advantages of the management philosophy.

Cornice Engineering (2008) mentions that automation is a technique that is vital for facilities to remain competitive. Automation is a current trend as well as a future trend. Proper application of automation is a problem for many facilities, as well as a costly undertaking. If automation is applied correctly, it can be very beneficial to the facility. Automation can improve product quality, flexibility and customer satisfaction. In the future, it is thought that the entire facility may be automated, especially with the development of new technologies. In some facilities this is the case, but this is not the usual, especially in South Africa, where many people are employed by factories.

One of the biggest trends that the future holds is to change how facilities' planning is seen and the constraints thereof. Flexibility is becoming one of the key factors that hold manufacturers back from achieving better productivity and efficiency. Planning and forecasting various possibilities so that facilities are able to handle changes without negatively impacting the facility.

As mentioned by V. Hardy (2004), there are many factors to consider for the future of facilities planning. An important factor to consider is whether in the future there will still be facilities and what the capabilities of technology in the future should be. The impact on the

environment is becoming a vital consideration in facilities planning. Factories are moving towards improving their efficiency of power and water use, as well as waste disposal.

As the globalisation takes place, it is becoming more important to break down language barriers as well as other social barriers. Flexibility is thought to become the main focus of facilities planning in the future.

Tim Springer and Steve Lockwood (2004) mention that the most important future trend will be a shift in paradigm. Facility planning should not be thought of as a long term cycle. Factors in facilities planning need to be considered as having a short life cycle. Traditionally, facility planning has focused on managing the cost and space of a facility. In the future, the focus is thought to be increasing profit and streamlining processes. This requires facilities to be flexible and that they can adapt to changes in processes without much effort. Facilities need to learn to anticipate changes, so rather than battle to cope with change; the facility is able to easily change their schedules or the products that are being manufactured. Routine is no longer something that facilities can rely on.

Flexibility is already becoming an important factor in facility planning. This is becoming an important focus when designing facilities. To be competitive requires the facility to be able adjust to changes without incurring high costs or expending much effort.

Methodology

Information regarding the current layout of the company was obtained through an extensive study carried out during a field visit. This information was then used to assess the shortcomings of the current layout and several improvement alternatives to the layout was then generated using various facility layout planning techniques. Each alternative was then assessed in terms of material handling to determine the best solution.

Analysis of Existing Layout

1. Layout Type

At *Company ABC* the workstations are divided according to similar processes. This means that process layout is applied to the workstations.

An example of how process layout is applied is the workstations where the 160A and 200A welding machine are assembled. Both these welding machines have similar parts to be assembled; the only differences between the two are the sizes and current rating. Therefore, a similar assembling process occurs for the two welding machines at the same workstation.

Components are received in small batches at the workstations, usually in batches of 10. A wide range of parts arrive at the assembly station. There is, however, a particular process to be followed in assembling the welding machines. This is a small deviation from the theoretical properties of process layout.

The equipment used to assemble the welding machines has flexibility in that it can be used on many different sized machines.

2. Process Positioning Strategy

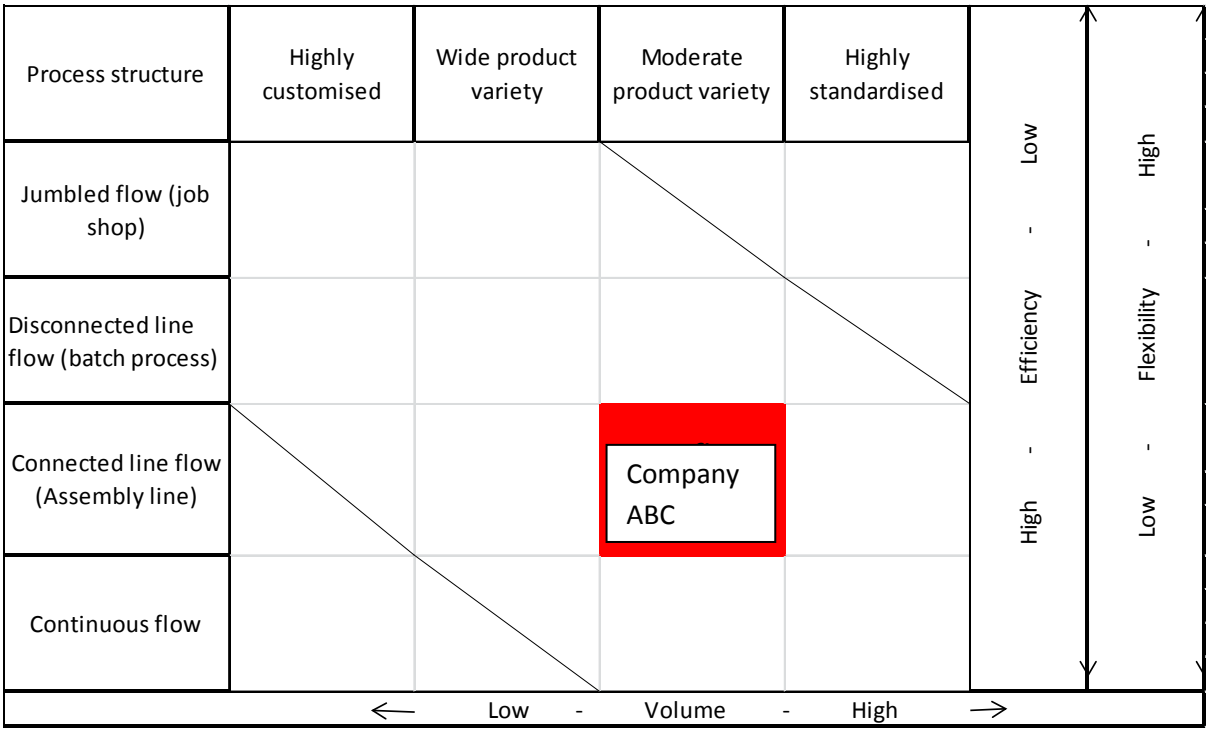


Figure 1: Process positioning strategy

Company ABC produces welding machines and accessories for the welding machines. The products manufactured would fall into an assembly line with a moderate variety. The variety of the welding machines consists of different ranges in amplitude of the machines. This results in moderate volume of products, for example 100 200A machines are manufactured per month. Certain components need to be made before the assembly can take place. Different departments manufacture the various components which are then sent to the assembly department, where final assembly takes place. Therefore, the flow of the process is fixed. The efficiency is relatively high, as *Company ABC* is able to focus on producing high quality products at a reasonable rate. The flexibility of the process is relatively low. If there was to be a sudden and drastic increase in demand, *Company ABC* would have trouble adapting.

3. Product Positioning Strategy

Company ABC assembles make-to-order products. The company only responds directly to actual orders received. The demand is relatively stable therefore overtime is rarely required. The stable demand allows for a constant flow of materials from one department to another in the process of making a machine. *Company ABC* does not really experience times when there are no orders and where departments have no orders to respond to. As soon as the machine has been ordered and made, it is sent to the customer. Therefore, a limited number of completed machines are stored at *Company ABC*.

Safety stock is kept to a minimum since demand variability is low. The type of inventory that must be kept is the various components and the raw materials that are required for the assembly of a machine. Bobbins of copper wire are kept for threading when more threads are required to be made. PC boards are ordered in bulk and therefore available for attaching vital components with soldering when required. There is inventory of machine housing, bolts, wires, buttons and other assembly components that are kept. Therefore, when an order is received, the system can immediately respond and start the process of manufacturing a welding machine. It seems, however, that no proper planning is done to determine the level of inventory that should be kept. Decisions are based on experience and judgements, not recognised best practices.

4. Production Planning and Scheduling Approach

The following approaches can be used when planning and scheduling for production:

- Material Requirements Planning (MRP)
- Just-In-Time (JIT)
- Drum Buffer Rope Scheduling (TOC)
- Just-In-Sequence (JIS)

Company ABC does not make use of a formal production planning and scheduling technique. Over the past few years, *Company ABC* has been expanding. However, no formal planning has accompanied this growth and therefore no formal scheduling approach has been adopted. At present, the approach that *Company ABC* uses is adequate to meet the demand.

The production planning and scheduling approach that is used by *Company ABC* makes use of a whiteboard. This whiteboard is used as a visual representation of the production requirements. The board records monthly stock levels and monthly orders. There is a section for current stock numbers of each machine. On another section of the board, a block is made for each type of machine. In each block, the various orders are listed, and the number of machines that need to be manufactured. As an order is completed, the order is crossed off and the number of machines to be manufactured is adjusted.

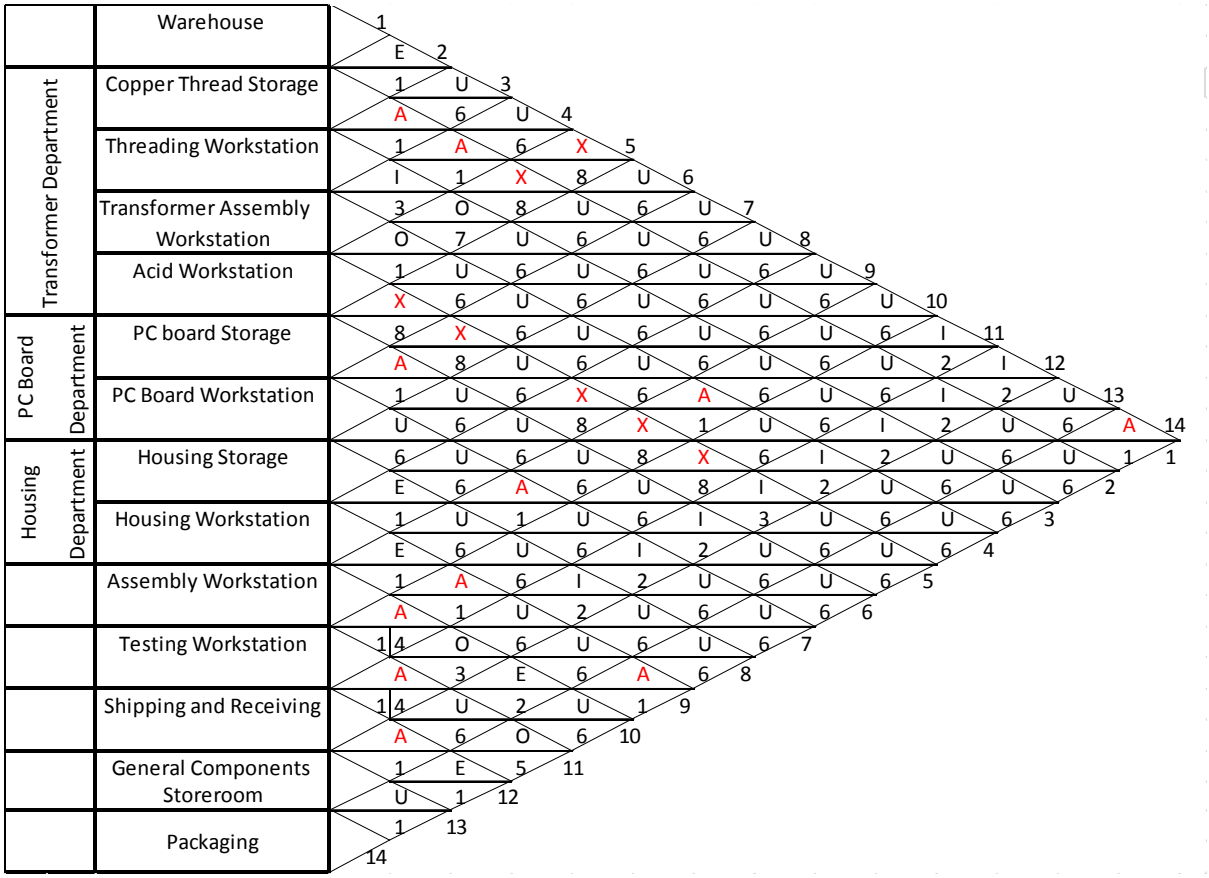
Jan Dries is the Production Planner, and communicates to the workers what the current demand is, how much of each product should be assembled and by when. This is done using the whiteboard. Mr. Dries has been working at *Company ABC* for 9 years and uses his own experience and judgement to determine what the production rate should be.

Company ABC has various departments that are constantly at work to produce components. This includes the threading of the copper strands, making of transformers, wiring of the PC boards and assembly of the final machine. There is constant flow in each department, so products from each department are always available for use in the next department. This correlates with principles that are used in MRP. In MRP there is a buffer inventory so that all workstations are kept busy. This is the situation. Due to the current demand, there is no significant build-up of inventory at any point in the system. A possible bottleneck could be the wiring of the PC boards, however, at present the current capacity is acceptable for *Company ABC.* They are able to manufacture a welding machine in 2 -3 days. There is no

specific method of controlling the capacity in the system. The capacity that is available, in terms of the hours worked by workers, is fully utilised.

Flow Planning

1. Relationship Chart



Code	Reason
1	High frequency
2	Medium Frequency
3	Low Frequency
4	Ergonomics
5	Safety
6	Unrelated Activities

Value	Closeness
A	Absolutely Necessary
E	Especially Important
I	Important
O	Ordinary Closeness
U	Unimportant
X	Not desirable

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3	Low Frequency
4	Ergonomics
5	Safety
6	Unrelated Activities
7	Related Activities
8	Damage

Figure 2: Relationship chart

When redesigning the facility, the relationship chart will help to identify which workstations need to be close to each other. When workstations are placed next to or near the correct workstations, the flow of parts will be continuous, no time will be wasted transporting parts, efficiency will increase and proper space utilisation can be implemented.

The relationship diagram indicates that it is absolutely necessary to have the following workstations close to one another:

1. Copper thread storage and threading workstation
2. Copper thread storage and transformer assembly workstation
3. PC board storage and PC board workstation
4. PC board workstation and assembly workstation
5. Transformer assembly workstation and assembly workstation
6. Housing workstation and testing workstation
7. Testing workstation and shipping and receiving

It is important to have the shipping and receiving area close to all workstations, as shown in the relationship diagram. Since it is not possible to move the shipping and receiving area, proper material handling equipment will have to be used to facilitate the frequent flow of materials to and from the shipping and receiving area.

Since the acid used at the acid workstation will damage any material that it comes in contact with, this workstation should be as isolated as possible.

2. From-to Chart

From \ To	Threading Station	Acid Station	PC Board Station	Housing Station	Assembly Workstation	Testing Station	Warehouse
Threading Station		10					
Acid Station					10		
PC Board Station					30		
Housing Station					4		
Assembly Workstation						10 30 4 17 **61**	
Testing Station							10 30 4 17 **61**
Warehouse							

Figure 3: From-to chart

Component		Production Quantities per hour	Movement factor	Equivalent Flows	Routing
1	Transformer	10	1	10	A-B-E-F-G
2	PC Boards	15	2	30	C-E-F_G
3	Housing	4	1	4	D-E-F-G
4	General components	17	1	17	E-F-G

Stations		Total" From"	Total "To"
A	Threading Station	10	0
B	Acid Station	10	10
C	PC Board Station	30	0
D	Housing Station	4	0
E	Assembly Workstation	61	44
F	Testing Station	61	61
G	Warehouse	0	61

Table 1: From-to relationships

The from-to chart illustrates and identifies the volume of flow to and from all the workstations. It is important to determine these flows so that adequate space is assigned to the correct stations.

The following conclusion can be made by looking at the last table:

1. The highest flow from a station occurs from the assembly workstation and the testing station
2. The highest flow to a station occurs to the testing station and to the warehouse.

In order to properly apply the findings of the from-to chart, one would have to determine exactly how much space would be required to and from these workstations so that no queues or bottlenecks will occur. Adequate storage and aisle space must be assigned to support the flow of materials between the various workstations.

Numerical Space Requirements

The space requirements for facilities are a vital component needed to design a sufficient facility. Flexibility within the plant is needed due to ever changing technology, product mix, demand levels, and organisational designs for the future. A facilities planner has the vital role of projecting probable space requirements for uncertain future trends.

Parkinson's Law is directly related to the context of facilities planning. It states that things within your facility will expand to fill the available capacity sooner than you plan, thus leaving you with no space even though future expansion was considered initially. At *Company ABC,* Parkinson's Law has been proven true. This is seen by the random placement of storage racks, workstations and raw materials.

It is important to approach your facilities space requirements systematically. This is done be developing your facility "from the ground up". This means that the basic processes and objectives need to be dealt with before proceeding to the detailed processes. This can be done by sequentially determining the space requirements for the individual workstations, departments and then the whole facility.

1. Equipment

The equipment used to assemble the components and welding machines are relatively small. Each workstation has its own set of tools (including wire stripper, pliers, nut drivers, crimper and screwdrivers) as well as equipment (such as a soldering iron). There is no tool cabinet or set place to store the tools and equipment, but workers at least have the luxury of having their own set (as opposed to sharing tools and equipment).

No machine travel occurs, since the only machine used during assembly is the threading machine. This is a machine that takes up a lot of space, but remains static throughout the assembly process.

The overhead crane is seldom used, and this results in wasted space. The support structure of the crane is considered to be a monument i.e. something that cannot be moved when redesigning the facility.

Maintenance is required on the testing machines. Preventative maintenance is done on the testing machines to prolong the useful life of the machines.

2. Material Space Requirements

The shipping and receiving area is large enough for a delivery truck to enter. Raw materials and parts are delivered here, and are then transported to the required storage areas. The materials that travel to and from workstations during the assembly process are relatively small, and do not require a large space for transporting. Materials are carried by workers to the relevant workstations; therefore the only space required is for a person to walk in. There is enough space on the workbenches to place all the parts and components. Linbins are placed next to each workstation, containing generic parts such as wires, lugs, nuts and bolts.

Company ABC's warehousing activities include the storage of finished welding machines as well as old repairs. This area is not an actual warehouse, it is only a space dedicated for finished goods. The machines are stored on racks which are situated along the walls within the warehouse area. The warehouse and testing station are situated next to each other.

Welding machines that have been sent in for repairs has been placed in the warehouse for no apparent reason and creates an unnecessary occupation of space. The manager, Mr Dries, is also unsure of the status of these repairs.

Only a limited number of finished goods are stored in the warehouse since cross-docking usually occurs: once the welding machines are packed, they are immediately shipped to the relevant customers.

Bins that are dedicated to scrap materials are found throughout the facility. Once every few months, the scrap material is removed and sold to a scrap yard.

As noted in the equipment section, no dedicated areas are visible for the storage of tools and maintenance materials. Cleaning equipment was not visible, but it is assumed that a dedicated space exists for housekeeping purposes.

3. Personnel Space Requirements

The workbenches in the facility are large enough for the workers to perform their work on. Space between workbenches are somewhat cluttered though. Many storage racks, linbins and tables are randomly placed in the facility, and sometimes obstruct the walkways. Minimal material handling equipment is used; therefore little space is dedicated to such systems. A great cause for concern is the 160A and 200A welding machines that have to be

carried from the assembly workstation on the top level to the testing station on the bottom level. Even if a material handling system was in place, the stairs create a definite obstacle.

The chairs and the workbenches seemed extremely uncomfortable. Many of the cushions had been fixed by duct tape, and some workers had to sit on bar stools. These chairs may prevent the workers from working at their full ability since workers are required to sit down to perform their work.

4. Whole Facility

Further expansion of the facility is not possible, since it is surrounded by other industrial firms and roads. Since the top level does not fill up the total available space, it may be possible to expand the top level if required. This would obviously interfere with production, and should only be considered if no alternatives exist.

Consider the numerical space requirements shown on the next page. These space requirements are based on the current layout, and not on the minimum space requirements of each department. The minimum space requirements will be determined at a later stage and used in the proposed facility layout.

Table 2: Space specifications

Individual workstations	Actual workstation (m^2)	Aisle (m^2)	Total space (m^2)
Threading station	6	6	12
Transformer assembly station	6	4.5	10.5
Acid station	15	7.5	22.5
PC boards' station	12	4.5	16.5
Single assembly station	12	15	27
Housing preparation	12	15	27
Housing storage	16	12	28
Single testing station	2.4	3	5.4
Required aisle width	1.5	m	

Departments	Total space (m^2)
Transformer department: includes threading, transformer assembly and acid station	45
PC board department	22.5
Assembly: includes all 6 assembly stations	162
Housing: includes prepration and storage	55
Testing: includes both testing stations	10.8
Warehouse	18
Storage for general components	40.5
Shipping and receiving	10.5
Total	364.3

Facility	Total space (m^2)
Bottom level	600
Top level	175

Material Handling

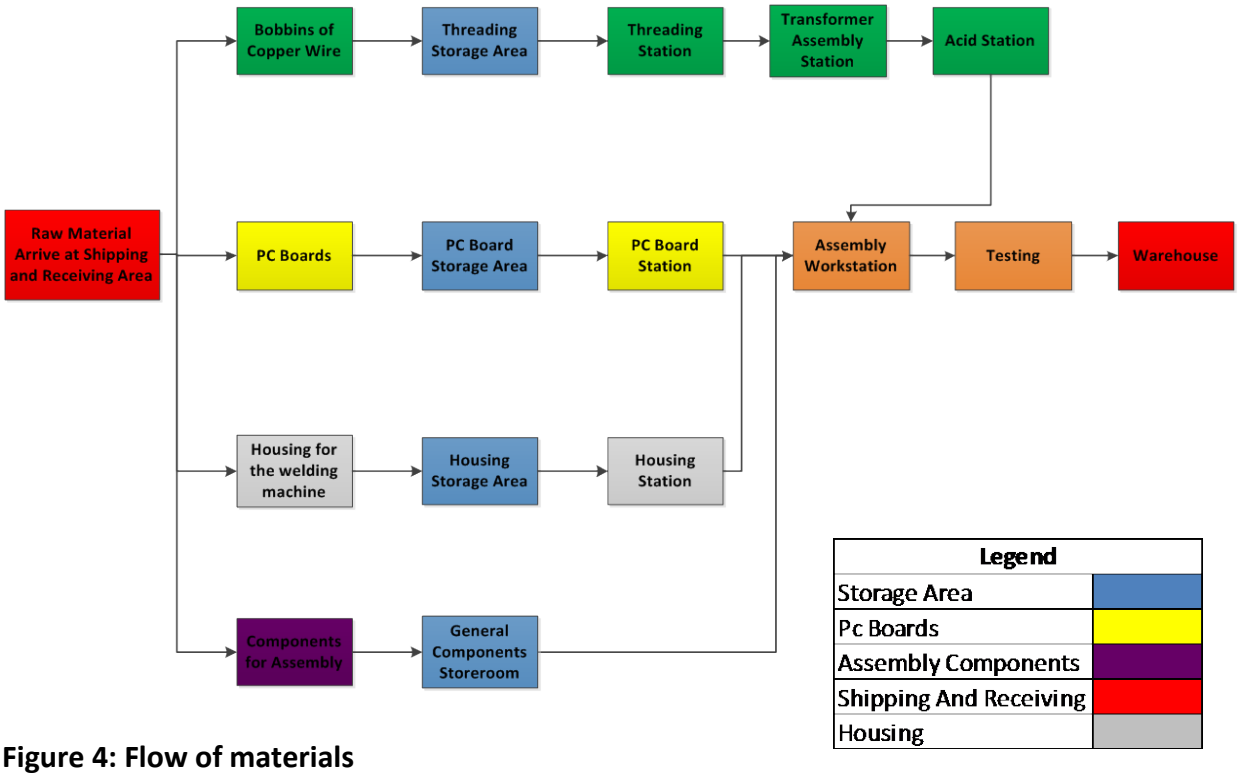


Figure 4: Flow of materials

Raw materials are delivered to *Company ABC* in trucks by various suppliers. There is a shipping and receiving area at the front of the factory with a large door through which materials can be brought. These raw materials include bobbins of copper wire, PC boards, various components for the transformer, housing for the welding machine and other components required for the assembly of the machine.

When the raw materials arrive at the factory, they are distributed to the appropriate storerooms. This is done manually by workers who carry the raw materials. No use of trolleys or any other material handling equipment is used to transport material. Unit load principles are not applied when raw materials are moved, except when raw materials arrive in boxes. Handling the material by hand also reduces efficiency.

The various places where raw materials are transported to and stored include:

- Copper bobbins by the threading storage area next to the threading Station
- Copper threads are hung up in the threading storage area next to the threading station
- Machines that are completed or are in for repairs are stored in warehouse at the back of the factory

- Expensive components are placed in a general components storeroom at the front of the factory where they can be locked away
- PC boards are stored in boxes in the PC board storage area where vital components are soldered to the PC boards
- Housing for the welding machines is stored in the housing storage area which is next to the housing station.

There are two levels at the factory. On the top level there is the copper threading station, storage areas, the transformer assembly station and the assembly workstations of the 160A and 200A machines. The bottom level includes assembly workstations of the 300A, 400A, 500A, 600A and 700A machines, storage rooms, PC board assembly station and the testing station. There are two stairways that connect the two levels. In some instances, the stairs present a safety concern. After 160A and 200A welding machines are assembled, it is carried down the stairs to the testing station. The welding machines are heavy and obstruct the view of the worker carrying it.

Once the required components are assembled at the various workstations, the worker responsible for the assembly of the finished component will carry it to the next workstation downstream from him. The welding machines are standardised and contain the same type of components. The main difference between the different sized welding machines is the number of components in each. Therefore, standardisation in the equipment also occurs.

When the workers are assembling the transformers, gloves are worn. After the transformers are assembled, part of the copper wire should be soaked in acid for 3 hours. Workers are then required to wear safety glasses, a visor and an apron in addition to gloves. No safety glasses were worn by workers who were soldering. Strict safety procedures are not enforced by management, creating possible unsafe working conditions.

Generic parts such as wires, lugs, nuts and bolts, buttons and other components that are used in the assembly of the welding machines are kept in small boxes, known as linbins. Each workstation has a set of linbins with the required materials. Each workstation has its own set of tools required for the assembly process. Tools such as a soldering iron, crimper and wire stripper are used for assembly. This allows the worker to remain at their workstation and not have to get up and fetch tools or generic parts on a regular basis.

Once a welding machine has been assembled, it is carried to the testing station. The 700A welding machine is a very large machine and wheels are put onto it for ease of movement. Therefore, all the machines are carried to the testing station except the 700A, which is rolled

to the testing station. No visible safety procedures or equipment are used at the testing station, even though high voltages are a cause for concern.

From the testing station the machines are moved next door to the warehouse. The machines are packaged in boxes, along with an instruction manual.

Company ABC has a truck that is used for the distribution of welding machines to the customers. Finished goods are usually delivered to the customer immediately without being stored in the warehouse. Packaged goods are carried to the shipping and receiving area, where it is loaded onto the truck by the workers. Multiple trips have to be made to and fro, since workers are not able to carry multiple welding machines to the truck.

An overhead crane is available for material handling purposes. In the past, it was extensively used to handle an older model welding machine. This model was phased out, and is currently only used when one of these machines come to *Company ABC* for repairs.

The only official method of handling information is a white board on the lower level of the factory. Current stock levels, fulfilled orders and current demand are listed on the white board. Information is mainly passed verbally from management to workers.

Departments

The primary activity of *Company ABC* is the assembly, packaging and delivery of welding machines. Secondary activities include repairs and maintenance, administrative activities, selling spare parts and personnel services. Personnel services include the minimum requirements that have to be met by management, such as locker rooms, restrooms and health services. Since ergonomic requirements and human capabilities affect employee morale, these are also included under personnel services in this report.

The following departments were identified:

- Shipping and receiving
- Storage for general components
- Transformer department
- PC board department
- Assembly departments
- Housing department
- Testing department
- Packaging department
- Warehouse

1. Shipping and Receiving

One area is dedicated to both shipping and receiving functions, since *Company ABC* has realised that shared resources are used between these two functions. Presently, shipping and receiving takes up 10.5 m^2.

Shipping and receiving is grouped into a department because it includes all activities related to the transport of raw materials and welding machines to and from the facility. Another reason to grouping it into one department is the fact that similar resources are used to carry out all shipping and receiving functions.

A delivery truck carrying raw materials will enter the shipping and receiving area through an industrial roller shutter door. Once the truck is parked, workers will unload the truck. The workers do not make use of docks to facilitate unloading of raw materials; a ladder is used by workers to climb into the truck and unload the raw materials.

During the unloading process, packages are randomly packed on the shop floor. Consider the exaggerated scenario shown on the next page. The departments where the raw materials are needed are labelled in the blocks.

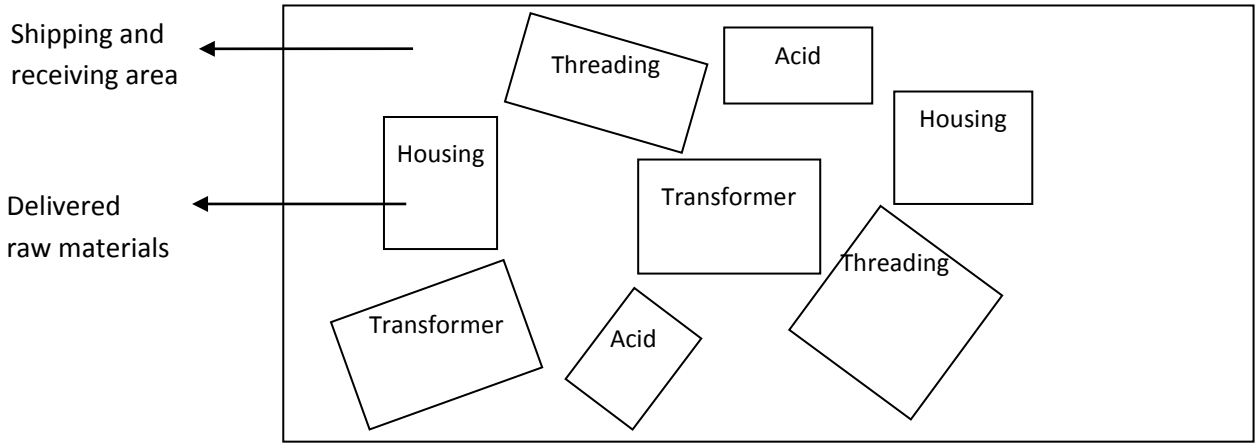


Figure 5: When raw materials are unloaded from the delivery truck

Workers will first unload all packages from the delivery truck and then carry it to the relevant departments. Since packages are randomly placed on the floor, no space is left to travel between the packages and proper inspection cannot be done. Inspection is supposed to support the primary activity of assembling welding machines, but proper inspection cannot be done due to the current unloading process. Thus, this area does not support the primary activity in ensuring that raw materials received are of good quality and are received in good condition.

When the partial inspection process is completed, workers will carry the individual packages to the relevant departments. No material handling equipment is used to transport the raw materials, and time is wasted since multiple trips have to be made to each department. No proper material handling system is in place in the shipping and receiving area, and thus does not support the secondary activity of personnel services.

A similar process will occur when finished goods are shipped. The finished goods are carried from the warehouse to the shipping area by the workers. Once again, no material handling equipment is used to facilitate transport of the welding machines to the shipping and receiving area. Since the completed welding machines are very heavy, this activity damages the workers' backs and possibly affects their morale. By not supplying the necessary

material handling equipment, management is sending a message that workers' health and safety is not important.

Once the delivery truck arrives at the shipping and receiving area, workers load the completed welding machines onto the truck and the welding machines are delivered to the customers. The ladder is again used by workers to get into the truck to load the finished welding machines.

The shipping and receiving area supports the primary activity of assembling welding machines in that enough space is allocated where raw materials can be delivered. If the raw materials cannot be delivered, welding machines cannot be assembled, and *Company ABC* will cease to exist.

The secondary activity of repairing and maintaining welding machines is also supported, since damaged welding machines, sent in for repairs by mines, will be delivered by a delivery truck to the shipping and receiving area.

2. Storage for General Components

This area currently takes up 40.5 m^2. Expensive components are locked away in storage cabinets which are lined along the walls of this area. Pallets are found in the centre of the floor, and random items are stored here. The pallets present a possible safety hazard, and no material handling equipment (such as a forklift) is owned by *Company ABC* that will enable them to easily move these pallets.

Storage for general components is a department on its own, since the storage provided here is different than the storage areas found at the workstations. This area is specifically dedicated to expensive components that require extra security measures. The extra security measures are simply storage cabinets that can be locked. The keys are held by the production planner. When workers from the assembly station need a component that may be locked away, they ask the production planner to unlock the cabinet.

There are no labels on any of the cabinets, and it seems that randomised storage is used: components are stored wherever space is available. Even though space utilisation is high when randomised storage is used, the disadvantages definitely outweigh the advantages. One of the disadvantages is time wasted when picking materials.

Incoming raw materials that need to be locked away are packed in front of those components that have already been stored in the cabinet. LIFO is occurring as a result of the storage methods used.

This area supports the primary activity of assembling welding machines. Just as with the shipping and receiving area, assembly of welding machines cannot take place if general components are not stored properly.

3. Transformer Department

The transformer department includes the threading workstation, transformer assembly workstation and the acid workstation. These activities are closely related to one another, and the end result is a completed transformer that will be used in the assembly of the welding machines. It was therefore decided to group these three activities into one department.

The workstations that form part of the transformer department are situated relatively close to each other on the top level of the facility. The total space utilisation is 45 m^2. Three workers are dedicated to the transformer department and they travel between the different workstations to complete work where ever it is required.

When copper bobbins are delivered to the shipping and receiving area, it is carried to the top level and stored next to the threading machine. There is no designated area for the storage of the copper bobbins, but there is enough space left for the worker to move around the threading machine.

Once the copper has been threaded, it is hung onto the wall next to the threading workstation. This form of storage takes up very little space, and whenever copper threads are required at the transformer assembly workstation, workers will fetch the number of copper threads that they need.

At the transformer assembly workstation, copper threads are wound around the transformers in batches of ten. When an increase in demand occurs, these batches may be larger and the size thereof is decided on by the production planner, Jan Dries.

Once a batch is completed, the transformers are carried to the acid workstation, where the end of the copper threads will be soaked in acid for three hours. The acid disintegrates the non-conductive cover to expose the conductive wires.

Protective clothing should be worn by any worker who handles the acid. The protective clothing includes gloves, an apron, safety glasses as well as a visor. Even though workers

are required to wear these items, management does not strictly enforce these rules. Management realises the dangers of this area, but feel it is unnecessary to implement the proper safety procedures required. The acid workstation is separated from the rest of the facility with a screen, but the table on which the acid is placed seems to not be properly protected. It seems as if the acid can easily be knocked over if one is not careful.

The transformer department supports the primary activity of assembling welding machines. The transformers are key components of the welding machines, without which it cannot function. The necessary tools, equipment and workspace are supplied to workers so that they may complete their work.

In terms of safety, this department falls short in supporting the secondary activity of personnel services i.e. providing a safe working environment. It is crucial that the employer enforces the necessary rules that will prevent employees from getting injured. Many times, these employees are the breadwinners of their families, and if they get injured at work their whole family will be left without an income.

4. PC Board Department

The PC board department consists of an assembly workstation as well as storage units. Currently, the PC board department utilises 16.5 m^2, but it does not actually require this amount of space.

In one of the corners of the PC board department, a kettle and microwave is found. It is a necessity to provide workers with the appliances they need to prepare their lunch and coffee/tea during their breaks. It is, however, necessary to provide these facilities in a kitchen and not in one of the departments. When workers from other departments want to use the appliances, the PC board worker gets distracted and may become less productive. The steam from the kettle may also damage the circuit boards that are stored in this department.

In other words, the PC board department takes into account the secondary activity of personnel services. This is not at all required, and it would be ideal to have a separate kitchen that is dedicated to providing workers with the appliances they need in order to eat and drink coffee or tea during their breaks.

Storage space is supplied by household bookshelves and the storage cabinets used are similar to the ones used in the general components storage area (as discussed in section 1.1.2.). An L-shaped office desk is used as the work bench, and finished PC boards are

packed in boxes on the desk. The storage shelves and cabinets support the primary activity of assembling welding machines. By ensuring that all the components needed for the PC boards are stored in this department, the worker is able to assemble all the PC boards required for the final assembly of the welding machines. The primary activity of *Company ABC* is thus supported by the PC board department.

Since no ergonomic equipment, such as a proper workbench or ergonomic chair, is found in this department, the secondary activity of personnel services is not supported.

It was decided to group PC board assembly and storage as into one department, since the activities that occur here are completely separate from the other departments at the facility.

5. Assembly Department

Six assembly workstations are found throughout the facility and make up the assembly department. Since similar activities are done at each assembly workstation, it was decided to group the separate assembly workstations into one department, even though the different workstations are found on the bottom and top level of the facility. Each station contains a workbench and aisle that utilises 27 m^2 of space.

Welding machines come in various sizes, namely 160A, 200A, 300A, 400A, 500A, 600A and 700A. The 160A and 200A are similar in the type of components that it is made up of, and only differ in size. For this reason, these two welding machines are assembled at the same assembly workstation that is found on the top level of the facility. The rest of the welding machines are assembled at separate workstations found on the bottom level of the facility.

At each assembly workstation, linbins are found containing generic parts, such as wires, lugs, nuts and bolts. Labelling is inconsistently found on the linbins, which gives the impression that an effort was once made to visually manage the facility.

A variety of chairs are found at each of the assembly workstations, none of them being ergonomic. Some chairs had been fixed using duct tape and look incredibly uncomfortable. Workers spend the whole day sitting at their workstations and the type of chair will play a very important role in productivity and employee morale.

Many fans are found throughout the facility, which creates a better working environment in the summer. All of the assembly workstations have proper lighting in the form of fluorescent lights. Each workstation has a custom-built frame to which the fluorescent lights are attached.

The 160A and 200A welding machines are carried down a flight of stairs to be taken to the testing department, which is a definite safety hazard. The workers at the rest of the assembly workstations on the bottom level also need to carry the assembled welding machines to the testing department.

The assembly department definitely supports the primary activity of the facility. Each worker has his own set of tools and linbins, and this enables them to complete assembly without walking around the facility to find tools or generic parts used in the assembly process. Enough space is available at each workstation for the workers to assemble the workstations.

Ergonomic requirements are not taken into account at the assembly department. As noted above, the chairs seem uncomfortable, and the ideal is to provide ergonomic chairs to each of the workers.

Since no material handling equipment is supplied to workers for the transport of welding machines, human capabilities are not taken into account. The welding machines vary between 30 kg and 55 kg, and forcing workers to carry it to the testing station is absurd.

There is enough space at each of the workstations for repairs to be done. If any internal damage is found in a welding machine, it will be sent to the relevant workstation. Even though internal repairs are rarely done, space is still available if such a situation presents itself. Therefore the secondary activity of repairs and maintenance is supported by the housing department.

6. Housing Department

At the housing department, preparation activities occur. Labelling with stickers is done, safety warnings are attached and handles are screwed onto the housing. Housing preparation consists of a workbench that is identical to the workbenches found in the assembly department, and also takes up 27 m^2.

Storage of raw materials occurs separately from the housing preparation workstation. The worker responsible for housing preparation has to walk 5 m to the housing storage area which is found against one of the walls of the facility. The raw materials are placed on and underneath a table of size 16 m^2. The aisle space required for the storage area amounts to 12 m^2.

Even though the storage area is separate from the housing preparation activities, these two areas are grouped into one department. The ideal situation would be to have housing raw materials stored next to the housing preparation workstation.

Batches of prepared housing are carried by the worker to the testing department, where final assembly will occur after the welding machines have passed all the tests. Ideally, the housing department should be placed next to the testing department to decrease time spent by workers moving to and from the housing department.

The primary activity of assembling welding machines is supported by this department, since the housing is needed before packaging and delivery of the finished welding machines can occur. Even though the housing is not heavy, it is abnormally shaped and difficult to carry many at a time. Therefore, human capabilities are not taken into account in this department. This is especially a problem since the worker has to carry the raw materials from storage to the workstation, as well as prepared housings to the testing department.

99% of repairs that have to be done will be to simply replace the housing. Oftentimes, the housing gets badly damaged when it is used during heavy duty mining activities, and these damaged machines are delivered to the housing department for repairs. There is enough space available to place the damaged welding machines, but no specific area or storage rack is dedicated to such welding machines. In terms of space, the housing department supports the secondary activity of repairs and maintenance even though there is no dedicated space for the damaged welding machines.

No ergonomic chairs are found in this department, resulting in the secondary activity of personnel services not being supported by this department.

7. Testing department

Two testing workstations are found in the testing department, along with a large table where assembled welding machines are placed when awaiting testing. The machines used to test the welding machines are almost the size of the workbenches, creating a crammed work area for the workers.

Once again, ergonomic chairs are not used in this department. This creates an unfriendly worker environment, and does not support the secondary activity of personnel services.

Since high voltages are used to test the welding machines, this department should be well maintained to prevent any injuries. No critical injuries have occurred at the testing department in the past decade, giving the impression that workers realise the risk that is present in testing the welding machines. No safety warnings are found anywhere near the testing stations, and this could be a safety concern for new employees or visitors to the facility.

Once a welding machine has passed all the tests, housing is placed onto the welding machine. Depending on the situation, the welding machine will either be stored in the warehouse or be taken to the packaging department before being shipped from the shipping and receiving area.

If repairs have been done on damaged welding machines, it will be tested before being shipped back to the customer.

Testing is a very crucial step that welding machines have to go through before it can be sold to the customers, and thus supports the primary activity of the facility.

8. Warehouse

Ceiling-high storage racks are found along the walls of the warehouse, where welding machines are packed. Old welding machines that were sent in for repairs are also stored in the warehouse. Since management does not know the status of these damaged welding machines, it is evident that there is no proper communication between management and employees with respect to repairs. The damaged welding machines should actually be sent to the department responsible for repairing it.

The secondary activity of repairs and maintenance is supported by the warehouse, but this is not necessary, since the warehouse should only contain finished products.

The warehouse provides storage for finished welding machines and supports the primary activity of the facility.

9. Packaging Department

The packaging department is a newly created department which will be implemented in the proposed facility layout. Currently, packaging is done in the testing department.

After the housing is placed onto the welding machine, the welding machine will either be stored in the warehouse or be packaged immediately and sent to the shipping and receiving area to be delivered to the customer. If the welding machines have been placed in the warehouse, it will be transported from the warehouse to the packaging department where it is placed in a box along with a user manual when it is needed.

Packaging is the final step that the welding machine has to go through at *Company ABC* before exiting the system at the shipping and receiving area. At present, packaging is done wherever space is available in the testing department. Therefore the current non-existent packaging department does not support the primary activity of packaging welding machines (which it should).

10. Other

Furthermore, other areas have been identified in the facility. These areas are not used in the actual assembly of the welding machines, but enable *Company ABC* to function as a business and carry out supporting activities. Even though these areas will not be included in the proposed facility layout, it will briefly be discussed in this section.

These areas are:

- Reception, which includes a few shelves dedicated to the selling of spare parts
- Offices
- Boardroom
- Restrooms
- Parking

10.1 Reception

The reception area utilises 24 m^2. A large L-shaped reception desk separates the customers from the employees. The reception area certainly takes into account the primary and secondary activities which take place at the facility.

If private customers do not wish to phone to place orders for welding machines, they may visit the facility and do so at the reception desk. The books needed to record customer orders are kept at the reception desk, and are later used by Admin & Finances to add the new customer orders to the system.

There are a few shelves behind the reception desk which are dedicated to keeping stock of spare parts. Selling of spare parts is not the primary activity of *Company ABC*, but it does generate extra revenue and increase customer satisfaction. These spare parts can be sold to any customer who wishes to replace parts that have been damaged. If damage to their welding machine is of a greater extent, customers bring their welding machines to the reception area to be handed in for repairs. This is in contrast to how bigger customers (mines) will handle their damaged welding machines: these customers send their welding machines via a delivery truck. In this report, the focus is on damaged welding machines that are delivered at the shipping and receiving area and does not include any damaged welding machine brought to reception by private customers.

Another shelf is dedicated to displaying products sold by *Company ABC*, which supports the secondary activity of selling spare parts.

10.2 Offices

The offices support secondary activities of the facility, which include management, administration, finances and human relations.

10.3 Boardroom

The boardroom is used to hold management meetings, as well as any meetings held with sales representatives. The boardroom takes into account the secondary activity of administration.

10.4 Restrooms

It is a requirement by law to provide restrooms in any working facility. Separate restrooms are dedicated to administrative employees and floor workers. The restrooms falls in the category of personnel services and are within the required 60 m distance from the different workstations.

10.5 Parking

An area in front of the building is dedicated to parking. It is unclear whether enough parking is available for all employees, but the parking area is < 150 m walking distance from the

facility entrance. Not much free space is available and it is difficult to manoeuvre between the facility entrance and the parking spaces.

Two gates lead into the parking lot. One gate is used by employees, customers and visitors. Another gate is used for delivery vehicles, which are allowed to enter the shipping and receiving area through an industrial roller shutter door.

The parking area thus supports both primary and secondary activities.

The following table summarises the activities that are supported by each of the departments. Activities that should be supported, but are not, are marked with a red cross. Activities that are supported by the department, but do not need to be supported by that specific department are marked with a green cross

Table 3: Activities supported by departments

		Primary Activities (pertaining to welding machines)			Secondary Activities			
		Assembly	Packaging	Delivery	Repairs and maintenance	Selling spare parts	Personnel services	Administration
Shipping and receiving		X S	X	X			A	
Storage for general components		X						
Transformer department		X					A	
PC board department							A S	
Assembly department		X			X		A	
Housing department		X			X		A	
Testing department		X			X		A	
Packaging			A					
Warehouse		X			S		A	
Other	Reception				X	X		
	Offices							X
	Boardroom							X
	Restrooms						X	
	Parking			X			X	

Legend:

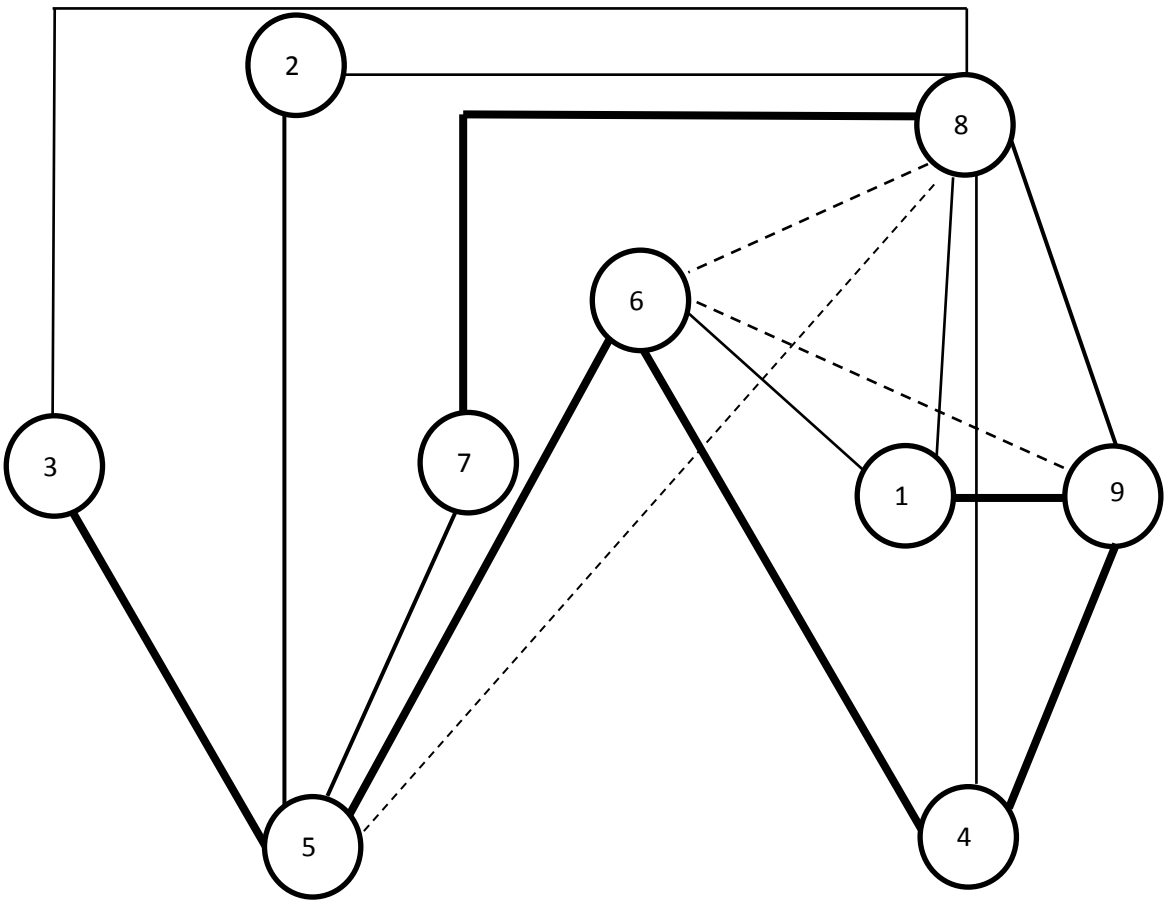
X – Activities supported

A – Activities that should be supported

S – Activities that are unnecessarily supported

Alternative Block Layout Calculations

1. Space Relationship Diagram



Departments	
1	Warehouse
2	Transformer Department
3	PC Board Department
4	Housing Department
5	Assembly Department
6	Testing Department
7	Storage Department
8	Shipping and Receiving Area
9	Packaging Department

Legend	
	Absolutely Necessary
	Especially Important
	Important
	Ordinary Closeness

Figure 6: Space relationship diagram

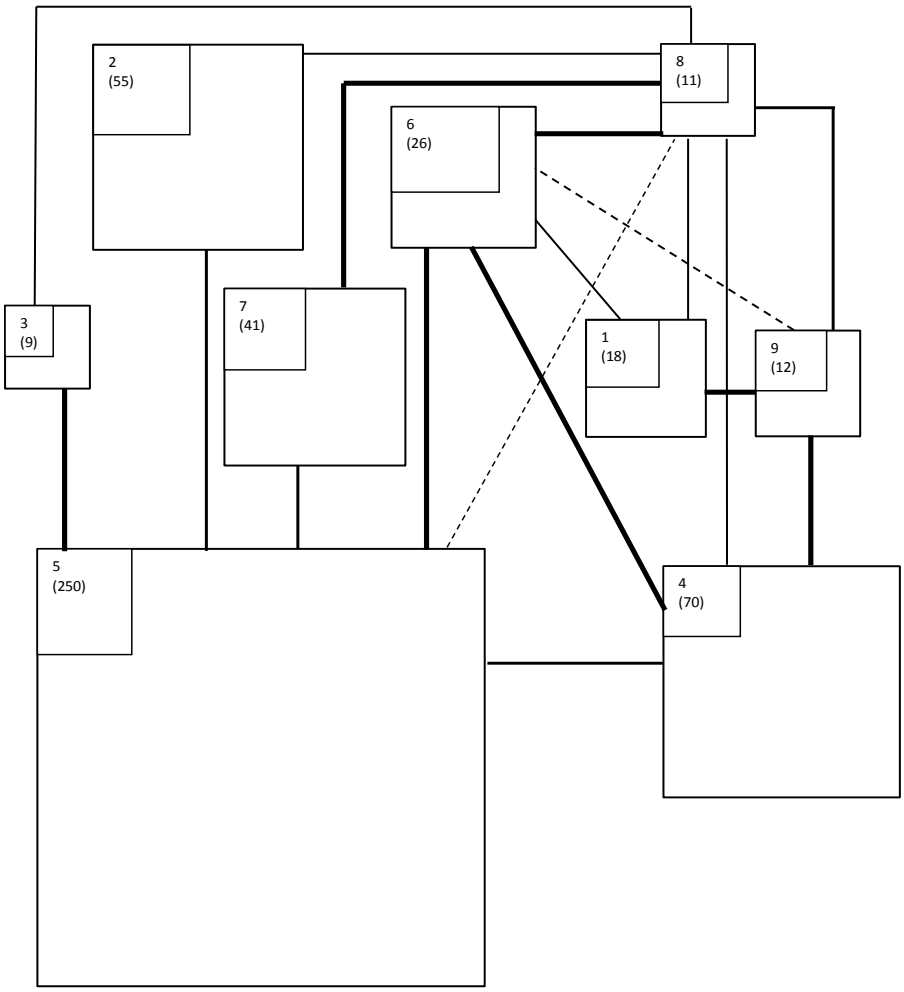


Figure 7: Space relationship diagram

Departments	
1	Warehouse
2	Transformer Department
3	PC Board Department
4	Housing Department
5	Assembly Department
6	Testing Department
7	Storage Department
8	Shipping and Receiving Area
9	Packaging Department

Legend	
	Absolutely Necessary
	Especially Important
	Important
	Ordinary Closeness

2. Material Handling Objectives

Company ABC will benefit in numerous ways by implementing a new facility plan and material handling system. The objectives related to material handling are discussed in this section, and the alternative block layouts, found in section 2.3, will aim to reach these objectives. The material handling objectives are:

2.1 Improve Ergonomics

At present, workers have to carry welding machines to and from the departments where it is needed. Proper material handling equipment will be chosen to alleviate the physical strain put on workers. The material handling equipment chosen to transport the welding machines will also increase the safety and efficiency.

Ergonomic chairs will also be allocated to all workstations in the final facility layout.

2.2 Improve Safety

It is necessary to greatly improve safety measures taken at the acid station. Material handling equipment will be implemented in order to increase safety awareness, as well as the actual usage of safe material handling equipment. The acid station will be properly isolated from the rest of the facility to prevent people from accidentally knocking over the acid.

As noted in section 3.1, the material handling equipment used to transport the welding machines will increase safety, since workers do not have to carry the welding machines by hand. Welding machines range from 33 kg to 50 kg and obstruct the view of the worker when carrying it. If the worker drops the welding machine, damage can be made to surrounding equipment, to the welding machine and to the worker. The fact that workers carry the welding machines will be completely removed in the final facility layout.

2.3 Improve Handling of Information with Respect to Repairs

The fact that management do not know the present status of the damaged welding machines indicates that this information is not properly handled. A method of handling this information will be proposed in the different alternative layouts, and the best option chosen to be implemented in the final facility layout. It is important that the correct people can extract information needed about the repairs; i.e. if the housing needs to be replaced on a damaged welding machine, the production planner, Jan Dries needs to convey this information to a worker who works in the housing department. Success of this objective depends on the willingness of the production planner to manage and control the information about the damaged welding machines.

2.4 Increase Flexibility

The material handling system will increase flexibility in the facility. The material handling equipment suggested can be used for several different activities, thus increasing flexibility.

2.5 Utilisation of Gravity

The top level of the facility greatly reduces the productivity of the facility, since a lot of time is wasted by transporting materials up and down the stairs. In the proposed facility layout, gravity can be used as an advantage to easily transport goods assembled on the top level to the bottom level. Since the all the materials used in the assembly process need to be handled with care, the necessary material handling equipment will be used in order to facilitate safe movement from the top level to the bottom level.

2.6 Increase Throughput & Reduce Time Wasted During Transportation

Material flow is currently low due to the fact that all items are carried by hand. Multiple trips have to be made since the volume of material that needs to be carried is too big. The weight of welding machines also forces workers to make multiple trips to and from the departments where it is needed. By using material handling equipment, unit loads can be transported between the different departments, and throughput will thus be increased.

Since multiple trips are made by workers who transport materials between the workstations, a lot of time is wasted. Therefore, when fewer trips are made, less time is wasted.

2.7 Reduce Pilferage of Copper Wire

Security measures will have to be taken in order to reduce pilferage. Scraps of copper wire is usually stolen by the workers and sold to scrap yards. Management needs to determine how important it is to reduce pilferage, since security measures can be a costly improvement to make. If the security measures will cost more than what the cost saving will be on the reduction of pilferage, it will not be a viable option.

2.8 Implement Unit Load Principles

The material handling equipment used will ensure that unit loads are used. The unit load principle will be beneficial to *Company ABC* since it will result in more effective material flow.

3. Factors to Consider

3.1 Material Flow

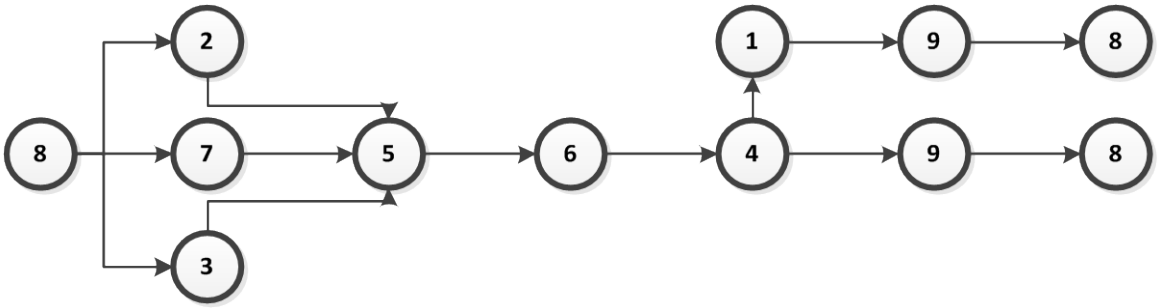


Figure 8: Departmental Material Flow

	Department
1	Warehouse
2	Transformer Department
3	PC Board Department
4	Housing
5	Assembly
6	Testing
7	Storage
8	Shipping and Receiving
9	Packaging

This material flow is based on the processes that the components have to go through during the assembly process. Since the method of assembling welding machines is fixed, this material flow is used in all three alternative block layouts.

The aim of the alternatives is to prevent material to unnecessarily flow through any departments when transporting it to the next department downstream. Backtracking should also be reduced as much as possible.

3.2 Constraints

A few constraints have been identified that will restrict the optimal design of the alternatives. The constraints are:

3.2.1 Scope

It was decided to only include departments involved in the assembly of welding machines in the proposed facility layout. This limits the design because all other departments in the

facility, such as offices, reception and restrooms, have to be kept in the same place. This means that the available space used for the alternative block layouts is smaller than the actual facility. This constraint will be evident in the alternative block layouts, since the reception area stays in the same place for each alternative. Also, the area of the bottom level seems to be smaller than the top level in the alternative block layouts; this is because the offices are also found on the bottom level on the left hand side. For simplicity reasons, the offices have not been included in the alternative block layouts. The final facility layout will, however, include the offices.

3.2.2 Delivery Trucks need to be able to access the Shipping and Receiving Area from the street

The shipping and receiving area is limited to the wall closest to the street (represented by the bottom line in the alternative block layouts). Since delivery trucks enter through the shipping and receiving area, easy access to the street is needed. No other walls in the facility can be accessed from the street, since these walls are built too close to the fence surrounding the facility.

4. Minimum Space Requirements

To generate the alternative block layouts, the minimum space requirements for each department were determined. Consider the table below showing the minimum requirements for each department:

Table 4: Minimum space requirements

	Department	Area (m^2)
1	Warehouse	18
2	Transformer	55
3	PC Board	9
4	Housing	70
5	Assembly	250
6	Testing	19
7	Storage	41
8	Shipping and Receiving	11
9	Packaging	12
	Minimum total space required	485

After the initial block layouts were designed using the minimum space requirements, open spaces were found in all three alternatives. The next step was to increase the size of some of the departments to fill the available space of the facility. Different departments' sizes were increased based on judgement and logic. The departments that were made bigger will be identified in each of the alternatives, and reasons will be given for the choices.

Alternative Block Layouts

1. Alternative 1

1.1 Block Layout for Alternative 1

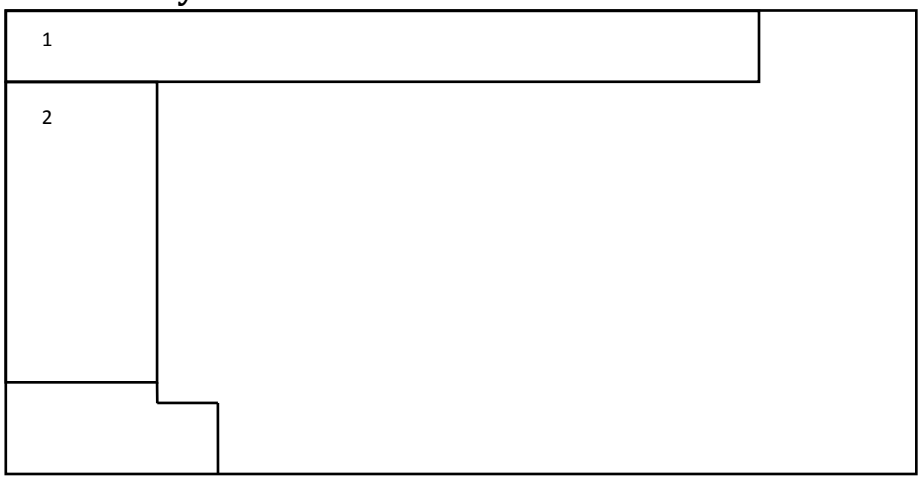


Figure 9: Top level, alternative 1

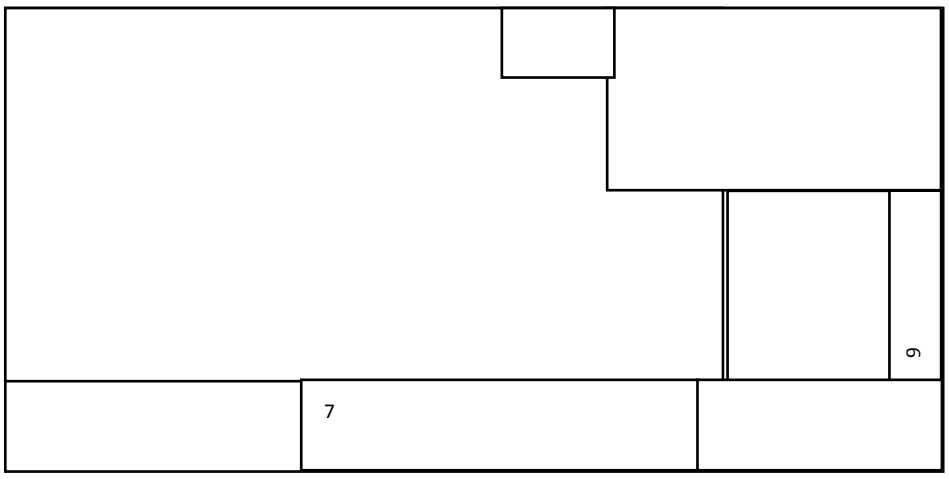


Figure 10: Bottom level, alternative 1

	Department
1	Warehouse
2	Transformer Department
3	PC Board Department
4	Housing
5	Assembly
6	Testing
7	Storage
8	Shipping and Receiving
9	Packaging

The sizes of the following departments were increased in alternative 1:

- Assembly department (5)
- Testing department (6)
- Shipping and receiving area (8)

The sizes of the departments listed above were increased in order to allow for future expansion. If the amount of products that need to be manufactured per month increases, the enlarging of these departments would be important to accommodate this. By enlarging these departments, more machines can be assembled, tested and shipped.

1.2 Proposed Material Handling System for Alternative 1

Table 5: Proposed material handling equipment.

From	To	Equipment
8	2	Hand Trolley
		Crate by hand
	7	Hand trolley
	3	Crate by hand
2	5	Crate by hand
7	5	Hand trolley
3	5	Crate by hand
5	6	Hand trolley
6	4	Hand trolley
4	9	Hand trolley
	1	Hand trolley
		Crane
1	9	Crane
		Forklift
9	8	Forklift

1.2.1 Using Forklifts

- Warehouse (1) to packaging department (9)
- Packaging department (9) to shipping and receiving area (8)

When welding machines are transported from the warehouse, a forklift (situated on the bottom level) will be used for the horizontal movements of the welding machines to the

packaging department. After packaging has been completed, the forklift will be used to transport the welding machines to the shipping and receiving area.

Using forklifts will improve the ergonomics and decrease worker fatigue, because workers will no longer have to carry heavy products. This will also minimize the time taken to move these products. A disadvantage to using forklifts is the fact that it requires a lot of aisle space. Another disadvantage is the high investment costs and maintenance costs.

1.2.2 Using Cranes

- Housing department (4) to warehouse (1)
- Warehouse (1) to packaging department (9)

Cranes will be used for the vertical movement that will take place the housing department on the bottom level and the warehouse on the top level. When welding machines, stored in the warehouse, need to be packaged before being shipped to the customer, the crane will again be used for the vertical movement that will take place between the warehouse on the top level and the packaging department on the bottom level.

Using cranes will improve ergonomics, since no heavy lifting has to be done by the workers. Cranes move at a very slow speed, therefore the time spent moving the welding machines between the bottom and top level will be very long.

1.2.3 Using Crates

- Shipping and receiving area (8) to transformer department (2)
- Shipping and receiving area (8) to PC board department (3)
- Transformer department (2) to assembly department (5)
- PC board department (3) to assembly department (5)

The materials that will be moved between the departments listed above are all light, therefore workers will be able to carry all of it by hand. To reduce the number of trips, the materials will be unitised and carried in crates.

Crates are low in cost, and have a long lifetime. When not in use, it can easily be stacked to save space.

1.2.4 Using Hand Trucks

- Shipping and receiving (8) to transformer department (2)
- Shipping and receiving area (8) to storage department (7)
- Storage department (7) to assembly department (5)
- Assembly department (5) to testing department (6)
- Testing department (6) to housing department (4)
- Housing department (4) to packaging department (9)
- Housing department (4) to warehouse (1)

When large items need to be moved (for example raw materials delivered to the shipping and receiving area that arrive in boxes), the movements require the aid of a hand cart. These items are not heavy enough to justify the use of a forklift, but either too big or too heavy to make use of a crate.

A hand cart offers more flexibility than a forklift. It is also more effective than a crate because multiple large items can be moved at once. It also provides a more economical solution than using forklifts, and a more ergonomically solution than using crates.

2. Alternative 2

2.1 Block Layout for Alternative 2

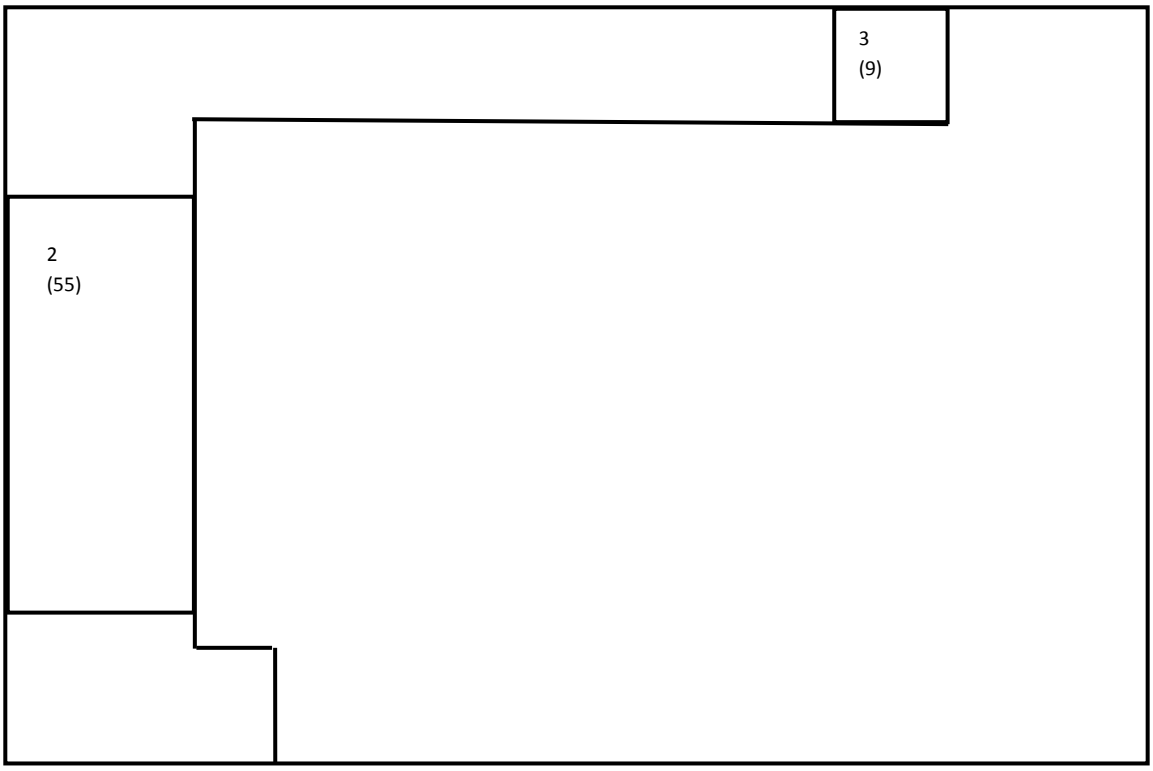
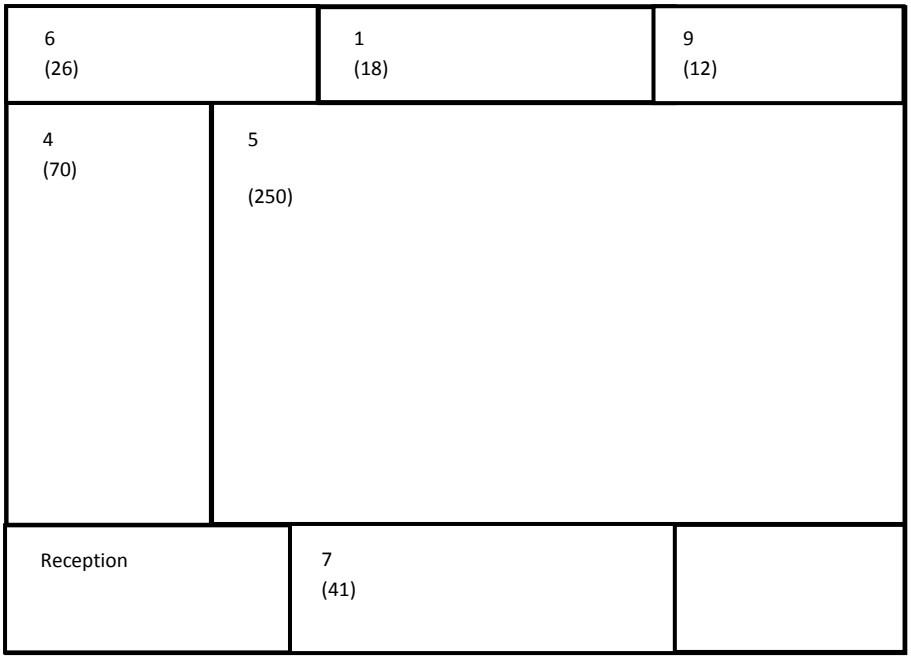


Figure 11: Top level, alternative 2



Department	
1	Warehouse
2	Transformer Department
3	PC Board Department
4	Housing
5	Assembly
6	Testing
7	Storage
8	Shipping and Receiving
9	Packaging

Figure 13: Bottom level, alternative 2

None of the walls in alternative 2 were removed, and none of the departments were made bigger than their minimum required size.

2.2 Proposed Material Handling System for Alternative 2

From	To	Equipment
8	2	Crate by hand
	7	Hand cart
	3	Crate by hand
2	5	Crate by hand
7	5	Hand cart
		Crate by hand
3	5	Crate by hand
5	6	Platform truck
6	4	Platform truck
4	1	Hand cart
4	9	Hand cart
1	9	Hand cart
9	8	Hand cart

Table 6: Proposed material handling equipment, alternative 2

2.2.1 Shipping and Receiving Area (8) to Transformer Department (2) and Shipping and Receiving area (8) to PC Board Department (3)

Similar material handling equipment is proposed for these two movements. Materials will be manually transported to the top level by the workers, carrying a crate to either the transformer department (2) or the PC board department (3). The departments with light

material components were specifically placed on the top level to ensure that the transportation of materials to the top level will not require a lot of effort. Departments using heavy material components were placed on the lower level, since heavier components are more difficult to transport.

2.2.2 *Shipping and Receiving Area (8) to Storage Department (7)*

Once the materials are ordered and delivered to the shipping and receiving area (8), it could be transported to the storage department (7). A hand cart will be used, since raw materials usually arrive at the shipping and receiving area in boxes.

2.2.3 *Transformer Department (2) to Assembly Department (5)*

The transformers assembled at the transformer department will be carried in crates, down the stairs, to the assembly department. Once again, the crates are proposed since transformers are light in weight. Unitising the loads also decrease the number of trips that have to be made.

2.2.4 *Storage Department (7) to Assembly Department (5)*

If a large amount of raw materials need to be transported to the assembly department, a hand truck can be used for this movement.

Alternatively, crates can be used if the raw materials are transported in small quantities, and are not too heavy.

2.2.5 *PC Board Department (3) to Assembly Department (5)*

PC boards are light and are transported in small batches to the assembly department, thus crates can be used to facilitate this movement.

2.2.6 *Assembly Department (5) to Testing Department (6)*

The welding machines cannot be stacked on one another, since the housing has not been assembled to the welding machine yet. Therefore a large flat surface is required onto which the welding machines can be placed. A platform truck is ideal for this movement, but since

the size of the platform truck can only transport approximately 5 welding machines at a time, multiple trips will have to be made to the testing department.

2.2.7 *Testing Department (6) to Housing Department (4)*

The same platform truck used in paragraph 10.5.2.1.6. will be used to facilitate this movement. Similar reasons justify the platform truck being used.

2.2.8 *Housing Department (4) to Warehouse (1) and Housing Department (4) to Packaging Department (9)*

When the housing has been assembled to the welding machines, it can easily be stacked. Care needs to be taken to not scratch the housing, since it would have to be replaced in such an instance. A hand truck will be used to facilitate the movements shown above, and will enable the workers to stack a few welding machines on to each other. This reduces the number of trips that need to be made.

2.2.9 *Assembly department (5) to testing department (6) and assembly department (5) to warehouse (1)*

Once the welding machines are assembled, they are sent to the testing area (6). The welding machines are quite heavy therefore trolleys will be used to transport the machines from the assembly area to the testing area. Once the welding machines have been tested they are then sent to the warehousing area (1) with a trolley as well.

2.2.10 *Warehouse (1) to packaging department (9)*

When a welding machine that has been stored in the warehouse and needs to be shipped to the customer, the welding machines are transported to the packaging area (9) with a hand truck.

2.2.11 *Packaging department (9) to shipping and receiving area (8)*

The welding machines are packaged into boxes, which are easily stacked onto a hand cart. Unitisation therefore occurs, reducing the number of trips that need to be made.

Hand carts are used extensively in this alternative, since it is an inexpensive way to unitise larger loads. The hand carts can be used for numerous movements in the facility, thus increasing the flexibility that the equipment adds to the facility.

3. Alternative 3

3.1 Block Layout for Alternative 3

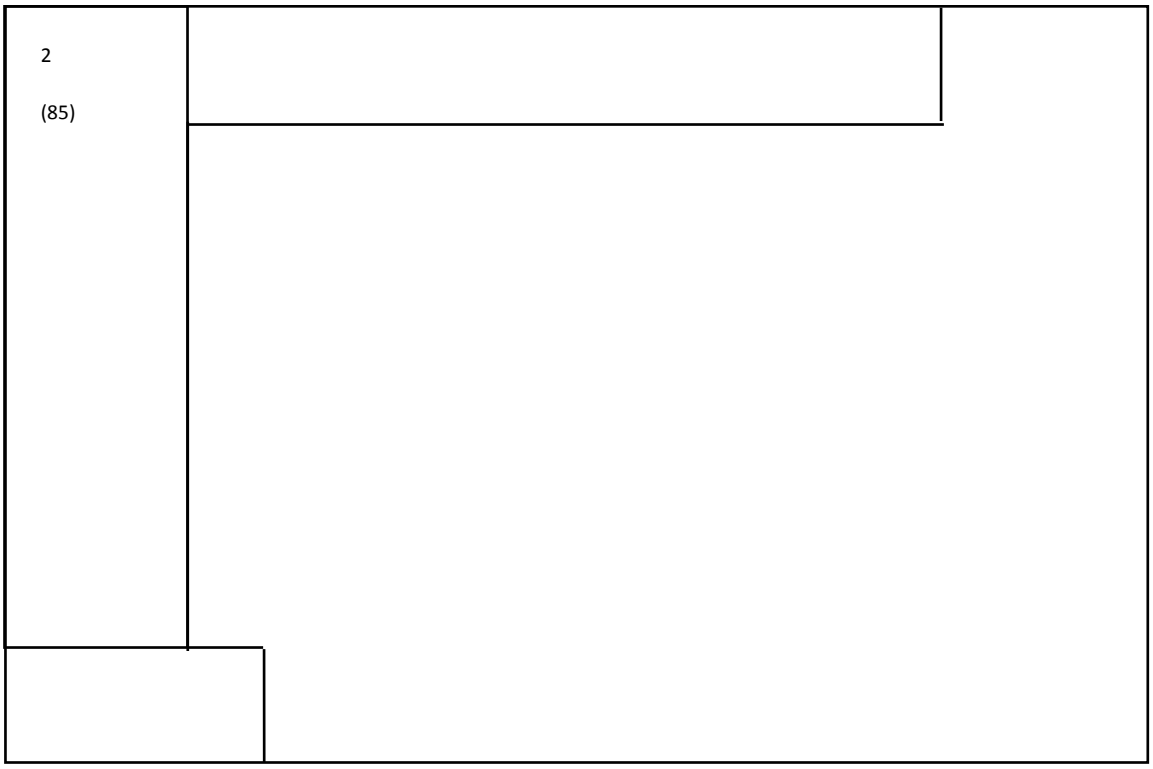
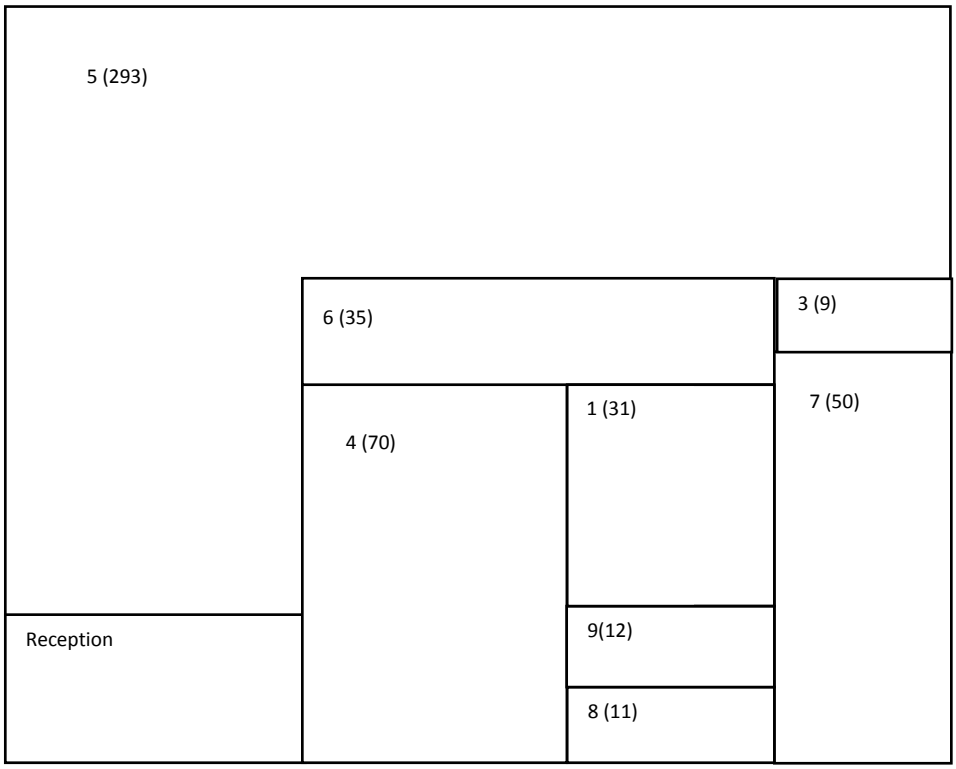


Figure 14: Top level, alternative 3



Department	
1	Warehouse
2	Transformer Department
3	PC Board Department
4	Housing
5	Assembly
6	Testing
7	Storage
8	Shipping and Receiving
9	Packaging

Figure 15: Bottom level, alternative 3

The sizes for the following departments were increased in alternative 3:

- Warehouse (1)
- Assembly department (5)
- Storage department(7)
- Testing department (6)
- Transformer department (2)

If *Company ABC* were to expand, the most crucial departments would take priority in expanding. Since the assembly department is responsible for the primary activity of assembling welding machines, this department's size was increased.

The warehouse, storage areas and testing departments were thought to also play an important role in the assembly process, and the sizes of these departments were also increased.

The transformer department was assigned more space, since a barrier will be placed around the acid station. Barriers usually take up a relative amount of space, and provision was made for this option.

Open space was left at the top level of the facility, since this alternative was designed to restrict the amount of activities which occurred at the top level as much as possible. Horizontal movement is a nuisance and requires extra material handling equipment. Therefore only the transformer department was placed on the top level. This decision was made based on the fact that the acid station needs to be as isolated as possible from the rest of the facility, due to safety hazards.

3.2 Proposed Material Handling Equipment for Alternative 3

From	To	Equipment
8	2	Walkie stacker
		Crate by hand
		Dumb Waiter
	7	Hand cart
	3	Hand cart
2	5	Chute conveyor
7	5	Hand cart
3	5	Crate by hand
5	6	Hand cart
		Hand truck
6	4	Hand cart
		Hand truck
4	9	Hand cart
		Hand truck

Department	
1	Warehouse
2	Transformer Department
3	PC Board Department
4	Housing
5	Assembly
6	Testing
7	Storage
8	Shipping and Receiving
9	Packaging

Table 7: Proposed material handling equipment, alternative 3

3.2.1 Shipping and Receiving Area (8) to Transformer Department (2)

A walkie stacker could be used to transport material from the shipping and receiving area (8) to the transformer department (2) by lifting the pallets of material to the top level. Walkie stackers are ideal for short travel distance and also for storage of items at a low vertical height (might be a disadvantage as the top level may be too high). The palletising of raw materials required at the transformer department (on the top level) will reach the objective of implementing the unit load principle.

An alternative to the walkie stacker, could be a crate carried by hand: workers can simply place the raw materials in a crate and carry it to the top level. Once again, the unit load principle is implemented with this method. Since the raw materials used at the transformer department (2) are light, workers will not be injured when carrying these crates to the transformer department.

3.2.2 Shipping and Receiving Area (8) to Storage Department (7)

From the shipping and receiving area a hand cart may be used to transport the material to the storage department as well as to the PC Board Department. A hand cart can then be used to transport material from the above prior mentioned departments to the assembly department. A hand cart is one of the simplest and most inexpensive types of material handling equipment. They are typically used for small distances and small loads.

3.2.3 Transformer Department (2) to Assembly Department (5)

A chute conveyor can be used to transport the transformers from the top level by using gravity to the assembly department. This is economical and more effective than for a worker to walk up and down the stairs to transport material.

3.2.4 PC Board department (3) to Assembly Department (5)

A crate may be used to unitise the PC boards to improve the efficiency of the worker transporting it to the assembly area.

3.2.5 Other

Similar material handling equipment can be used between the following departments:

- Assembly department (5) to testing department (6)
- Testing department (6) to housing department (7)
- Housing department (7) to packaging department (9)
- Housing department (7) to warehouse department (1)
- Warehouse department (1) to packaging department (9)
- Packaging department (9) to warehouse department (1)

A hand cart or can be used which is an inexpensive and a versatile way of transporting material between departments.

Using the above mentioned material handling equipment instead of the workers physically carrying the materials will improve the ergonomics at the facility. It will also increase the throughput of the material between the different departments; since the equipment will greatly reduce the time spent transporting materials. Safety will improve as there will be less risk in carrying the materials. Material handling frequency will be minimised and therefore decrease breakage of the components and material being transported.

Evaluating the Alternatives

1. Evaluation Criteria

Many factors were chosen to evaluate the alternatives against. The factors were chosen based on the importance to the management of *Company ABC.*

1.1 Cost

Cost is very important. *Company ABC* does not want to incur high costs to change their layout. Their budget can also not accommodate high annual costs.

1.1.1 Initial Investment

Some of the alternatives require construction to be done to the facility, and all of the alternatives require that new material handling equipment need to be bought. The costs of all of these activities that need to be done will be calculated for each alternative.

Since *Company ABC* has a limited budget, the alternative with the lowest initial investment will score the highest in the weighted average matrix in section 11.2.

Costs of material handling equipment were sourced from an online catalogue: National Material Handling Products, Inc. Even though sourcing prices from one supplier does not necessarily result in giving the most reliable initial investments; it does, however, result in a comparative analysis based on similar inputs.

For each material handling equipment mentioned, a basic option and luxurious option is shown in the table 6. The basic option would be the most basic item sold by National Material Handling Products, Inc. The basic option would satisfy the basic need present at the facility. The luxurious option refers to a more advanced and luxurious item, that would satisfy the basic need as well as some of the wants of the facility.

Weights were assigned to each alternative, based on the number of times that each of the material handling equipment will be used.

Based on the prices of the basic and luxurious options, the minimum and maximum costs of each of the alternatives were calculated, as seen in table 7. Please note that this is not the actual initial investment that would have to be made; the initial investments are only comparative values.

The construction cost was obtained by an industry expert, and refer to the breaking down of walls.

No initial investment cost is listed for an overhead crane because *Company ABC* has an existing overhead crane at their facility, which is not in use at present.

Table 8: Material handling equipment and prices thereof

Equipment	Basic option	Minimum cost	Luxurious option	Maximum cost	Weight assigned to alternative		
					1	2	3
Hand truck	Continuous handle	995.4	Twin handle	1106	1	2	1
Crate	Hand basket	69.78	Stack and nest container	126.4	2	2	1
Forklift	Used	48 000	New	120 000	1	0	0
Platform truck	Economy	1042.8	Adjustable height	3855.2	0	1	1
Chute conveyor	None	0	Specially desgined	45000	0	0	1
Construction	None	0	As proposed in alternative	2500	1	0	1

Table 9: Minimum and maximum initial investments

		Minimum cost	Maximum cost
Alternative	1	49134.97	123858.8
	2	3173.17	6320
	3	2107.98	52587.6

As seen above in table 6, alternative 1 has the highest maximum initial investment cost, and alternative 2 the lowest.

1.1.2 Annual Operating Costs

Annual operating costs are based on the cost of maintaining the material handling equipment, as well as the frequency of breakdown and cost of repairs related to each material handling system. The values obtained in table 3 were obtained by an industry expert.

Table 10: Approximate operating costs

		Annual maintenance costs	Probability of breakdown	Average cost of repairs	Total annual operating cost
Alternative	1	100 000	0.35	150 000	152500
	2	5 000	0.1	5000	5500
	3	20000	0.25	10 000	22500

1.2 Material Flow

Material flow was assessed by looking at how easily the material would move through the system using the proposed material handling equipment. This criterion is assessed qualitatively.

1.2.1 Alternative 1

Forklifts and the crane require enough space to operate effectively. Even though the mechanical movement might be quicker, cranes break the flow of material through the system because it is a long process to move material from point A to point B. Similarly with forklifts, the loading and unloading onto pallets might interrupt the flow of materials through the system.

The usage of crates will ease the flow of material through the system, since the crates are a form of unitising loads. Unitising loads decreases the number of trips that have to be made, and therefore increases the speed that material flows through the system.

1.2.2 Alternative 2

Since crates are predominantly used in alternative 2, the material can flow through the system without many interruptions. The main factor that would decrease material flow is the fact that workers need to carry materials up and down the stairs. This takes long and also results in fatigue.

1.2.3 Alternative 3

The material flows easily from one department to another and no major adjustments are required for the movement of materials. The use of the chute conveyor increases material flow through the system.

1.3 Safety and Housekeeping

This criterion is measured on the extent to which safe material handling equipment were utilised in each the alternatives.

1.3.1 Alternative 1

If the crane and forklift are to be used, safety precautions need to be taken to prevent any damage to the workers. The crane needs to be properly assessed to insure that it will not drop what is being carried. The employee will need to be trained to be cautious of both types of equipment.

When using an overhead crane, it is a safe practice to not allow any persons to walk or stand underneath a moving crane. This factor was not considered in alternative 1.

If there is not enough space available for forklifts to manoeuvre between the departments, the forklift driver may accidentally drive into one of the departments, or even into one of the

workers. Enough space was assigned for the forklift to move through the facility, but this remains a safety concern.

The crane and forklift will need proper housekeeping to prevent unnecessary breakdowns.

If the crane and forklift are to be used, safety precautions need to be taken to prevent any damage to the workers. The crane needs to be properly assessed to insure that it will not drop what is being carried. The employee will need to be trained to be cautious of both types of equipment.

1.3.2 Alternative 2

None of the material handling equipment proposed presents an immediate danger. It is, however, dangerous for workers to carry crates up and down the stairs.

Housekeeping can easily be done for this alternative, since crates only require daily wiping clean.

1.3.3 Alternative 3

The chute conveyor will require proper housekeeping to prevent blockages in the chute. The chute does, however, cancel out the safety concerns of carrying material down the stairs.

The use of a walkie stacker also reduces the amount of materials carried up the stairs to the top level, increasing the safety of the material handling system.

1.4 Disruption During Installation

All three alternatives require departments to be moved around. This activity will require the workers to help with moving all the equipment and material. Installation will be disruptive for all three alternatives, but some more than others.

1.4.1 Alternative 1

Alternative 1 requires that a wall be broken out. This will prevent workers in the affected departments to continue with their work. Dust will also disrupt workers in other departments.

The installation of the material handling will create a disruption since space will need to be allocated for the movement of the forklifts. Some walls will have to broken down, which will also disrupt the facility. Production will have to come to a halt while the layout is redone.

1.4.2 Alternative 2

The walls need not be broken out in this alternative. The only requirement during installation is the movement of departments.

1.4.3 Alternative 3

Alternative 3 requires walls to be broken out, as well as the installation of a gravity chute. This alternative will be the most disruptive.

1.5 Working Conditions and Employee Satisfaction

This was assessed by looking at the material handling equipment and whether it would ease the workload of the employee and improve the working conditions.

1.5.1 Alternative 1

Forklifts and the crane would improve working conditions since employees would no longer have to carry parts up the stairs. Moving products around would be easy and fast.

1.5.2 Alternative 2

Hand trucks provide the only means of facilitating the movement of material. Hand trucks are easy to manoeuvre around the facility, increasing employee satisfaction.

Workers have to carry materials using crates, thus working conditions are still not ideal.

1.5.3 Alternative 3

A gravity chute will provide an easier way to move completed transformers to the bottom level and this will improve working conditions for employees.

The manual movement of materials are reduced as much as possible thus employee satisfaction will be very high.

1.6 Ease of Maintenance and Rapidity of Repair

This was assessed by looking at the material handling equipment and whether the equipment would require maintenance and the speed thereof.

1.6.1 Alternative 1

The forklift as well as the crane will have to be maintained. Maintenance might take a few days, which would disrupt activities.

Battery powered forklifts can be charged overnight, reducing the disruption occurred to maintain it.

1.6.2 Alternative 2

The new layout will not be much different than the current one with respect to maintenance and repairs. The crates and trolleys do not need much maintenance. Crates will just need to be replaced if they brake or if they are damaged. The trolleys can easily be repaired and maintained, but will not completely disrupt the throughput of the facility.

1.6.3 Alternative 3

The gravity chute is the only item that may need to be repaired if a freak accident occurs which damages it. This may take a day or two if damage is severe. This will cause a disruption in the system.

Cleaning is required to prevent blockages, but minimal disruption will occur during this cleaning operation.

1.7 Frequency and Seriousness of Potential Breakdowns

This was assessed by looking at the material handling equipment and the risk that the equipment could break down and whether a breakdown would have a large impact on the running of the facility

1.7.1 Alternative 1

If the forklift and crane were to break down, this will definitely disrupt operations. The crane is used to facilitate numerous movements in the facility. Employees will still be able to move parts manually, but this will affect employee satisfaction.

The seriousness of the breakdowns will be high, since repairing the crane is a time-consuming process. Chances of crane breakdowns are moderate and may occur twice a year.

Preventative maintenance needs to be done on the crane to reduce the frequency of breakdowns.

1.7.2 Alternative 2

Damage caused to crates and hand trucks can be compensated for by having two reserves and replacing these reserves as they are used.

The frequency and seriousness of breakdowns is very low for this alternative, since crates and hand trucks can be easily repaired or replaced when breakdowns do occur.

1.7.3 Alternative 3

The frequency and seriousness of potential breakdowns are low, since no mechanical material handling equipment is used in alternative 3. Wheels of the hand carts may only need the occasional application of oil.

1.8 Limitations of flexibility and ease of expansion

This was assessed by looking at how easily the layout could change and be adapted. Was any equipment permanent and unable to be moved?

1.8.1 Alternative 1

Space has to be demarcated for the movement of forklifts. Crane movement will be limited to due to safety reasons. This limits flexibility of *Company ABC*. Workers are also not allowed to walk underneath the moving crane.

1.8.2 Alternative 2

The upper level has space for further expansion but since it is not ideal to place anything with a high frequency of flow there, expansion may be limited.

The only limitation to flexibility is the fact that walls remain between different departments. The use of material handling equipment increases flexibility, since it can be used in different scenarios.

Crates are used extensively in this alternative, increasing the flexibility of the material handling equipment.

1.8.3 Alternative 3

Space has to be assigned to where the conveyer chute will be build. This will cause a constraint in the layout because of the fact that the chute cannot be moved.

Since the walls have been broken down in this alternative, it is easier to expand the facility.

Using hand trucks for multiple movements increases the flexibility of the material handling equipment.

1.9 Throughput

This was assessed by calculating the total distance travelled in each alternative. Throughput is considered the most important factor. When an order is placed, *Company ABC* must be

able to make the product as soon as possible. The shorter the distance travelled, the faster the product can be made.

The coordinates of the centre of each of the department were calculated for each alternative. The rectilinear method was then applied to calculate the distance travelled between each department. The alternative with the lowest total distance travelled will be considered best with respect to throughput.

1.9.1 Alternative 1

Table 11: Total distance travelled, alternative 1

Alternative 1								
From	Coordinates			To	Coordinates			Total distance travelled
	x	y	z		x	y	z	$\lvert x-a\rvert+\lvert y-b\rvert+\lvert z-c\rvert$
8	23.65	14.57	0	2	2.51	10	3	28.71
8	23.65	14.57	0	7	13.3	1.95	0	22.97
8	23.65	14.57	0	3	14.7	18.5	0	12.88
2	2.51	10	3	5	8.1	12	0	10.59
7	13.3	1.95	0	5	8.1	12	0	15.25
3	14.7	18.5	0	5	8.1	12	0	13.1
5	8.1	12	0	6	17.8	8.02	0	13.68
6	17.8	8.02	0	4	23.65	14.57	0	12.4
4	23.65	14.57	0	9	20.13	8.02	0	10.07
4	23.65	14.57	0	1	22.02	18.47	3	8.53
9	20.13	8.02	0	8	23.65	14.57	0	10.07
9	20.13	8.02	0	1	22.02	18.47	3	15.34
						Total distance travelled		173.59

1.9.2 Alternative 2

Table 12: Total distance travelled, alternative 2

Alternative 2								
From	Coordinates			To	Coordinates			Total distance travelled
	x	y	z		x	y	z	$\lvert x - a \rvert + \lvert y - b \rvert + \lvert z - c \rvert$
8	20.8	2	0	2	2.44	9.5	3	28.86
8	20.8	2	0	7	14.9	2	0	5.9
8	20.8	2	0	3	23.36	18.5	3	22.06
2	2.44	9.5	3	5	13.3	10.5	0	14.86
7	14.9	2	0	5	13.3	10.5	0	10.1
3	23.36	18.5	3	5	13.3	10.5	0	21.06
5	13.3	10.5	0	6	4.4	18.5	0	16.9
6	4.4	18.5	0	4	2.8	10.5	0	9.6
4	2.8	10.5	0	9	16.66	18.5	0	21.86
4	2.8	10.5	0	1	11.66	18.5	0	16.86
9	16.66	18.5	0	8	20.8	2	0	20.64
9	16.66	18.5	0	1	11.66	18.5	0	5
						Total distance travelled		193.7

1.9.3 Alternative 3

Table 13: Total distance travelled, alternative 3

Alternative 3								
From	Coordinates			To	Coordinates			Total distance travelled
	x	y	z		x	y	z	$\lvert x - a \rvert + \lvert y - b \rvert + \lvert z - c \rvert$
8	13.74	1	0	**2**	2.42	7.63	3	20.95
8	13.74	1	0	**7**	18.82	4.42	0	8.5
8	13.74	1	0	**3**	18.82	16.84	0	20.92
2	2.42	7.63	3	**5**	2	17.5	0	13.29
7	18.82	4.42	0	**5**	2	17.5	0	29.9
3	18.82	16.84	0	**5**	2	17.5	0	17.48
5	2	17.5	0	**6**	8.46	16.41	0	7.55
6	8.46	16.41	0	**4**	7.5	5	0	12.37
4	7.5	5	0	**9**	13.74	3.07	0	8.17
4	7.5	5	0	**1**	13.74	5.78	0	7.02
1	13.74	5.78	0	**9**	13.74	3.07	0	2.71
9	13.74	3.07	0	**8**	13.74	1	0	2.07
						Total distance travelled		150.93

Based on the information shown in tables 8, 9 and 10, it is evident that alternative 3 has the lowest total distance travelled between workstations.

Weighted Factor Comparison Method

Ten factors were chosen to assess which would be the best alternative. Each factor was assessed and then given a score out of 10 depending on how well the criteria are satisfied.

		Alternatives		
Attribute	**Importance**	**1**	**2**	**3**
Initial investment	**8**	1	7	4
Annual operating costs	**9**	3	8	5
Material flow	**7**	3	6	10
Safety and housekeeping	**6**	2	7	9
Disruption during installation	**3**	4	8	2
Working conditions and employee satisfaction	**1**	10	7	9
Ease of maintenance and rapidity of repair	**4**	3	10	8
Frequency and seriousness of potential breakdowns	**5**	2	10	9
Limitations of flexibility and ease of expansion	**2**	4	5	6
Throughput	**10**	7	6	10
	Score	**190**	**403**	**405**
	Percentage	35	73	74

Table 14: Weighted factor comparison method

Consider table 7. As seen by the percentages, alternative 2 and 3 scored very similar marks. Since throughput is the most important factor to consider, alternative 3 (which scored 10/10 for this attribute) will be chosen as the final facility layout to implement.

Conclusion

By using the methods discussed in this report it was found that Alternative 3 is the best alternative and after implementation will result in the greatest improvement. Other alternatives are available and can be generated through additional investigation. Simulations were run after these results were obtained to prove that the new layout is more effective in terms of distance travelled, material handling and time.

Reference list

Cornice Engineering.(2008). *Automation Master Planning.*[Online]. Available: http://www.corniceengineering.com/Services/Cornice%20Engineering,%20Inc.%20Automation%20Master%20Planning.pdf[Accessed 03 April 2012]

Ghrayeb, O. (2002). *Facilities Planning.*[Online]. Available: http://www.ceet.niu.edu/faculty/ghrayeb/IE460/HW1_solution.pdf[Accessed 03 April 2012]

Hardy, V. (2004) *THE FUTURE FOR FACILITY MANAGEMENT: READING THE BONES* [Online]. Available: http://www.cedb.gov.hk/citb/psdas/content/doc/Prof_Vicky_Hardy.pdf[Accessed 03 April 2012]

National Council of Productivity of India.(2005). *Plant Layout and Facility Planning.*[Online]. Available: http://www.productivity.in/knowledgebase/Industrial%20Engineering%20Docs/d.%20Facilities%20Planning%20and%20Plant%20Layout/4.1%20%20Facilities%20planning%20and%20plant%20layout.pdf[Accessed 03 April 2012]

Neustro Consulting Ltd. (2011). *What is Lean Manufacturing.*[Online]. Available: http://www.neustro.com/lean_manufacturing.aspx[Accessed 03 April 2012]

Company ABC.(2011).*Company ABC: About Us*. [Online]. Available: http://www.reeflex.co.za/index.php/about-us[Accessed 03 April 2012

Company ABC.(2011).*Company ABC: Brochure*. [Online]. Available: http://www.reeflex.co.za/pdfs/brochure.pdf [Accessed 03 April 2012]

Company ABC.(2011).*Company ABC: Distributors / Agents*. [Online]. Available: http://www.reeflex.co.za/index.php/distributors-agents[Accessed 03 April 2012]

Strategos.(2011). *Plant Layout and Facility Planning for Lean Manufacturing.*[Online].Available: http://www.strategosinc.com/facilities_planning.htm[Accessed 03 April 2012]

Tokarev, S. (2010)**.***American business**:** Just-in-time production (JIT)*. [Online].Available: http://american-business.org/491-just-in-time-production.html [Accessed 03 April 2012]

Tompkins, J.A. & White, J.A. & Bozer, Y.A. & Tanchoco, J.M.A. 2010. *Facilities Planning*. New Jersey. Hamilton Printing Co.