CHAPTER 3
METHODOLOGY

This section will outline the study methodology - the plan for investigating the lost time in manufacturing at CCH. The methods will be based upon ideas taken from past studies in the literature.

The aim of the research is to find solutions that can reduce the lost time in manufacturing at CCH. The sources of lost time must first be located and therefore the first section of the project will be to investigate the processes at CCH. Process monitoring and data collection will be necessary for this stage. This data will allow the Overall Equipment Effectiveness to be calculated for every process and also for the overall manufacturing system. The OEE values will show areas of low efficiency; these areas should be where the biggest time losses are occurring. Analysing the losses in those areas will provide knowledge that can be used to formulate solutions to reduce the lost time.

3.1 Assumptions

The following will be assumptions to simplify the analysis:

1. The factory manufactures steel poles that are used for a variety of applications such as street/highway lighting, flag poles, and steel radio masts. The different applications obviously require slightly different manufacturing techniques. For example, the street light poles require the assembly and attachment of electrical parts and servicing equipment. However, this will not be considered as part of this research. Only the manufacturing processes that contribute towards the actual steel poles will be considered.

2. Customers have the option of choosing the specification of the poles. The height can range from approximately 10 metres up to 60 metres. However, the taller poles are split up into 2 or 3 sections to ease manufacturing and transportation. For this reason the analysis will assume that all poles have the same height. For poles that need more than one section the number of sections manufactured will

be counted, not the number of complete poles. For example, for a 40 metre pole consisting of two sections, the data collection will consider 2 poles to have been manufactured, not one.

3. There are two designs for the cross-section of the steel poles, circular and polygonal. They require different dies for the forming stage; otherwise the manufacturing processes are identical. The die change can take up to half a day, consuming considerable manpower and has been identified as a bottleneck area. Therefore, the die change will be investigated as part of the research but the different pole types that are produced will be assumed the same.

4. Customers have the option of specifying different finishes for the poles such as painting. These operations normally occur after the pole has been through all standard processes. For the purposes of this research it will be assumed that all poles have the same finish specification.

Scheduling/Sequencing

CCH does not have a policy of holding stock - it manufactures to order. Orders are passed through to the production department and scheduled accordingly. There is no computer-controlled scheduling system so scheduling is done manually by the production manager and his team. The machines all need to be set up which takes time. Some orders contain similar items which can be grouped together so the items can be manufactured at the same time. This reduces the number of times the machines have to set up.

3.2 Process Analysis

Each process must be fully understood before any analysis can be initiated.

3.2.1 Stage 1 – Cutting

This is the first stage in the production process. The material used is sheet steel rolled into coils. These coils are unwound prior to cutting by a hand-operated roller. The cutting machine also has a built-in set of rollers that level out any remaining curvature in the sheet steel before cutting it to the length which will eventually become the height of the section of pole. The actual cutting mechanism is a guillotine-type. The machine has to be adjusted to cut different lengths and so it is common for the steel to be cut in batches and stored. For example if the order being processed is for 70 poles then the machine will be set up and 100 sheets will be cut. The metal is still in sheet form and flat and so can be stacked vertically and does not consume much space. The remaining 30 are stored and can be used at a later date without having to set up the machine again.
The speed of this process is dependent on the operators and the actual cutting action itself takes only a split second. It is setting up the machine and positioning the material to be cut that takes up the majority of the time.

3.2.2 Stage 2 – Shearing

Although the length of the steel is now correct the sides are square and parallel. The sheet must eventually form a tapered pole and so the sides need to be sheared to the necessary trapezoidal shape. A similar machine to that of stage 1 is used for this task and cuts with the same guillotine-action. Setting up the machine is very important to get the correct dimensions and takes time. Similarly to the cutting stage, normally a little surplus is cut and stored to be used at a later date. It is still flat and so can be efficiently stacked vertically.

The process speed is similar to Stage 1 because the cutting action takes less than one second. However it should be noted that both sides of the sheet need to be cut but in Stage 1 there is only one 'cut'. Therefore the number of cutting operations is twice that of Stage 1. The metal sheet also has to be repositioned for the second cut which takes extra time.

3.2.3 Stage 3 – Forming

The material is now cut to the correct dimensions and has the necessary trapezoidal shape for a tapered pole. In this stage the flat metal sheet is formed into the overall shape of the final pole. This is done by the action of a metal press. A die is pressed down along the length of the metal sheet with the force of several hundred tonnes. The shape of the die influences the final shape.

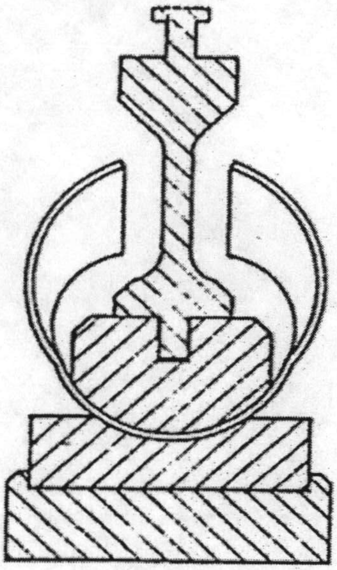

Figure 10: Diagram to illustrate the action of the metal press to form the sheet steel into a pole

The speed of the process is dependent mainly on the speed at which the machine can operate. The die is raised and lowered automatically and the operators cannot alter the speed. The metal has to be manually placed onto the press and removed. During the process it also has to be rotated after each pressing action to work on all the area of the sheet.

A very important point is the set up of the machine in this stage. As mentioned before, CCH manufactures poles with circular as well as polygonal cross-sections, specified by the customer. There is however, only one forming machine which means that the die on the press has to be changed for the different cross-sections. It is extremely heavy and requires a crane to lift. After the new die is installed it must be recalibrated. The whole die-changing operation takes up to half a working day and needs a team of workers.

3.2.4 Stage 4 – Welding/Fabrication

This process requires a longitudinal weld to close the seam along the length of the pole followed by attachment of the base and supporting brackets. Gas Metal Arc Welding (GMAW) is the welding method used. The process is labour-intensive using no heavy machinery. All the welding is done manually by the workers and so speed is fully dependent on how fast they can complete each pole. The workers have to be highly skilled in order to produce welds of suitable quality. The welders are therefore difficult to replace if they are absent for any reason. The poles are set in jigs to hold them steady and so the electrodes of the welding equipment can be attached securely. Normally one operator welds each pole and therefore a team of welders work simultaneously in order to process the required number of poles.

3.2.5 Stage 5 – Galvanising

After fabrication the poles are structurally complete but need galvanising to prevent corrosion from rust because once installed they are exposed to the elements for many years. The poles are galvanised with zinc, a process common with steel components.
The process does not simply consist of dipping the steel poles in liquid zinc. The poles must be prepared first and the preparation is often considered to be as important as the galvanising itself. Therefore, the stage consists of submerging the poles in several different 'baths' to treat the material. There are 4 main steps:

1. Caustic Cleaning – A hot alkali solution is used to remove organic contaminants such as dirt, paint markings, grease and oil. The poles must be rinsed after caustic cleaning to prevent contamination of the next bath.
2. Pickling – Scale and rust are removed by a bath containing a dilute solution of hydrochloric acid. The poles must be rinsed after pickling to prevent contamination of the next stage bath.
3. Fluxing – This solution of zinc ammonium chloride removes oxides and prevents further oxidation of the surface of the metal. Fluxing also promotes bonding of the zinc and steel.
4. Galvanising – The poles are dipped into a bath containing 98% pure molten zinc. The bath is maintained at a constant 450 degrees Celsius. The steel is immersed

until it reaches the bath temperature. Zinc reacts with steel on the surface to form an alloy. The pole is then slowly withdrawn, excess zinc drains off, and the pole is allowed to cool.

The size of the baths is such that they can accommodate two poles, fastened together in a jig, at the same time. Two cranes operate lifting the poles and so two lots can be processed simultaneously. Half-way through the process the first crane is disconnected and the second crane attached. The first crane can then begin again at the caustic cleaning stage. Thus effectively four poles can be processed at the same time.

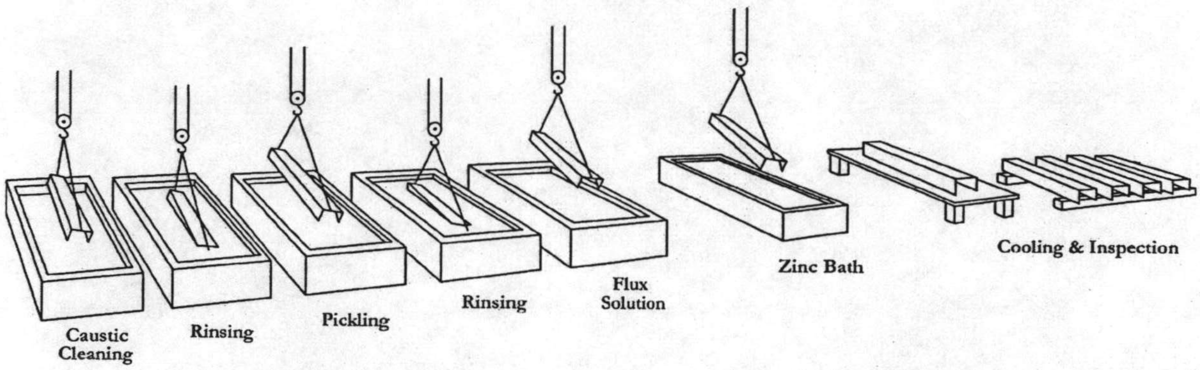

Figure 11: Diagram to show the sequence in the Galvanising Stage (www.highwaysafety.net)

3.2.6 Stage 6 - Finishing

After the poles have cooled down they are thoroughly inspected. Any defective areas are marked in chalk and corrected. This usually involves some corrective welding or re-galvanising. Customers are able to specify finishes to the pole such as painting and these operations are performed at this point, the pole having already passed through all other stages. Once a pole has passed inspection it is cleaned up, any sharp edges etc are smoothed over and the pole is finished. One of the assumptions is that all poles will be considered to be the same and so any painting time or time taken to perform special finishing operations will not be considered. However, the time taken to correct defects is lost time as the poles normally should not require this operation. Therefore the poles that need to have corrective work should be investigated.

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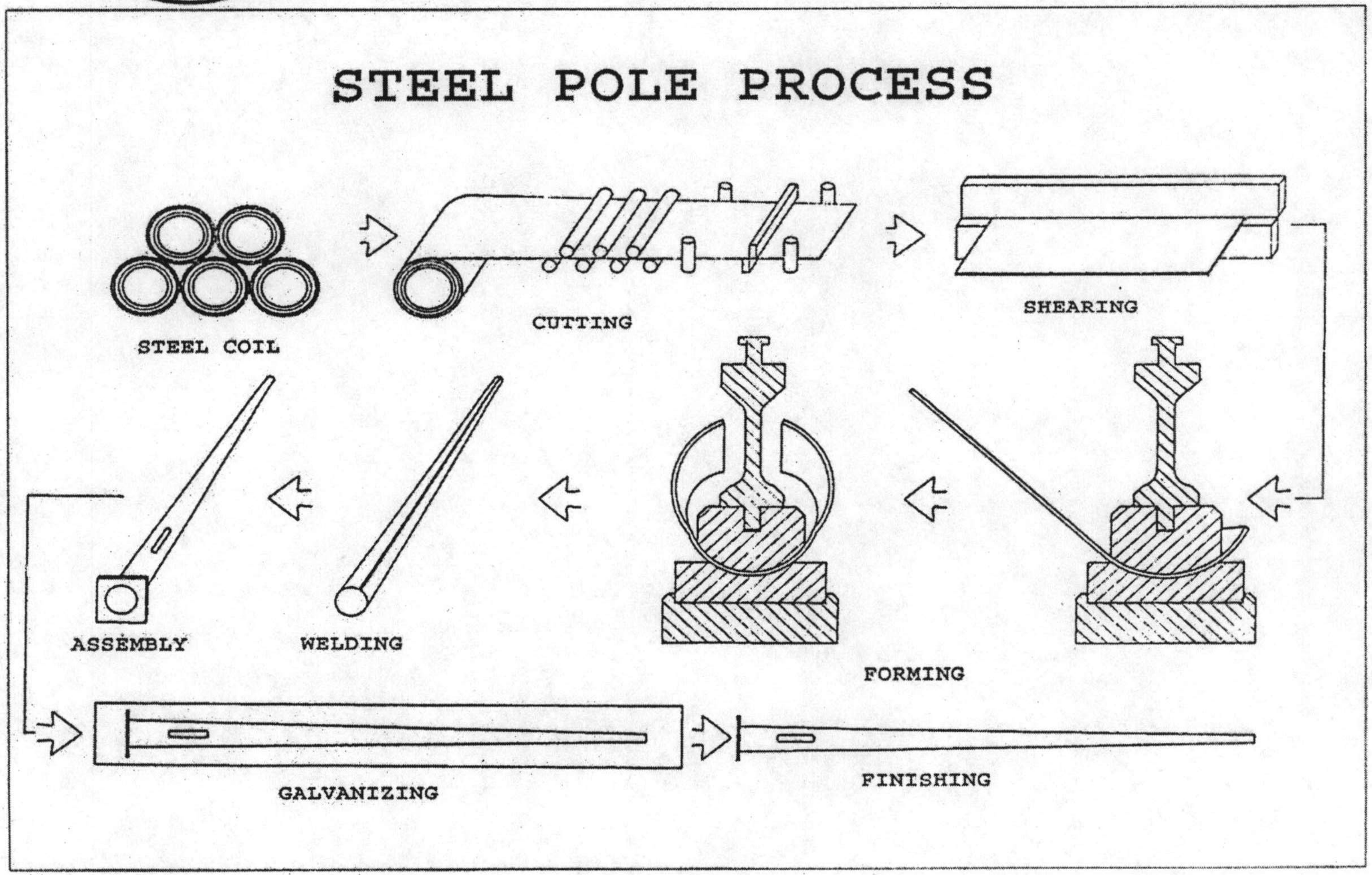

Figure 12: Diagram to show the overall process of making a galvanised steel pole at CCH

3.3 Process Mapping

Process mapping is a pictorial representation that can help the understanding of what exactly happens during a process. It is used to represent every step that contributes and being a picture is easier to understand. The overall production will be process flow charted, followed by the individual stages. The process charts should help provide clues as to where the time losses could occur.

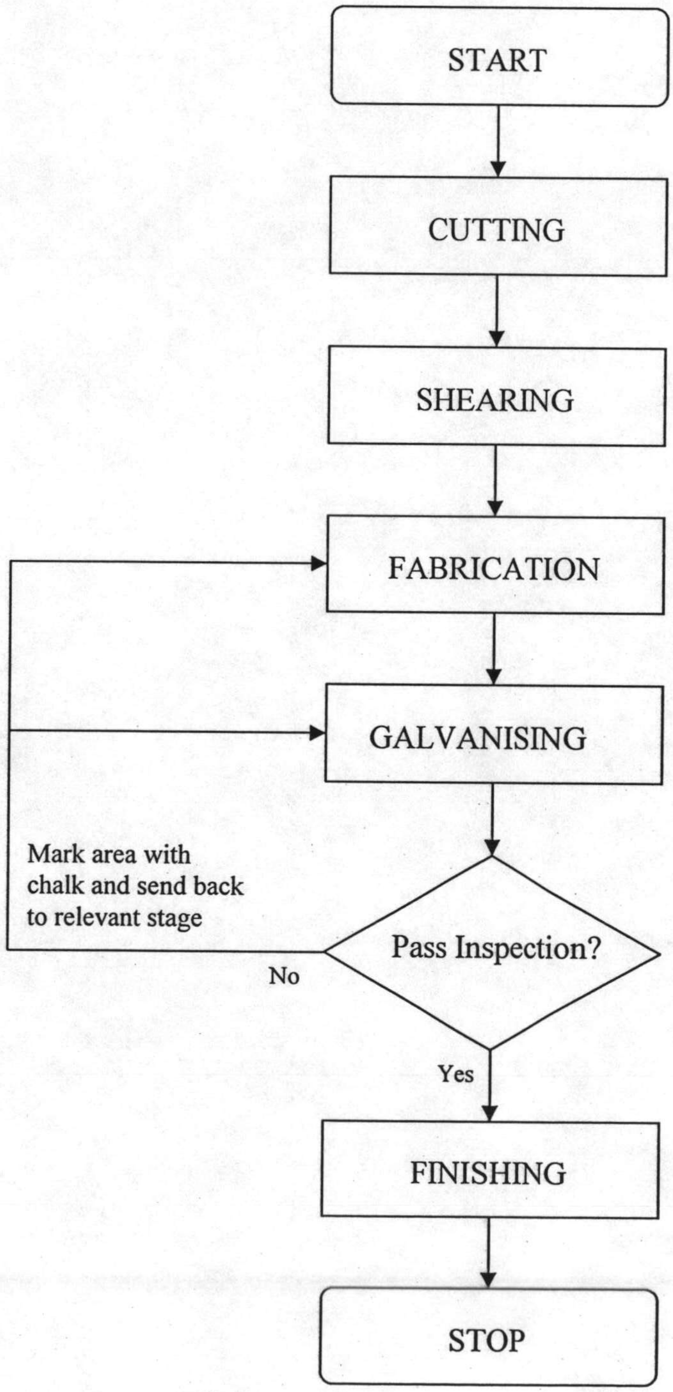

Figure 13: Process flow chart of steel pole manufacture

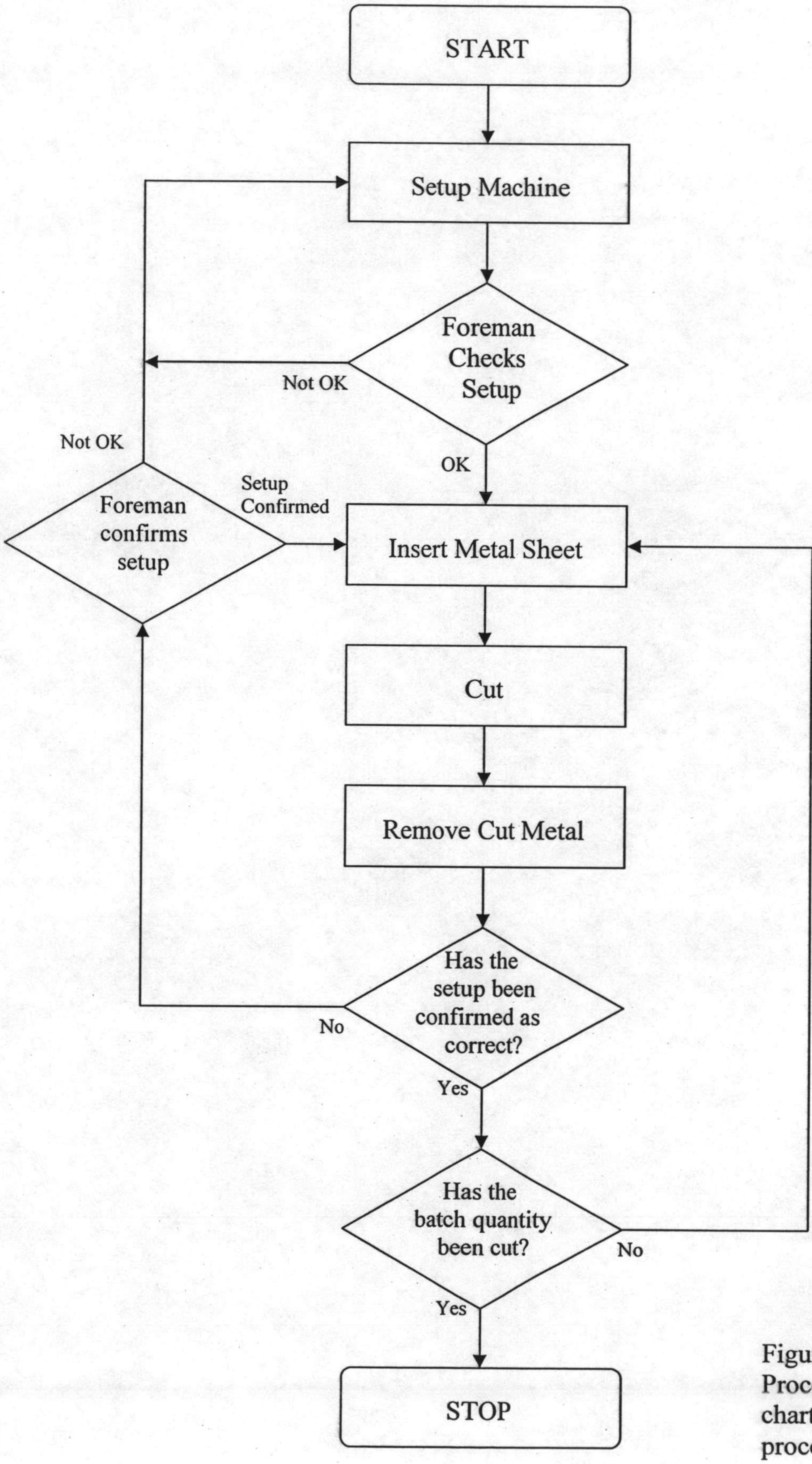

Figure 14: Process flow chart of cutting process

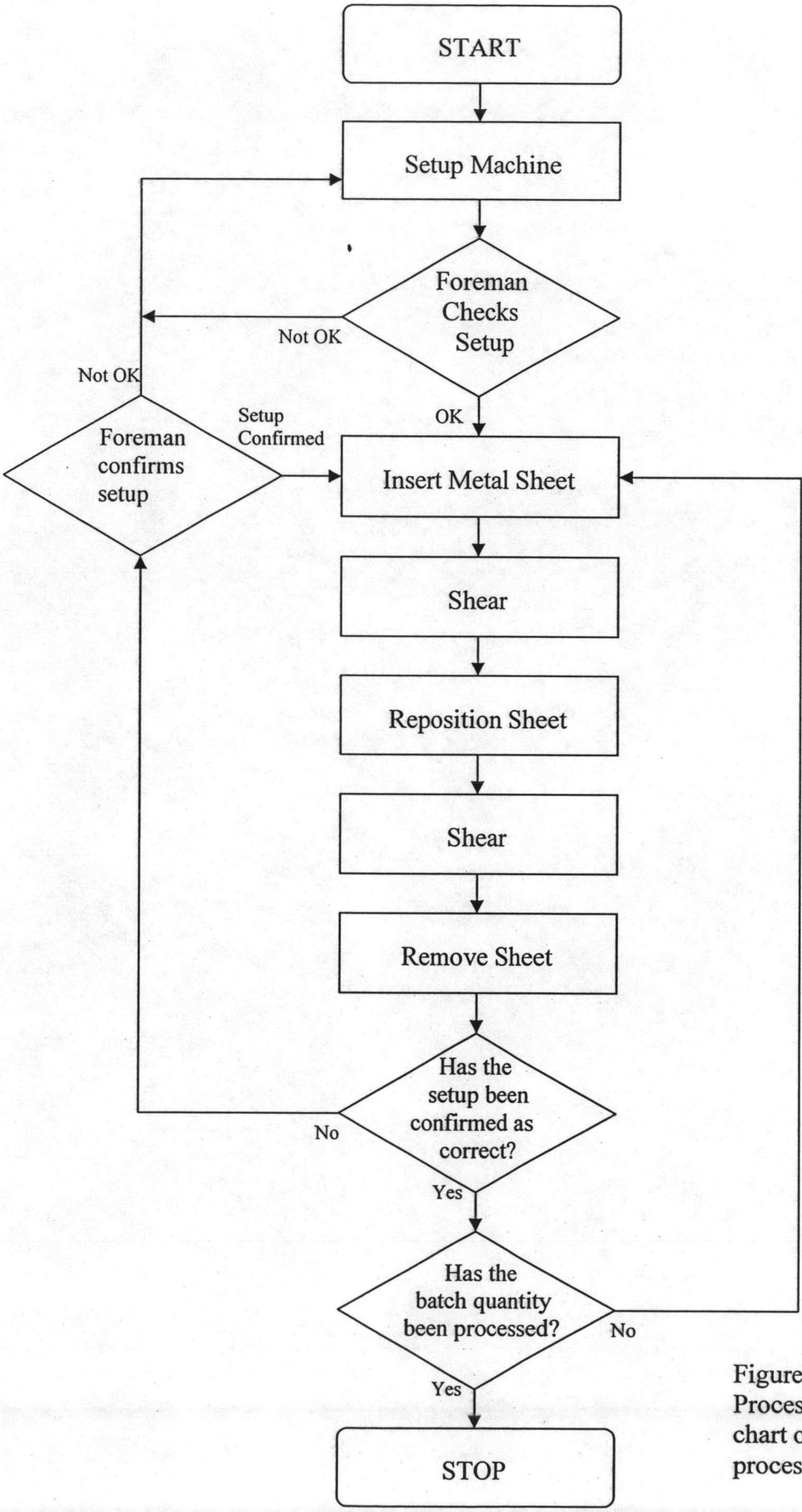

Figure 15: Process flow chart of shearing process

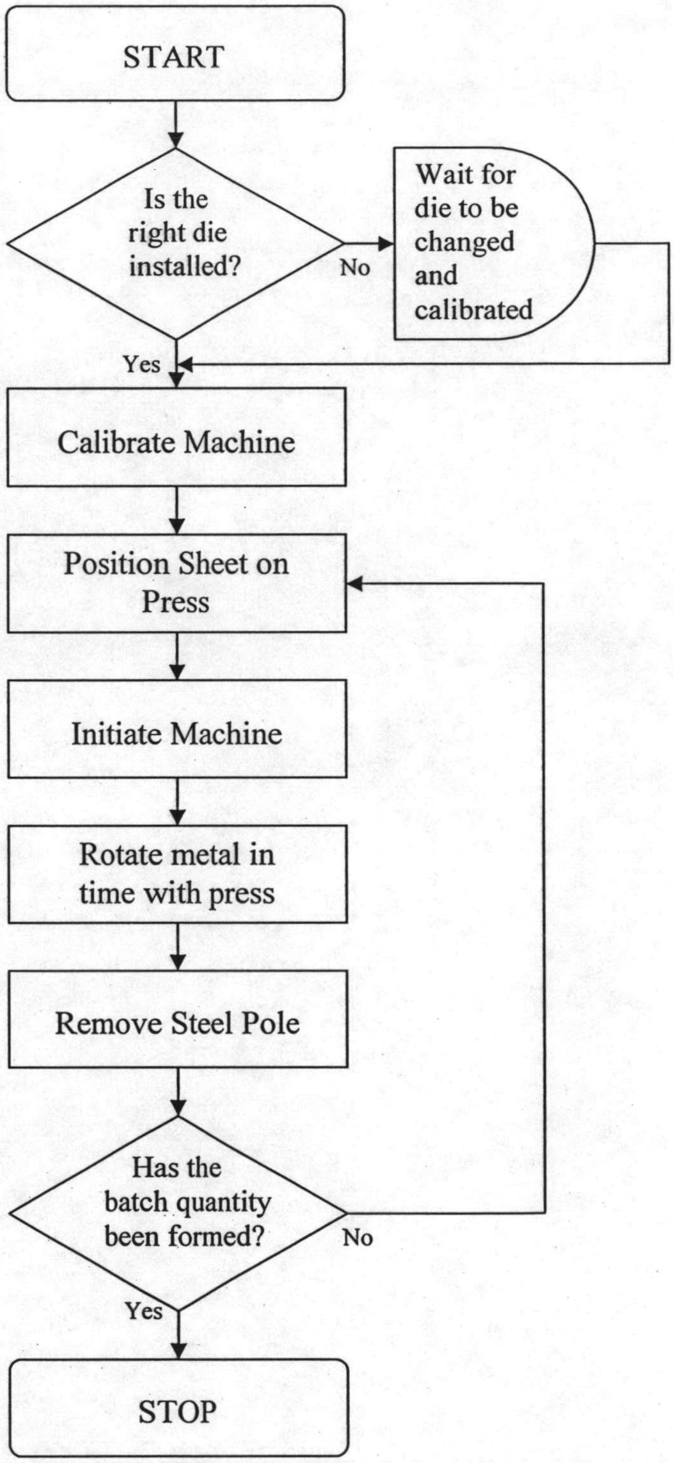

Figure 16: Process flow chart of forming process

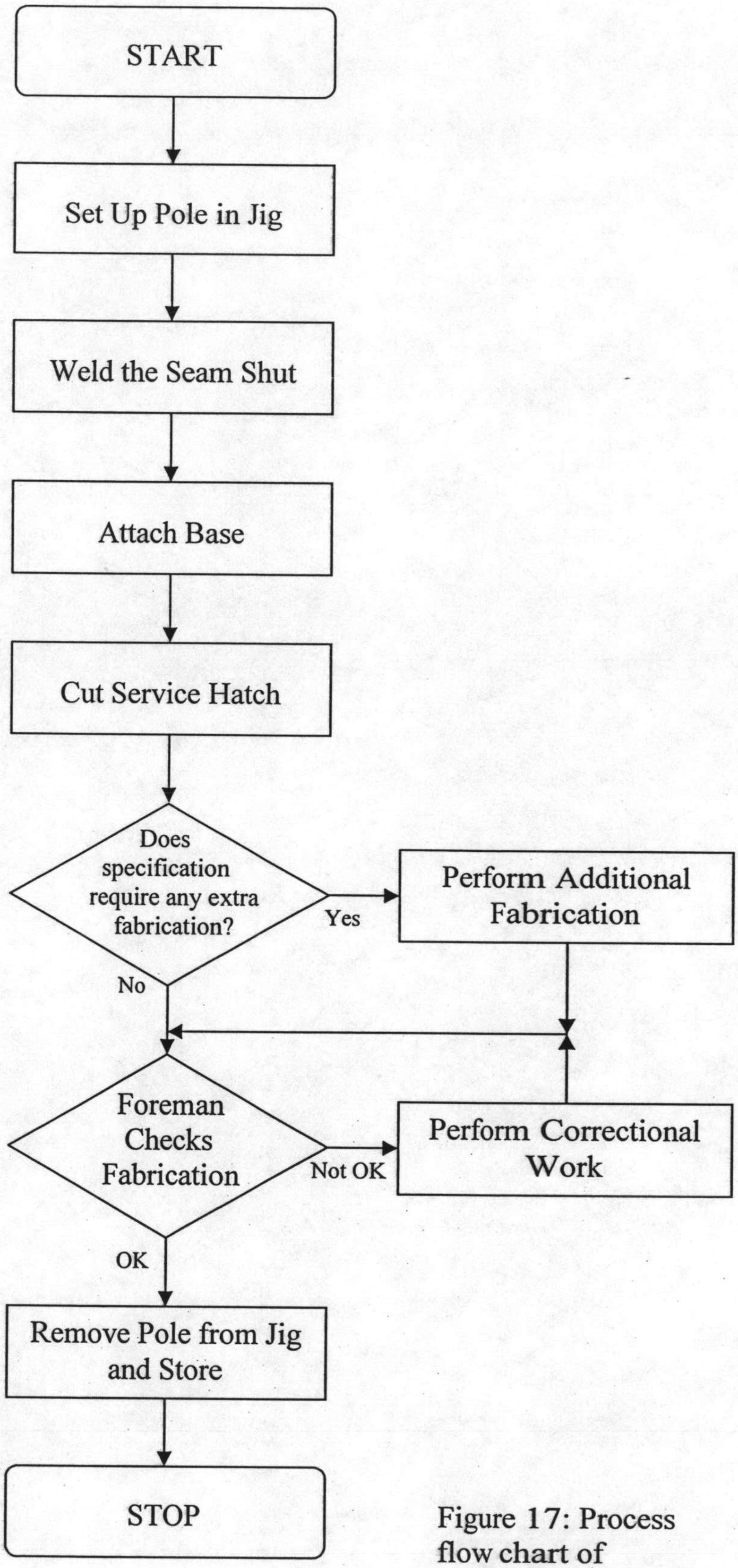

Figure 17: Process flow chart of welding/fabrication process

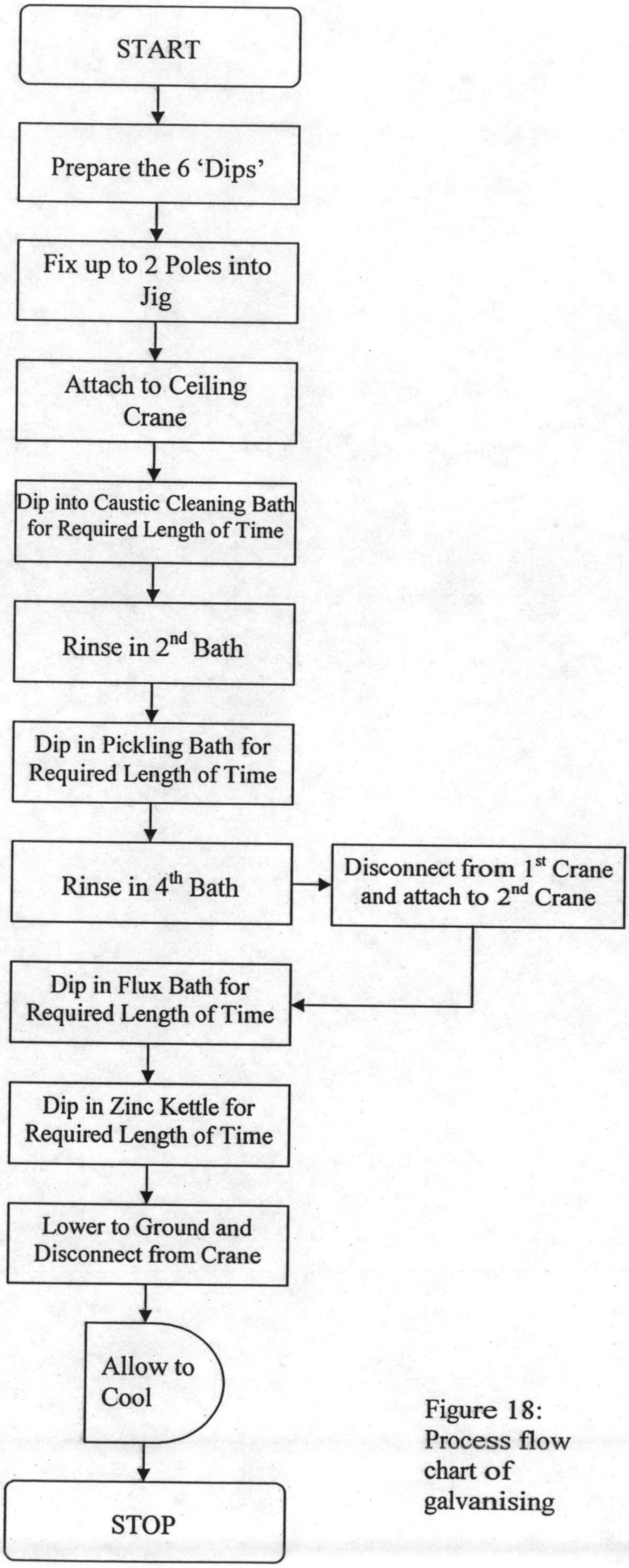

Figure 18: Process flow chart of galvanising

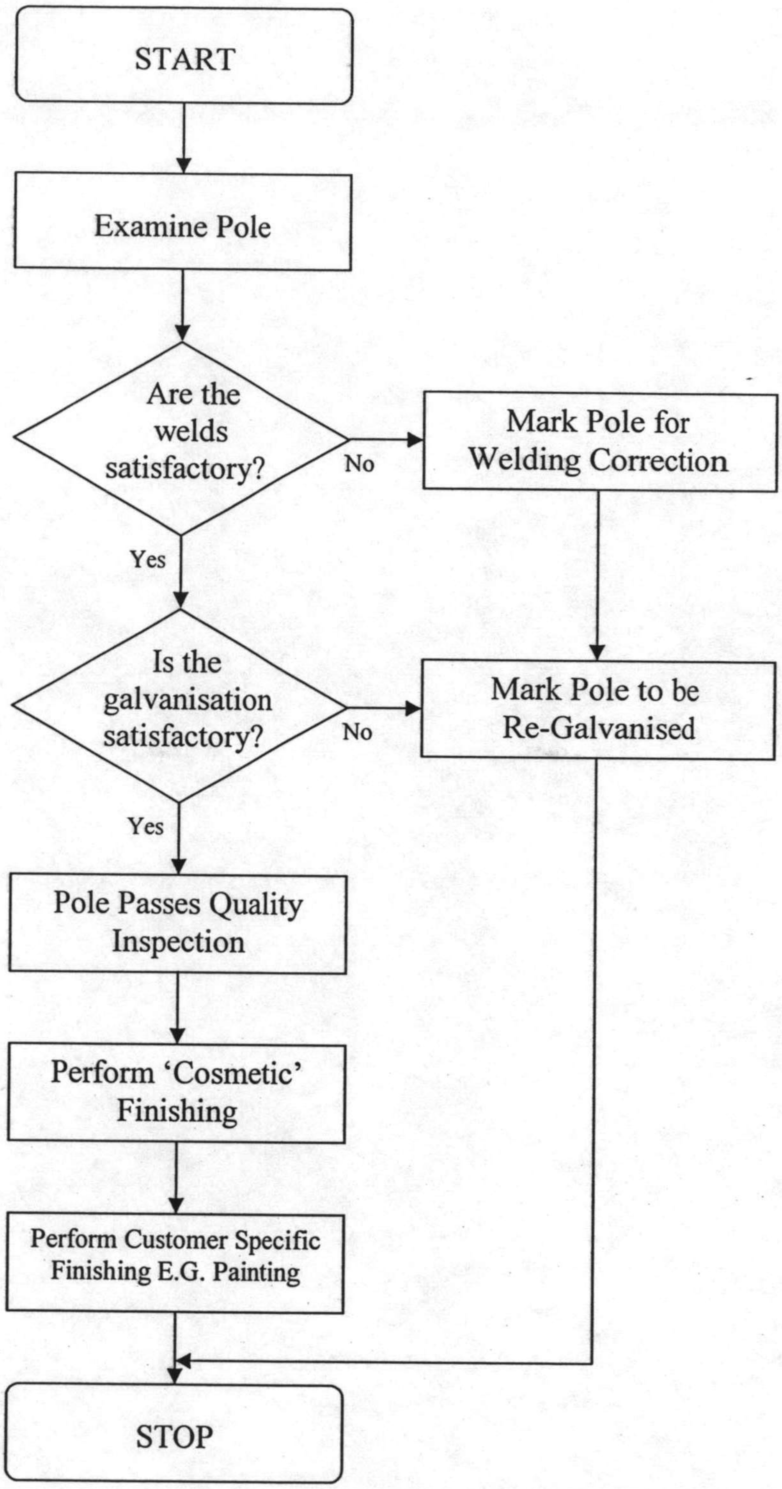

Figure 19: Process flow chart of finishing process

3.4 Plant Layout

The 6 stages of the process are situated in two building. Cutting, shearing and fabrication are grouped together in one building. Galvanising and finishing are situated in an adjacent building. The cutting machines of stages one and two and the press of stage three are located in a linear arrangement so that the completed work of one machine has the minimum distance to travel to the next station. Fabrication is located near the forming press in a partitioned area to prevent injury from the fumes or from the welding light. The raw material sheet steel coils are stored in the same building and so need minimal transporting to stage 1. Sheet steel from stages 1 and 2 is stored in stacks of up to 20 and so can be stored close to the machinery. After being pressed, the poles are rolled along guide rails into the welding/fabrication area. After fabrication the poles are stored in the fabrication area until there are enough to fill a truck. They are then transported the short distance to the galvanising area where they are unloaded waiting to be dipped. After galvanising the poles have to cool and so are left in a covered area next to the galvanising building where they are also inspected and finishing is performed.

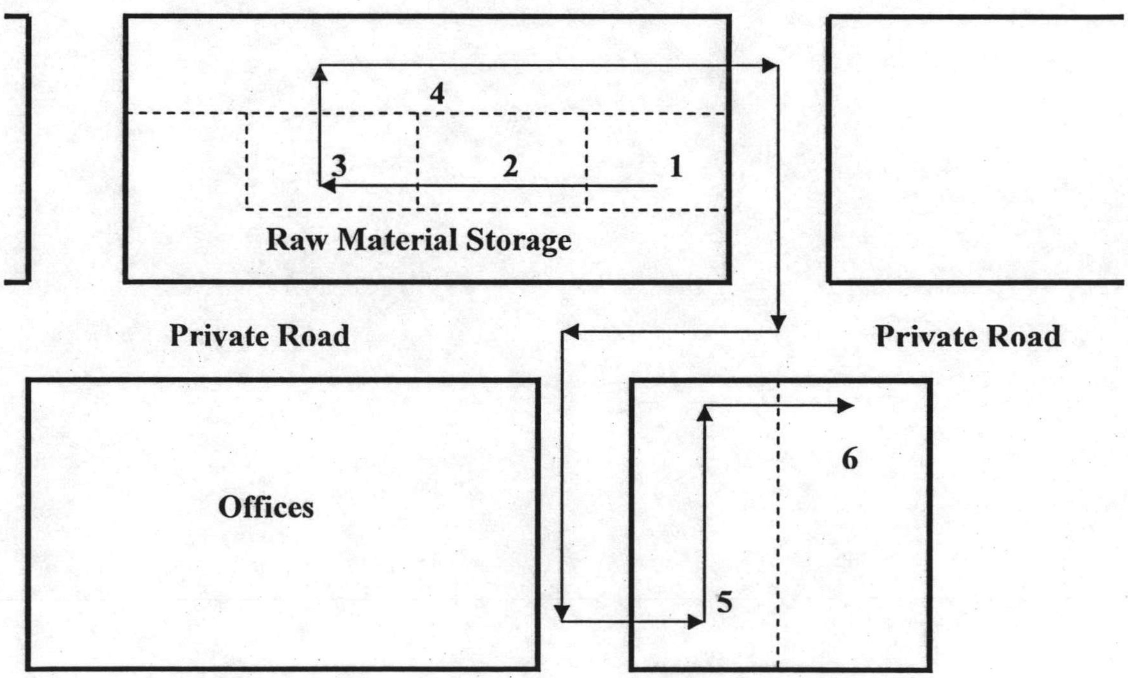

Figure 3.5: Layout of Factory Showing Processes

Legend: 1 = Cutting 2 = Shearing 3 = Forming 4 = Fabrication
5 = Galvanising 6 = Finishing

The layout effects material flow and it is desirable to have as short a distance for the work-in-progress to travel as possible. Optimising the layout has been shown to reduce costs and improve productivity. However in this study plant layout will not be considered due to the scale of operations. The galvanising area would be extremely difficult to relocate given that it is set in concrete. The various cranes would also need dismantling and re-installing. The company is in the process of redesigning the site due to a new road intruding onto the plot and so plant layout is already being studied as part of that project.

3.5 Methodology for Calculating OEE

As mentioned before, OEE is calculated as the product of three loss categories:

1. Availability Losses
    a. Breakdowns.
    b. Setup times.
2. Performance (speed) Losses
    c. Idling or minor stoppages.
    d. Speed losses.
3. Quality Losses
    e. Defective products or products that need rework.
    f. Yield losses.

The losses a. to f. are taken directly from Nakajima's six major losses of manufacturing. In order to calculate these 6 losses it is necessary to collect data concerning certain variables of the manufacturing processes. These variables will be taken from the research model of Ljungberg (1998).

- Working hours.
- Planned downtime.
- Downtime losses.
- Setup time.
- Output.
- Number of defects.

- Ideal cycletime.
- Actual cycletime.

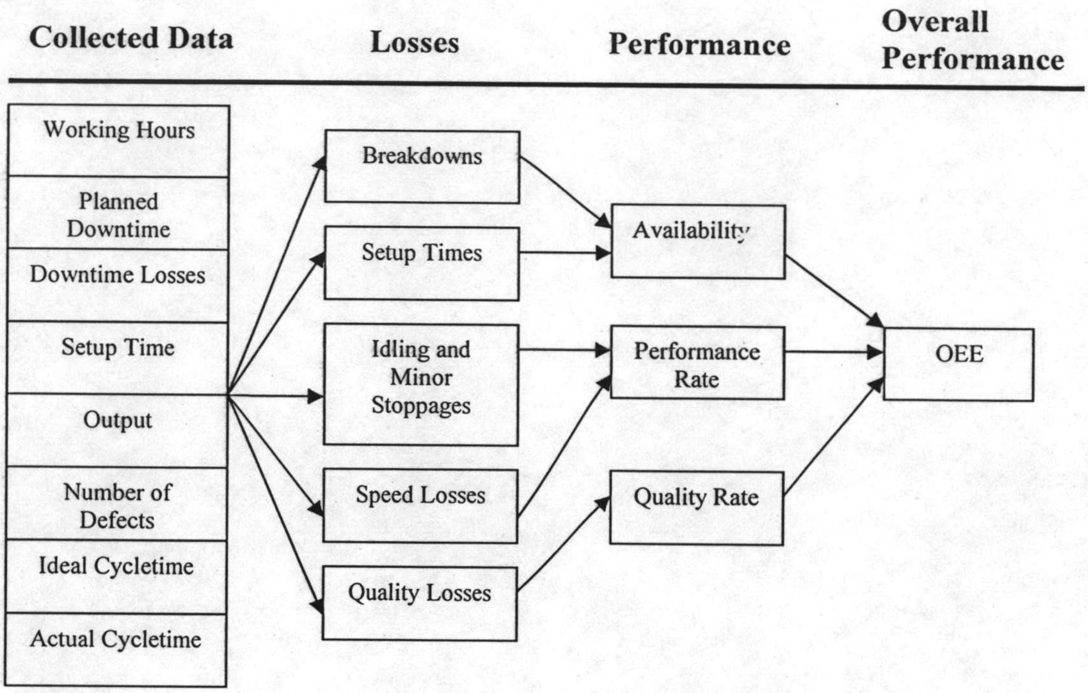

Figure 21: Research Model

The loss that is the most difficult to calculate in the above model is the time lost due to minor stoppages or idling. The time loss is defined to be a stoppage of less than 10 minutes in length and could be due to a component jam or an obstructed product flow. Due to the nature of these short stops, the operator is likely to be more concerned with getting the machine running again rather than looking for a stopwatch to measure the length of the stoppage and then recording the data. This difficulty is mentioned as a potential obstacle to data collection by Ljungberg (1998). However, if all other time losses can be measured then the following equation can be used to calculate the short stoppages as a lump sum:

Minor Stoppages = Actual Operating Time – Total Cycle Time

Where

Actual Operating Time = Working hours – planned downtime – downtime losses – set up time

Three of the eight data to be collected are relatively fixed and are generally set by management or factory foremen:

1. Working hours.
2. Planned downtime.
3. Ideal cycle time.

The remaining five must be collected in order for the losses to be calculated:

1. Downtime losses.
2. Setup time.
3. Number of defects.
4. Actual cycle time
5. Output.

3.6 Loss Definition and Quantification

When a work stoppage occurs it can be confusing as to what sort of loss should be recorded. The following list defines the stoppages by category:

1. Availability Losses
    - Machine breakdown longer than 5 minutes
    - Energy shutdown (air, hydraulic, electricity etc)
    - Changeover (planned or unplanned)
    - Parts shortage
    - Lack of manpower

2. Performance Losses
    - Reloading of components taking less than 5 minutes
    - Minor stops taking less than 5 minutes
    - Operating at less than ideal cycle time (speed loss)

3. Quality Losses
    - Defective product
    - Reduced yield (not applicable in this investigation)

Working Hours and Overtime

After talking to the production staff at CCH the factory's working hours were stated as 7:30am until 12pm, followed by a 1 hour lunch break. The afternoon shift is from 1pm until 4pm. This gives a normal day of 7.5 hours. The working week is Monday through Saturday and the factory is closed on Sunday. The company adheres to Thai national holidays as well as some Chinese traditional holiday.

It is clear that the company relies on overtime to achieve the required output. The production manager confirmed that the employees usually work overtime Monday through to Friday but not on Saturdays. The length of the overtime depends on how far behind schedule the particular department is. For example if there were a machine breakdown during the normal working hours then the employees would usually work two or three hours overtime. This overtime is not scheduled working time but will be included in the calculations.

Measuring Defects

The calculation of defects is a necessary part towards calculating quality losses and ultimately, OEE. This research is not only concerned with the OEE of the entire production of the steel poles but also with the OEE values of the individual processes that make up the entire system. At CCH, due to the high value of each product and the relatively low quantities, every pole is inspected after the finishing stage is complete. If any pole does not pass the quality inspection then the location of the defect is marked and the pole is sent back to the necessary department for correction. The poles are very seldom scrapped.

From initial checks with production staff it was made clear that the majority of defects are due to the welding and galvanising stages. Thorough inspection of the welds can highlight any weak areas. Defects from galvanising are easy to spot as the zinc covering is partial or missing. Defects from the other stages are extremely rare and cannot be sent to the stage responsible; once the poles are welded and galvanised it is impossible to re-perform cutting, shearing or forming.

3.7 Data Collection Methodology

The critical parameters of the six major losses need detailed data performance data. The data collection requirements can be very complex as the calculation of OEE is likely to be much more detailed than any previous analysis at CCH. Computerised data logging systems are used in some industries to monitor the machinery and the information from these systems is very precise. The computers can give the exact magnitude of the frequency and length of machine stoppages. In some cases the machine forces the operator to enter a fault code, specifying the cause of the stoppage, before the machine will start-up again. However, these computerised systems are expensive and difficult to use. There have been examples in industry of them being installed but not used. Moreover, there is no such computer system installed at CCH and so a more traditional method will have to be used.

At the other end of the spectrum, a simple data collection technique is to conduct frequency studies. This method records the frequency of stoppages, but not length or reason. A tally chart can be used and this can be a good way to introduce TPM activities to operators without discouraging them by asking them to do too much at once. This can provide a quick overview of losses. It should be remembered that, "the most important objective of OEE is not to get an optimum measure, but to get a simpler measure that indicates the areas for improvement" (Ljungberg, 1998; Jonsson and Lesshammar, 1999).

A compromise between the two extremes will be used in this investigation. After discussing the matter with the production department it was decided that for this investigation the data will be collected by shop floor supervisors and foremen with the help of the shop floor operators. CCH has recently been awarded ISO 9001:2000 and one of the requirements for the standard is the monitoring of processes within the factory. A measurement system is already in place to measure certain variables in production.

Foremen and supervisors are responsible for the monitoring. However, not all the variables required for the OEE calculation are currently being recorded.

As mentioned before, eight measurements are necessary to calculate OEE and three of the eight (working hours, planned downtime and ideal cycle time) are set by management or foremen. The remaining five must be found by data collection.

Downtime Losses

The breakdown losses must be recorded by the foremen. Whenever an operator encounters a machine breakdown he must contact his supervisor and report it so the maintenance team can be summoned. At CCH there are maintenance records and for every time the team is called to a breakdown the times and repair details are recorded. The foremen currently keep a record of every machine breakdown but for this investigation must also record any stoppages due to material shortages, labour shortages or power cuts.

Setup Losses

This is the changeover time between batches and is the time for the machine to be set up to process the next batch. It can also be the time taken for a machine to warm up before use. This is not currently measured at CCH and so the foremen will be instructed to measure the length of every setup change.

Output

The total number of units produced. This can simply be taken from the logbook of each process. This is one of the more obvious measurements and it is already being monitored and recorded. No additional measuring is required.

Number of Defects

OEE does not distinguish between pieces that need reworking and pieces that are scrapped so both will be counted towards the total number of defects. Defects in the cutting, shearing and forming stages are extremely rare. Immediately after galvanising the poles are thoroughly inspected and any sub-standard poles are sent back to be re-welded or re-galvanised.

Actual Cycle Time

Actual cycle time is the time taken to process each item. This is already being measured at the CCH factory as part of the continuous improvement policy. Therefore the foremen will record this information.

3.8 Calculation of OEE

The calculation of OEE can be performed in different ways and different research authors use different methods. This research will use the 'six major losses' to define the way in which OEE will be calculated. Therefore availability losses will be attributed to machine breakdowns and setup/changeover times. Performance losses will be calculated from idling/minor stoppages and speed losses. Quality losses will be taken from defects or rework.

$$\textbf{Availability} = \frac{\textbf{Actual Operating Time}}{\textbf{Planned Operating Time}}$$

where

Planned Operating Time = Total Shift Time
- Planned Maintenance

and

Actual Operating Time = Planned Operating Time
- Unplanned Maintenance
- Set-up and Changeover

$$\textbf{Performance} = \frac{\textbf{Actual Operating Time – Performance Losses}}{\textbf{Actual Operating Time}}$$

where

Performance Losses = Minor Stoppages + Speed Losses

Minor Stoppages = Actual Operating Time – Total Cycle Time

Speed Losses = Total Cycletime – Output * Ideal Cycletime

Quality = $\mathbf{\dfrac{Output - Defective\ Items}{Output}}$

OEE = Availability * Performance * Quality

OEE can be calculated for each stage of the manufacturing process as well as for the overall manufacturing stages combined together.