CHAPTER 2

THEORETICAL CONSIDERATIONS AND LITERATURE REVIEW

This section will present the theory surrounding the topic of lost time in manufacturing and past research work relevant to the topic. Published work on overall equipment effectiveness will be presented, followed by other important research which should be considered for this project.

Theoretical Considerations

Reducing lost time in manufacturing is a goal many companies around the world have been striving to accomplish for a long time and so there are many theories surrounding improving production efficiency.

2.1 Transportation Losses versus Operations Losses

The topic of time loss reduction can be split into two sections, transportation losses and operations losses. Transportation losses are those incurred during the transportation of work-in-progress between stages of the manufacturing process. Operations losses are those which occur during the actual processing stages of the process.

For a company such as CCH where the material being transported is heavy and bulky the transportation losses would be expected to be considerable. Overhead cranes are used in some stages which only increases the chance of additional losses. The layout of the plant, including the routing of the overhead cranes, is the topic of many studies. Various approaches to solving the problem include the Traditional Schematic Technique, Travel Charting and Sequence Analysis. Many of the modern techniques employ complex mathematical algorithms to calculate the optimum arrangements.

The company is currently planning to move operations to another site in the near future and has already made plans regarding the new plant layout. A team has been assigned specifically for the purpose of finding the optimum layout that will minimise the transportation losses. Therefore, only operations losses will be considered in the course of this study. It is understood that the operations of some stages will be directly affected by the layout design. For example, set up times of heavy machinery are dependent on the routing of overhead cranes which are needed to transport parts for the set up. However, since the projected plant layout has not been finalised it will not be possible to use it and therefore only operations losses can be investigated.

2.2 Six Major Losses, TPM and OEE

One of the most famous theories concerned with operations losses was put forward by Seiichi Nakajima who had considerable influence over Japanese manufacturers in the late 1970's and suggested his 'Six Major Losses' of manufacturing:

Availability Losses

1. Equipment failure (breakdown)
2. Setup or adjustment losses

Performance (speed) Losses

3. Idling and minor stoppages (shorter than 10 minutes)
4. Reduced speed losses

Quality Losses

5. Defects during the process and reworking losses
6. Yield losses

The above six losses were said to be the major losses manufacturers had to try to reduce in order to improve machine efficiency. Each of the losses reduces the valuable, productive operating time of the machines. By reducing the size of the losses, the machines would be producing more defect-free items per unit time.

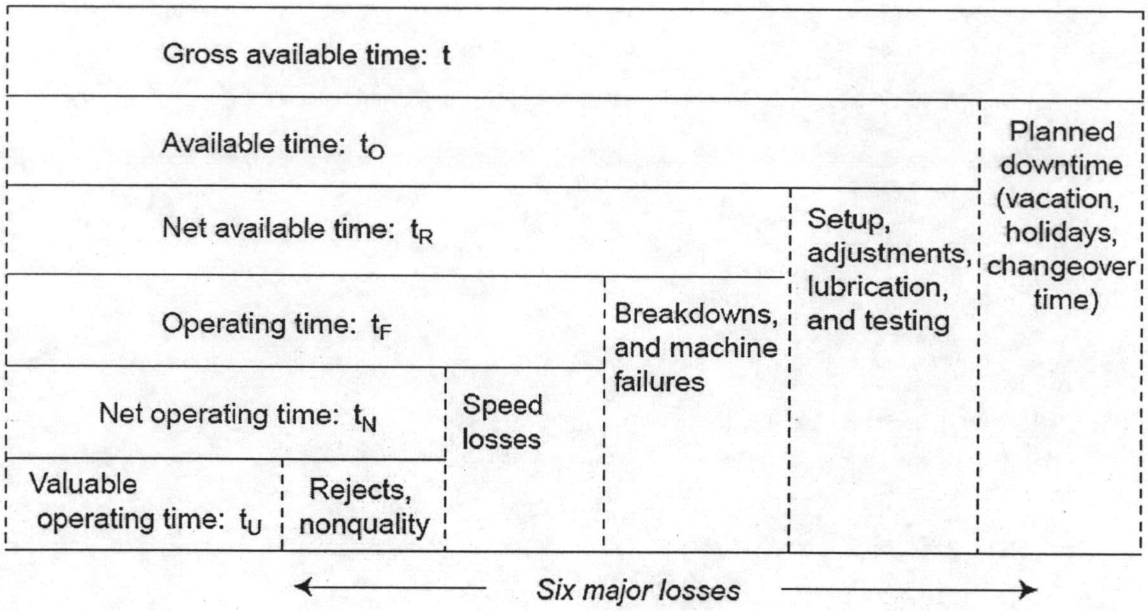

Figure 2: Illustration of Six Major Losses

Nakajima is often referred to as the 'father' of Total Productive Maintenance (TPM). TPM originated in the 1970's in Japan and was born out of the increasing global competition in the automobile industry. TPM seeks to maximise productive time, reduce non-productive time due to stops and breakdowns, keep optimum production speed and reduce non-quality. The three levers for improvement by TPM are availability, performance and quality. The performance indicator of TPM is Overall Equipment Effectiveness (OEE) which is defined by the six major losses and is a measure of the machine utilisation with respect to time.

2.3 Calculation of OEE

The factors used to determine OEE are:

- Operational availability $A_0 = \frac{t_F}{t_R}$
- Performance Rate $R_P = \frac{t_N}{t_F}$
- Quality Rate $R_Q = \frac{t_U}{t_F}$

The OEE is defined as $OEE = A_0 \cdot R_P \cdot R_Q$

The calculations of availability, performance and quality vary between sources, however, below shows one way to perform the calculations (Dal et al, 2000):

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

where

Planned Operating Time = Total Shift Time
- Planned Maintenance

and

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

Performance = Net Operating Rate * Operating Speed Rate

where

$$\text{Net Operating Rate} = \frac{\text{No. Produced * Actual Cycle Time}}{\text{Operation Time}}$$

and

$$\text{Operating Speed Rate} = \frac{\text{Theoretical Cycle Time}}{\text{Actual Cycle Time}}$$

$$\textbf{Quality} = \frac{\textbf{Total No. Produced – Number Scrapped}}{\textbf{Total No. Produced}}$$

The calculation of OEE should give a percentage and the higher the percentage the greater the level of machine utilization.

Nakajima (1988) suggested that ideal values for the OEE component measures are:

- availability in excess of 90 percent
- performance efficiency in excess of 95 percent
- quality in excess of 99 percent

These values would produce 'world-class' OEE value of 85%; however, other sources suggest appropriate figures over 50% (Kotze, 1993) or between 30% and 80% (Ericsson, 1997).

OEE can be used in many different applications. Firstly OEE can be used to 'benchmark' the overall production of the manufacturing plant and be used to measure improvement from previous measurements and gauge the progress made. Secondly OEE can be calculated for all production lines in the factory, highlighting any weak line. Thirdly, OEE can be used within a workshop measuring the performance of the individual machines. Any poorly performing station or machine can be identified and so resources can be directed towards that area to improve performance.

It is essential to understand the disturbances which cause the time losses. Johnson and Lesshammer (1999) classify disturbances in the manufacturing process as chronic or sporadic according to their frequency of occurrence. Chronic disturbances occur frequently, have little effect but are complicated as they are usually the product of many small causes. Sporadic disturbances seldom occur but have dramatic effects on the system. Sporadic effects are therefore easier to identify and are often said to be the more serious of the two in terms of losses. However, research finds that chronic disturbances can be the more detrimental due to the high frequency occurrence and the small effects which can go unnoticed.

OEE is often used to measure one half of Total Preventative Maintenance (TPM) in a company. The machine effectiveness and efficiency is where OEE can be used. The other half of TPM is the organisational approach to the accomplishment of maintenance activities. Both sides of the spectrum should be considered.

2.4 Japanese 5S

5S is a system for maintaining the workplace which allows more efficient operations. The method assumes that no effective, quality job can be done without a clean, safe environment and behavioural rules. Developed by Osada (1991) in the early 1980's, 5S is the acronym for five Japanese action words:

1. Seiri – Organisation

   Keep what is needed in the workplace, what is needed less frequently is stored and what is not needed is discarded. This is the basic idea behind the first step. Seiri helps to keep the workplace tidy, increases floor space, reduces raw material and reduces fetching times.
2. Seiton – Neatness

   This is the systematic arrangement of tools in the workplace for faster retrieval. In order to improve changeover times or reduce machine downtime the tools have to be at hand quickly and this is the driving force behind Seiton.
3. Seiso – Cleanliness

   After the initial cleaning operations the workplace must be kept clean to sustain the improvement. When machinery is clean it is much easier to detect faults such as breakages, leaks and misalignments. Regular cleaning helps to promote regular inspections.
4. Seiketsu – Standardisation

   Once the first 3S have been implemented it is necessary to set a standard otherwise the workplace can easily deteriorate back to the original state. Seiketsu turns 5S into a company policy so in the future performing the 5S steps comes naturally to employees.

5. Shitsuke – Discipline

   To keep the first 4S alive it is necessary to continually educate employees about maintaining standards. Displaying ongoing 5S results so everyone can feel involved and allow the 5S boundaries to grow.

Imai (1997) proposes Japanese 5-S as a pivotal activity in continuous improvement (Kaizen) and as a prelude to total productive maintenance. 5S can therefore be used as a way to improve machine effectiveness.

2.5 Literature Review

Measure of Overall Equipment Effectiveness as a basis for TPM Activities
Organ Ljungberg, International Journal of Operations and Production Management, Vol. 18, No. 5, 1998

Total Productive Maintenance (TPM) is a modern management technique which has been very successful in Japan, often improving machine utilisation rates from approximately 60 to 90 percent. TPM is based on three major concepts:

1. Maximising equipment effectiveness
2. Autonomous maintenance by operators
3. Small group activities

However, the author states how the implementation of TPM can be a difficult process and needs to be approached correctly. It is important to focus on processes, not results. Therefore, in order to improve processes within the company it is necessary to study the processes involved. If the reason and magnitude for the losses is not known resources can not be correctly allocated to solve the problems. A variety of measurement techniques are mentioned along with their respective benefits and disadvantages from computerised systems to the operators noting down their own results.

The author continues by identifying the following as independent variable categories that although not part of the manufacturing process nevertheless have an impact on the results:

1. Production process
2. Process knowledge
3. Maintenance activities
4. External conditions
5. Production Conditions

The complete model used in the author's research is below:

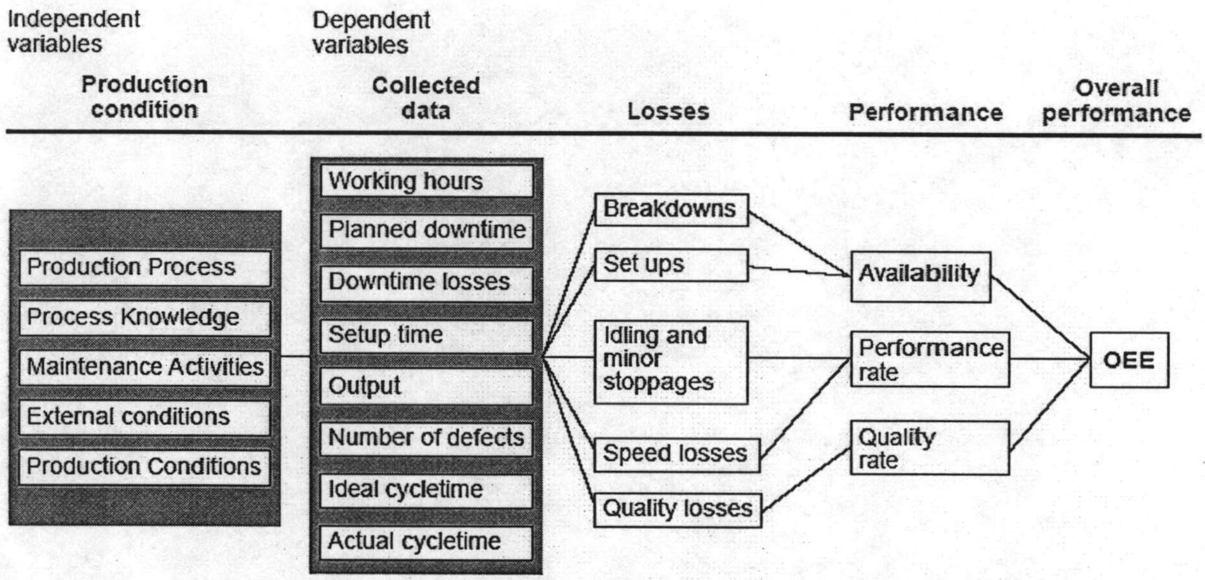

Figure 3: Example of Research Model (Ljungberg, 1998)

The author concludes by stating that the performance losses (minor stoppages and reduced speed losses) are dominant followed by downtime losses. Quality losses are normally not waste but rework which can be large in some industries. An interesting point the author makes is about the independent variables and that when the process is new to the company the OEE is generally 10% lower. This may not be important at CCH as the process has been in operation for many years.

Operational Efficiency and Effectiveness Measurement

Ki-Young Jeong, Don T. Phillips, International Journal of Operations and Production Management, Vol. 21, No. 11, 2001

This study restates the importance of accurate estimation of equipment utilisation in capital-intensive industries because the identification and analysis of hidden time losses are initiated by these estimates. However, this study introduces a new loss classification system which differs from that used by Nakajima and in many studies since. Nakajima outlined his famous 'six major losses' as shown below:

1. Equipment failure (breakdown)
2. Setup or adjustment losses
3. Idling and minor stoppages (shorter than 10 minutes)
4. Reduced speed losses
5. Defects during the process and reworking losses
6. Yield losses

However, this study uses a different set of losses based on SEMI E10-92 (1992) in previous researches. The authors believe that the loss classification system is tied to the industry type and the newer system is more suited to the capital-intensive industry. One of the reasons for this is the Nakajima-based system uses loading time to compute the time losses. Loading time does not take into account scheduled maintenance time for preventative maintenance or non-scheduled time such as off-shift or holiday. Most capital-intensive industries rely on multiple shifts to keep the machinery working as continuously as possible. The newer classification system is shown below:

1. **Non-scheduled time**: time during which the machinery is not scheduled to operate such as holidays and leave.
2. **Scheduled maintenance time**: time set aside for preventative maintenance.
3. **Unscheduled maintenance time**: time spent fixing a broken-down machine.
4. **R &D time**: due to high costs of the machinery, most companies use the same machinery for production, R& D and engineering. This means the machinery cannot always be used for production.
5. **Engineering usage time**: time spent for engineering check-up.

6. **Setup and adjustment time**: time spent during operation for setup and adjustment.
7. **WIP starvation time**: time during which machinery is ready but there is no work in progress from the previous station to process.
8. **Idle time without operator**: time for which there is WIP ready to be processed but no available operator.
9. **Speed loss**: time loss for which the machine works at less than the standard speed.
10. **Quality loss**: time for which the machine works making unsatisfactory parts.

Whilst many of these losses will be present at CCH some of them will not be relevant such as R&D. The company is manufacturing a low technological product and little or no R&D is performed on the steel poles.

On the subject of data collection the authors recommend a computerised data collection system even though the high cost of investing in such a system is noted as a potential barrier. The accuracy of the calculated OEE will be dependent on the quality of the data collected. This might not be possible at CCH as the management might initially be unwilling to invest in expensive measurement without first seeing results.

Two methods for calculating OEE are presented both using the same ten losses shown above. However, one method uses Nakajima's original calculation of Availability multiplied by Efficiency multiplied by Quality. The other method groups all time losses into 3 categories, total time loss, speed loss and quality loss. All items from the list above from 'non-scheduled time' (1) to 'idle time without operator' (8) are classified as the total time loss as these are the direct production losses used to compute the time efficiency. The exact procedures for calculating OEE using this method are shown in the following figure:

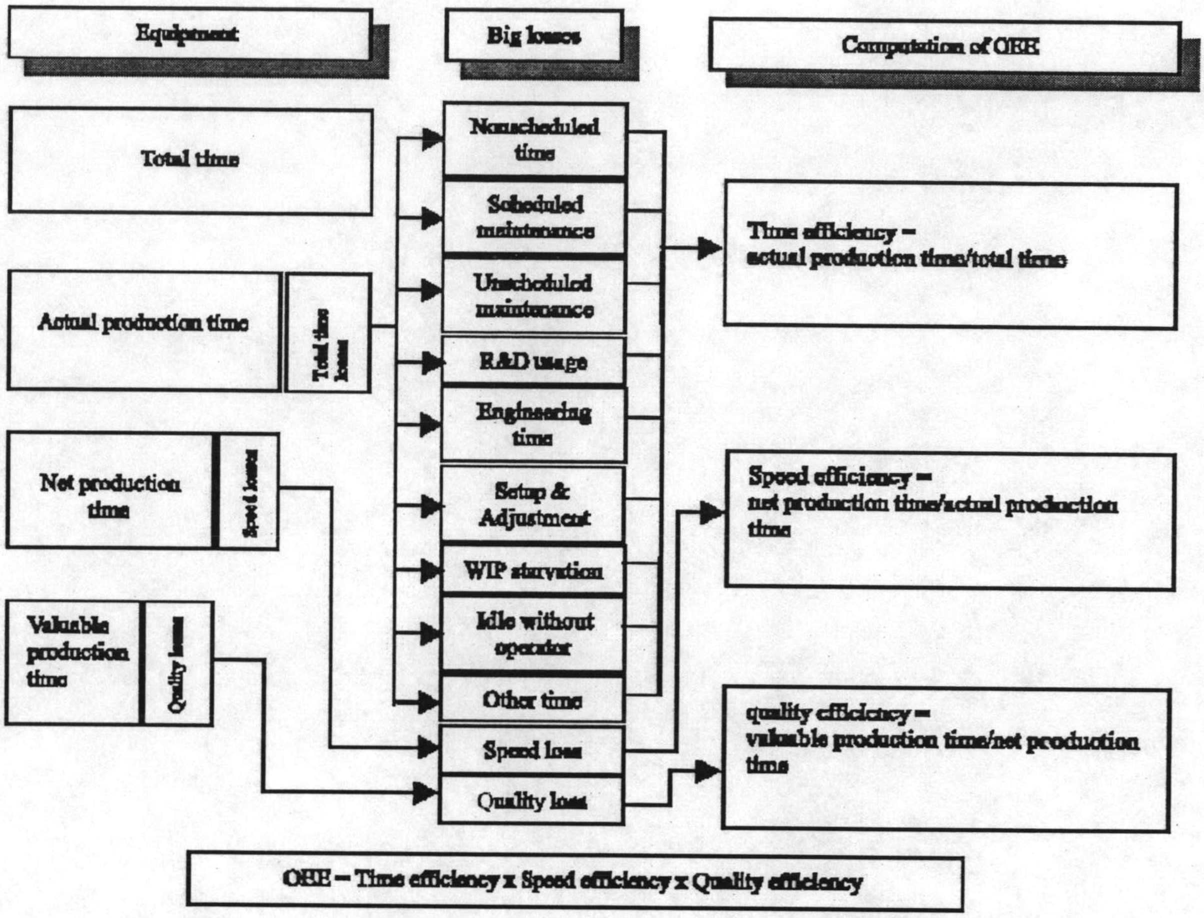

Figure 4: Alternative method for Calculating OEE (Jeong and Phillips, 2001)

The research next explains that once the losses have been calculated it is then time to attempt to reduce those losses. TPM emphasises the use of autonomous operators and small group activities in order to reduce losses but the authors state that management has to provide clear tools and methods. Also the characteristics of the losses have to be fully understood. Management policy controls some of the losses such as scheduled maintenance time, R&D time and engineering time. Other losses have links to external factors e.g. WIP starvation and setup time are affected by scheduling and dispatching policy.

Overall Equipment Effectiveness as a Measure of Operational Improvement

Bulent Dal, Phil Tugwell, Richard Greatbanks, International Journal of Operations and Production Management, Vol. 20, No. 12, 2000

This study is based on a case study at an automobile airbag manufacturer and the objective of the study was to use OEE as a measure of improvement. The initial value of OEE was calculated from existing performance measurements for downtime, speed losses and quality losses. It was stated that some of the measurements taken from the existing system needed to be reconfigured before they could be used for OEE calculation. After the initial recordings, the necessary data was collected daily by shop floor operators and the OEE calculated by shift leaders before being posted for everyone to see. Over a four week time scale objective was to increase OEE incrementally by reducing time losses. The three components of OEE are presented separately:

1. Availability

   The operators were required to report each instance of unplanned machine downtime and the reason for the stoppage. The authors mention there were difficulties due to inaccurate downtime reporting. On some occasions the lost time was not reported or the reason was missing from the data. It was necessary to set up a TPM workshop for operators and shift leaders to present a detailed analysis of machine downtime using past records and discuss simple yet effective solutions. The two main losses in availability were found to be downtime and maintenance which jointly accounted for 87% of lost time. Further root analysis was useful and the solution was to formulate standard operating procedures (SOP's) for the workforce to follow in case of downtime activities.

2. Performance

   To measure speed loses the study used the operating speed rate and net operating rate. Operating speed rate was the difference between theoretical speed and the actual speed. The net operating rate was the achievement of a stable operating speed over a period of time and therefore calculated minor stoppages as well as those that were unrecorded.

   The study found that the two main losses here were low quality sewing yarn (a raw material) and inconsistent air supply to the machines (a maintenance issue).

3. Quality

After fabric was woven it was inspected for faults and whenever one was found it was given a fault code. The machine, operator time etc were all known and so a system if identifying where the quality problems were originating from was formed. All the machines had fault sheets which were compiled daily into fault reports. Pareto analysis was used to find the major problems and the root causes were examined.

Human issues relating to OEE are considered to be important. It is suggested for management to work together with employees to increase worker participation. Also the physical environment needs to be considered because if the workplace is too disorganised and cluttered the workers lose their morale.

The calculation method used in this research does not strictly adhere to the guidelines set by Nakajima and his definition of availability, performance and quality losses. When calculating performance losses, the authors do not include minor losses in their calculation, but instead use the minor losses to calculate availability. Therefore only speed losses contribute to performance losses. Nakajima defined performance losses as idling/minor stoppages and speed losses combined.

The authors conclude by confirming that although OEE is a useful tool to measure equipment efficiency, it can be an even greater tool for measuring process efficiency improvement.

<u>Evaluation and Improvement of Manufacturing Performance Measurement Systems – The Role of OEE</u>

<u>Patrik Jonsson and Magnus Lesshammar, International Journal of Operations and Production Management, Vol. 19, No. 1, 1999.</u>

This study identifies six requirements of an overall manufacturing performance measurement system. These were four critical dimensions (what to measure) and two characteristics (how to measure). OEE was assessed against the six requirements along with the measuring systems of three manufacturing companies.

1. Strategy
   The measurement system translates the corporate and business strategies to all levels of the organisation.
2. Flow Orientation
   The measurement system integrates all functions, activities and processes along the supply chain.
3. Internal Efficiency
   The measurement system makes productivity control and comparison between internal functions possible.
4. External Efficiency
   The system interacts with customers and measures the level of customer satisfaction.
5. Improvement Drivers
   The measurement system not only works as passive control, but is instead used for continuous improvement.
6. Simple and Dynamic
   The measurement system is simple and dynamic, since several dimensions are to be included and since the circumstances for measurement are fast changing

OEE was found not to measure strategy, flow orientation or external efficiency to any extent. OEE is a measure of internal efficiency and so was useful when focusing on the characteristics improvement drivers and simple and dynamic. It is stressed that it is not essential to get an optimum measure of OEE but to get a simple measure to allow management to channel improvement resources to the area that needs it the most.

In the case of CCH the overall manufacturing performance does not need to be investigated. The lost time during the manufacturing process is under analysis and so OEE can be used with confidence.

Improving Operations Performance in a Small Company

A. Gunasekaran, L. Forker, and B. Kobu, International Journal of Operations and Production Management, Vol. 20, No. 3, 2000.

This study concerns productivity operations problems in SME's. Although the author defines an SME (small or medium size enterprise) as one which employs no more than 500 people (amongst other parameters), the information can still be useful in the case of CCH which has 800 employees. A series of concepts are brought together from other literature and case studies to produce a model for improving operation within an SME.

JIT is just in time manufacturing where material is 'pulled' through the system as and when it is needed, as opposed to a 'push' system where production is constant whether there is sufficient demand or not. One benefit of this is inventory is reduced, reducing losses from storage, parts becoming outdated etc. There is a wealth of literature on the subject should further research be necessary. Japanese 5S (translated as sweep, sort, spotless, standardise and step) also originates from Japan and has guidelines for maintaining the physical environment of the factory. Hoshin exercise, again Japanese, encourages gradual improvement while not leading to productivity losses when undergoing the change process. These methods are proven to have a positive effect on productivity but do not cost much to implement. The difficulty is in the required change of work culture.

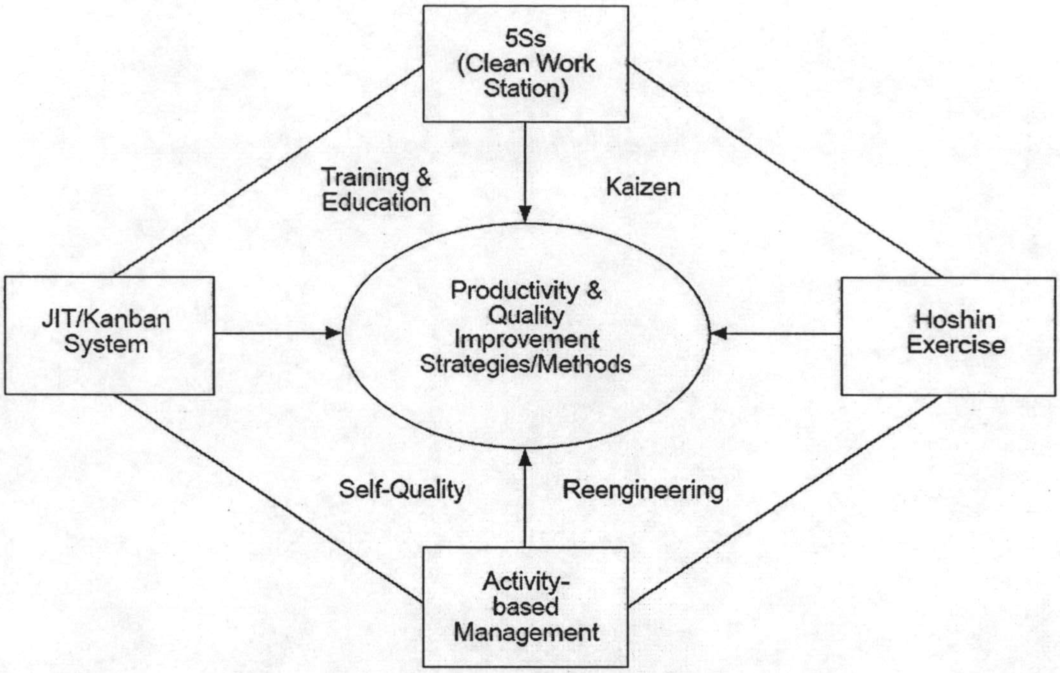

Figure 5: Improvement Methodology (Gunasekaran et al, 2000)

The research methodology used in this study was as follows:

1. Monitor the process.
2. Record performance.
3. Analyse performance over time.
4. Propose solutions that include areas for improvement.
5. Implement the solutions.

The data collection method had two stages:

1. A shop floor study to see how the operators were working
2. Identification of what the real problems were.

Target sheets were distributed to operators so reasons for targets not being met could be gathered and analysed.

Analysis of the data was by material flow diagrams, cause and effect diagrams and Pareto analysis. Solutions were generated by brainstorming sessions, impact analysis and the priority matrix. The tools to improve productivity were as follows:

1. Management of inventory.
2. Design and planning of the operating system.
3. Design and specification of the process.
4. Layout of the cells.
5. Design of the jobs and work.

Having completed their study the author recommends the following as implementation issues regarding improving productivity in SME's:

1. Simple non-financial measure are often the most appropriate to provide the direction for improving performance.
2. Tools such as Pareto analysis are easy to understand but importantly clearly show the problem areas.
3. SME's should start with Japanese 5S implementation as it requires little capital investment apart from the training.
4. Time and motion studies e a basic approach to reducing production costs through reduced machine setup times.
5. A gradual implementation process is beneficial as it reduces production losses and improves the morale of the workforce.
6. Employee involvement through empowered teams can be an excellent way to promote improvement programs.

Design of Experiments to Study and Optimise Process Performance

R. Konda, K.P. Rajurkar, R.R. Bishu, A. Guha, M. Parson, International Journal of Quality and Reliability Management, Vol. 16, No. 1, 1999.

The authors outline a nine-step strategy to optimise a production process and verify the strategy using a case study. The nine stages are as follows:

1. Identify potential factors that might be affecting the process by brainstorming and cause and effect diagrams.
2. Choose factors for the study; this could be input voltage, machining speed or any variable that can be controlled and has an affect on the process.
3. Select possible extreme working ranges for the variables chosen in step 2.
4. Select experimental levels from within the ranges selected in step 3.
5. If possible trial run the process using all combinations of factors from step 4 for a short run to ensure no process failures will occur due to interactions.
6. Choose an orthogonal array for experiments or any other experimental design.
7. Run the experiments as designed. Must be performed randomly.
8. Analyse the results, verifying with experiment objectives.
9. If the results do not meet the objectives of the experiment then it could be due to inappropriate factors from step 2. Either formulate a new set of factors or analyse the part design or process itself to verify they do not need re-engineering.

This approach could be used to investigate the process problems in any of the production stages at CCH. However, this method was designed to investigate the process of Wire Electrical Discharge Machining of beryllium copper alloys. This is a modern technology with several factors, discharge current, surface roughness, pulse duration etc. The process at CCH is relatively simple and so perhaps this methodology is not suited to the situation.

Determination of Operations/Production Downtime for Group Replacement Maintenance Policy

J. Knezevic, International Journal of Operation and Production Management, Vol. 14, No. 7, 1994.

This study has the objective of calculating the downtime which will ensue by using different versions of group replacement policy. Group replacement policy is where if one member of the group fails all members of that group are replaced. For example, in a machining shop with 4 identical machines performing identical operations, if one machine breaks a drill bit, all machines will have a new drill bit installed at the same time. The idea is that in the long term there will be less un-scheduled downtime which will reduce costs.

The three versions of group replacement are presented:

1. Simultaneous – Replacement of all necessary parts performed simultaneously.
2. Sequential – One replacement operation completed before moving to the next.
3. Combined – A combination of the other two.

A series of mathematical formulae are presented which predict downtime using each of the three methods. A manager interested in using group replacement policy can select which is preferential for the situation.

Group technology policy could be applied at CCH but at this stage the time losses are the focus of this analysis. Group technology can be considered at a later time.

A Review of Improvement Methods in Manufacturing Operations

Thomas Grunberg, Work Study, Vol. 52, No. 2, 2003

The purpose of this paper was to present a categorisation of performance factors and a measurement model. First, the author briefly describes how most improvement methods generally have the same format, a 'pre-phase' preparation and planning step, measurement and implementation and finally an evaluation and possible restart of the improvement cycle. The most famous example is the Deming 'Plan-Do-Check-Act' cycle:

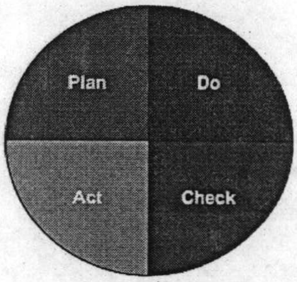

Figure 6: PDCA Cycle (Grunberg, 2003)

However, most improvement methods have different focuses. For example, Organisational Development (OD) has a focus on human interactions whereas the Theory of Constraints focuses on bottlenecks within the manufacturing process. The factors that may affect the overall performance, productivity and profitability (PPP) are shown in the diagram:

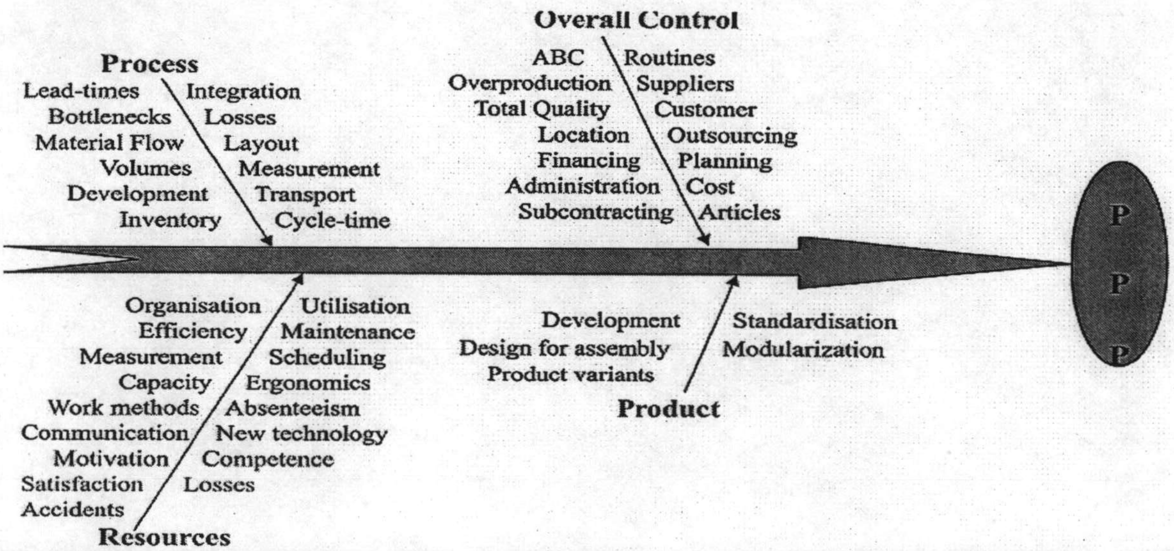

Figure 7: PPP Factors (Grunberg, 2003)

The factors are grouped into four categories, Process, Resources, Overall Control and Product. Under each category are the factors that make up the performance, productivity and profitability of that category.

Next, the process/measurement model is presented:

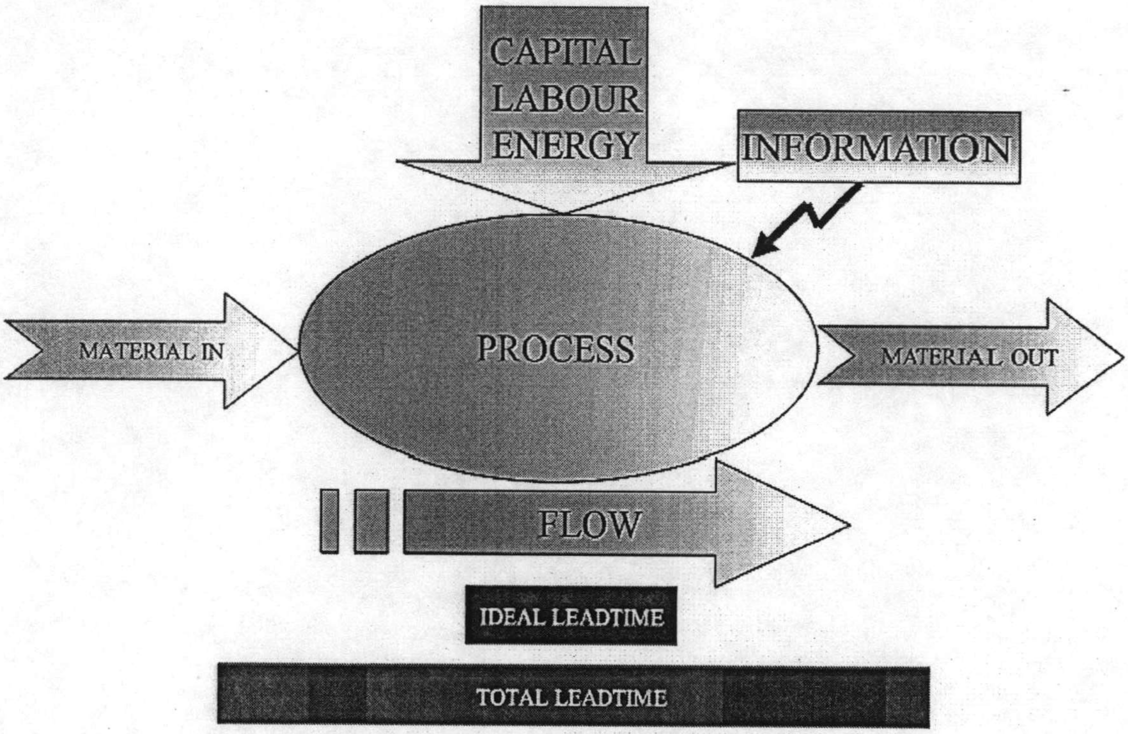

Figure 8: Process/Measurement Model (Grunberg, 2003)

The author recommends that for each of the major components in the above model, it is necessary to consider the appropriateness of measurements and the particular importance when measuring speed, volume, quality, precision and cost.

This model can be considered when investigating the processes at CCH but the categories of factors should be adjusted. The product category is not under investigation. From the other three categories, many factors can be considered.

Rethinking Pareto Analysis: Maintenance Applications of Logarithmic Scatterplots
Peter F. Knights, Journal of Quality in Maintenance Engineering, Vol. 7, No. 4, 1997.

This study concerns the application of Pareto analysis in maintenance engineering. Pareto is often used to identify the failure codes which are responsible for the majority of equipment repair cost or downtime. Based on the failure codes identified, action can be taken to reduce the maintenance costs or increase machine availability. However, three deficiencies of using Pareto Analysis are presented:

1. Maintenance costs and downtime are products of two variables; the number of failures occurring within a certain timeframe and the average associated cost, or mean downtime. Pareto histograms based on downtime (or cost) alone cannot determine which factor is the dominant cause.
2. Pareto analysis will miss the individual event that causes severe downtime or cost. Pareto analysis will also miss the frequent failure that causes little or no cost but causes interruption to production.
3. Pareto histograms are not generally useful for trending comparisons. This is because the ranked position of failures often changes from one period to the next.

To solve the problem with Pareto analysis, an alternative method is presented, where logarithmic scatterplots are used. These preserve the basic information of Pareto but indicate whether the dominant factor behind the failure is downtime of frequency of occurrence. Furthermore, by applying limit values the log graph can be slit into different segments to indicate whether the failure is chronic or acute, facilitating root cause analysis. Resources can be directed towards reducing chronic failures which are often associated with considerable losses.

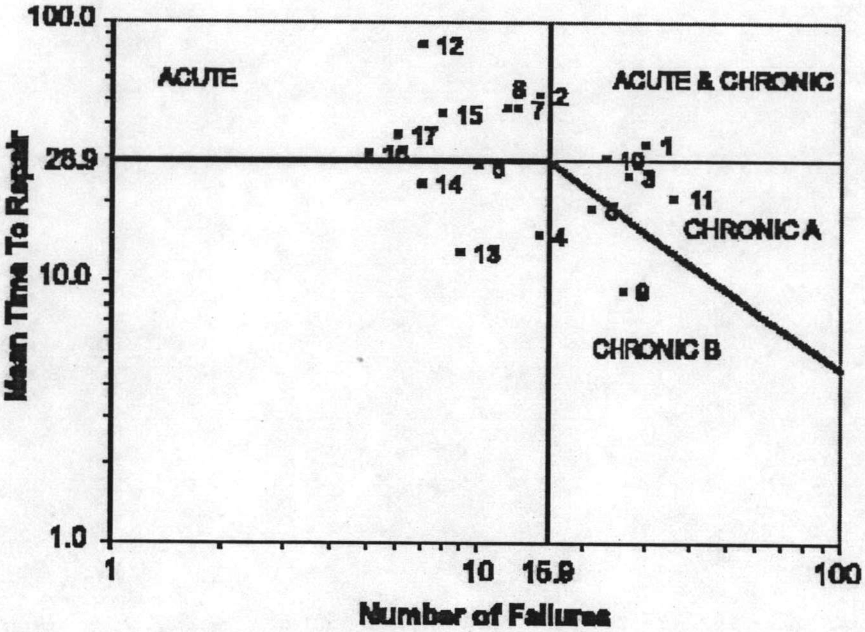

Figure 9: Segmented Logarithmic Scatterplot (Knights, 1997)