STUDY OF THE IMPACT OF BREAKDOWN REDUCTION ON ENERGY CONSUMPTION IN A MANUFACTURING INDUSTRY BY APPLICATION OF LEAN-TPM PRINCIPLES

BY

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DECLARATION

DECLARATION BY STUDENT

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ABSTRACT

At Wrigley East Africa, Nairobi an effort was made to implement Total Productive Maintenance (TPM). It is a Production management method and Wrigley's ultimate goal in introducing TPM was a means to achieve leaner production and a calming of the material flow. In Total Productive Maintenance, reliability and availability are the ultimate goals and the way to accomplish the goals is through elimination of major losses. These losses are only due to mechanical nature and visualized by the key figure; Overall Equipment Effectiveness (OEE). The main Key performance indicators for this research were; Mean Time Before Failure (MTBF), Mean Time To Repair (MTTR), Breakdown Percentage and Energy Usage. Through literature studies, a training workshop with TPM consultancy firm Efeso™ and a visit to an exemplary TPM implementing company Unilever (K), the tasks to be performed were set and a master plan of execution developed. In order to visualize production losses, a sheet for recording production progress in a timely manner was developed, a database for data storage was set up, together with a computer aided analysis, and a program to compute reports written. This research accomplished a reduction in breakdowns from 12.5% to 5.5% on PK machine. In doing so, OEE increased, and subsequently energy consumption per unit Standard Stocking Unit (SSU) reduced from 0.021KWH/SSU to 0.012KWH/SSU. The gains in productivity or effectiveness were achieved only through measures in TPM, mainly the Preventive Maintenance (PM) pillar, and not harder labor. The tools used in achieving these goals included; Autonomous maintenance, Continuous improvement, Root cause analysis for failure, Preventive maintenance among others.

DEDICATION

To

My Parents,

My Wife

And Our Children

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LIST OF ACRONYMS

CIP or CI	Continuous Improvement Process.
EAMI	East Africa Middle East and India
FMEA	Failure Mode and Effect Analysis
JIPM	Japan Institute of Plant Maintenance.
MP	Maintenance Prevention.
MTTR	Mean Time To Repair
MTBF	Mean Time Before Failure
OEE	Overall Equipment Effectiveness.
OPE	Overall Plant Effectiveness.
OPL	One Point Lesson
PDSA or PDCA	The Deming Cycle (Plan-Do-Check/Study-Act).
PK	Machine Name
RCA	Root Cause Analysis
SSU	Standard Stocking Unit
TPM	Total Productive Maintenance.
WEA	Wrigley East Africa
Wm. Wrigley	William Wrigley group of companies.

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CHAPTER ONE

INTRODUCTION

1.1. Background Information

As a global player in the confectionery industry, Wrigley East Africa (WEA) has a great interest in Lean Technology and other effectiveness-enhancing measures. This originates in high competitiveness from other manufacturers outside the region, especially the regions with low operating costs i.e. labour and energy costs. With the now ever escalating energy prices, it has become urgent for industries to use this commodity in an effective way to avoid passing on the cost to consumers (KIPPRA, 2011).

As a means to approximate greater effectiveness and a solid, continuous production, WEA has set about incorporating Total Productive Maintenance (TPM).

For decades, industrial and other organizations concentrated most of their attention on production, generally ignoring the maintenance function. Recently there has been a gradual attitude change in how general corporate managers view the maintenance function (Peterson, 2013). One of the most important factors forcing this change was that maintenance departments became major cost centers within those organizations. Today with general operating costs rising at the rate of 10% each year, there is the potential for the realization of significant savings in the maintenance department that deserves serious scrutiny (Bruce, 2011). By implementing TPM practices that will be outlined in the following chapters, significant savings can be attained, as well as the ability to manufacture in an efficient way.

This research intends to demonstrate a relationship between implementing TPM in maintenance and energy consumption per unit of product produced. The research will implement TPM methodology in reducing machine breakdowns, while measuring the energy consumed using sub-meters and thus collect data relating to breakdown level and energy consumption.

The motivation of this research is that, most of the previous studies have concentrated only on machine effectiveness, energy reduction, and energy efficiency without relating breakdowns to energy use.

1.2. Statement of the Problem

TPM concept is a relatively new concept in industries in Kenya, i.e. few factories in Kenya have implemented it for example Nampak, Unilever (K), but is much developed in other countries such as India, USA and Japan. Part of the purpose of this study is to prove that indeed TPM is workable in Kenya through a case study of WEA. Most Industries in Kenya still use the old method of maintenance, i.e. Breakdown maintenance and Preventive maintenance, without using the lean-TPM tools to avoid recurrence of breakdowns, this research will incorporate the lean-TPM tools in reducing breakdowns and maintaining them at that low level.

Previous studies have concentrated either on Breakdown reduction, Energy reduction and/or OEE, but this research will link breakdown reduction through lean-TPM with energy consumption which has not been done before. .

1.3. Objectives

1.3.1 General Objective

- To develop a model for breakdown reduction in industrial machines based on TPM principles

1.3.2 Specific Objectives

The specific objectives of this study are to:

i) Develop a maintenance information system for WEA.

ii) Develop an OEE calculator for the machines.

iii) Reduce machine breakdowns using lean TPM tools.

iv) Trend energy Consumption with breakdown levels

1.4 Delimitations

Due to time constraints and the expansive nature of TPM, all work was limited to a project area comprising of a single line of machines on breakdown and energy reduction area only, albeit with the option in mind of straight and easy adaption of tested standards at other lines. Also, any solutions for visualizations should be as inexpensive and simple to implement as possible.

1.5 Company Profile

The WEA limited is part of the Wrigley junior group of companies situated all over the world. It is grouped into three the regions namely East Africa, Middle East and India as one region, with Russia and Europe being the other two regions. Having been founded in 1956, WEA has grown to supply the region with confectionary products, upto and including the United Arab Emirates. Because of the increased cost of production arising from the increased energy costs and the need to compete favorably in the region, the company has seen the need to increase it's operational efficiency through the introduction of lean TPM.

The company makes a range of products that include PK™ brands (Menthol, Licorice, Peppermint, Dulce, Winterfrost and Strappleberry), and the Big G™ brands. To make these products the company has invested on 7 PK machines (the machines produce brickpack type of products and the principle of operation is through knock off system), 7 Flex machines, which operate through the flow wrap principle and 5 Big G machines for wrapping these products.

For the pilot study of TPM, effort was on the PK machines since this is where there is a production constraint. The rationale of choosing these lines was mainly because all the products from these lines were for export, and demand was much higher than could be supplied with the equipment in the earlier state of effectiveness as is shown in Fig 1.1 below.

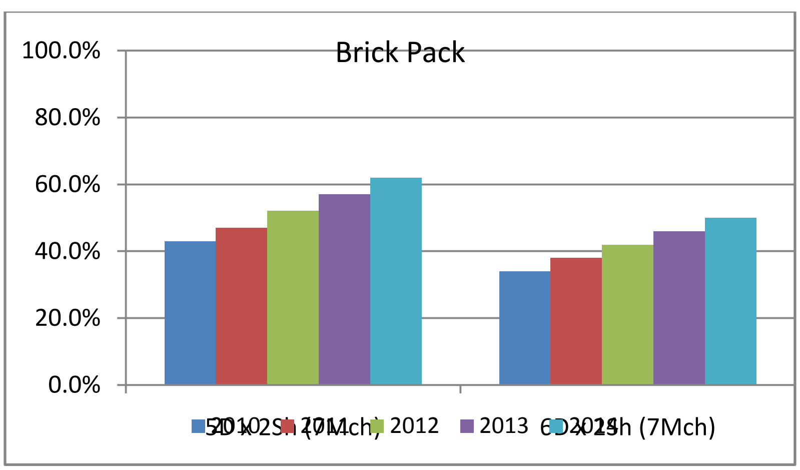


Figure 1.1: Case Fill Rate for PK 1.8 Brick Pack projected over 4 years

Legend:

5D x2Sh (7Mch) - the production is on a five day, two shift schedule with seven machines.

6D x2Sh (7Mch) - the production is on a six days, two shift schedule with seven machines.

$Case\ Fill\ Rate = \frac{Planned\ \ Demand}{Actual\ \ Production}$, The Target is usually 100%.

A miss in Fill rate means a lost sale, hence a loss to the company, which justifies the reason why the TPM pilot is undertaken on PK lines. Other lines have fill rate of over 85%.

CHAPTER TWO

LITERATURE REVIEW

2.1 Lean Manufacturing

Lean manufacturing is an approach in manufacturing that aims to improve product quality and output, reduce costs, and eliminate all possible waste. Total Productive Maintenance (TPM) is used in lean manufacturing in order to help achieve that. Early automobile manufacturing had sparked the creation of lean manufacturing. John Krafcik and Taiichi Ohno had combined the necessary criteria in order to create the Toyota Production system (TPS). This combination includes the skill and knowledge with the standardisation of the work involved in TPS.

Efficiency of the moving assembly line was also emphasized and they also added the concept of teamwork. (Womack et al., 1990). The term "Lean Production System" was introduced by John Krafcik in 1998 in his review of the TPS; while Womack et al. (1990) had popularized the term of "Lean Manufacturing". Regularly, lean manufacturing is always related with benefits such as increased quality, reduced inventories, increased customer satisfaction, increased flexibility, and reduced manufacturing times (Womack and Jones, 1996; Ross and Francis, 2003; Alavi, 2003). It is difficult to convince the managers and employees to think and act in a different way. It is also difficult to manage external relationships with the suppliers and customers. Customers may be unable to place predictable orders, causing the organisation fail in preparing the inventory to meet demand. While on the suppliers' side, they may find it hard to deliver subassemblies or a small quantity of parts (Womack and Jones, 1994).

Lean production optimizes the skills of the workforce, by encouraging continuous improvement activities, by integrating direct and indirect work and giving workers more than one task. Therefore, manufacturing a large variety of products can be carried out with lean production. This also will decrease development time, investment, space, increase the quality and reduce the cost, with less of every input (Dankbaar, 1997).

There is an important goal in lean manufacturing practice which is to become highly responsive to customer demand with the production of high quality products. This goal has to be carried out in the most efficient and economical method which are by reducing various waste in inventory, human effort, manufacturing space, and time to market. To make this happen, elimination of all kind of waste is essential. Waste exists in many forms and can be spotted at any place and in any time of operations. Waste and losses do not add any value to the product and on the contrary it will only consume the resources.

2.2 Continuous Improvement Methods

Three main methods for improvement are discussed and used in this thesis. To ensure comprehension of said methods, a respective explanation is provided.

2.2.1 Deming Cycle

W. E. Deming originally developed the cycle as *"Plan-Do-Check-Act"* (PDCA), but later changed check to study as he found it to better illustrate his intentions with that step (Klefsjo, 2001).

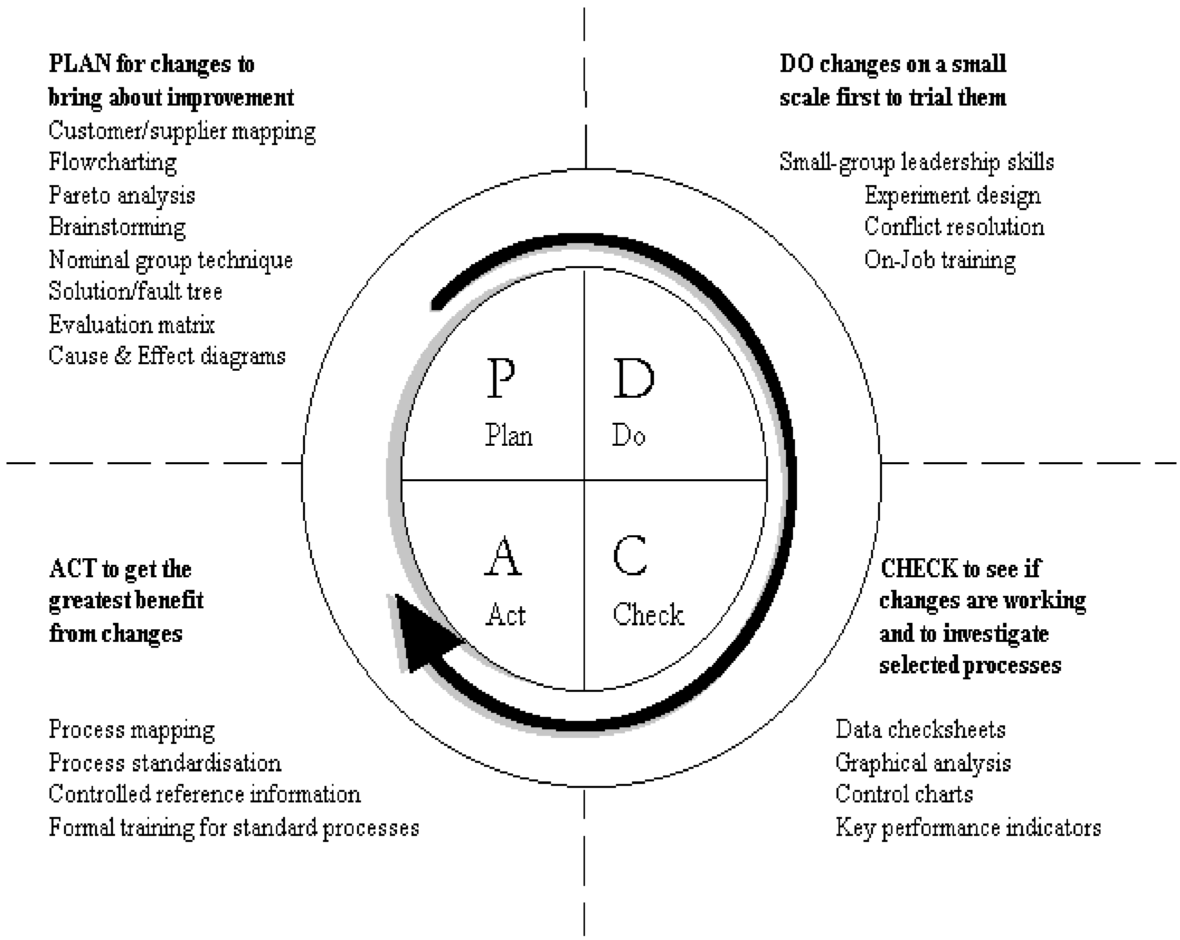


Figure 2.1: PDCA cycle, source Wikipedia(2011)

The cycle is developed as a method to promote the continuous improvement process (CIP). It is divided into four general steps, which are to be taken in order and as the name suggests it is a cycle.

When a problem is initially identified, the source has to be searched. To find potential sources, ready methods such as an Ishikawa diagram, Failure Mode and Effect Analysis (FMEA), or the root cause analysis can be applied. After sorting out the potential candidates and collecting all relevant data, principal objectives need to be established.

This signifies the Plan stage. In the next step, “Do”, the objectives are executed in appropriate scale. To confirm an improvement, the new processes are studied (step three) and compared to the original. Depending on the outcome of the implementation, the fourth step involves acting accordingly. If the sought after results were achieved, the processes need to be standardized, else we learn from the mistakes and the cycle is continued from start again with new insight.

2.2.2 Ishikawa Diagram

The Ishikawa diagram, also called a fishbone diagram due to its appearance, is a diagram developed to find root causes of an identified problem. It is named after its inventor, Kaoru Ishikawa, who first started using the method in 1943 at Kawasaki Steel Works in Japan. It is constructed with the effect, or problem at the right and its possible causes to the left. To begin with, it is not always easy to come up with causes to a problem, which is why in industrial settings, the causes can most often be divided into some of seven major categories to start from (Klefsjo, 2001). These categories are management, man, method, measurement, machine, material and mother nature. An illustration of an Ishikawa diagram can be seen in figure 2.2, to find possible causes to continue analysis with, the fishbone is then branched out further with primary and secondary causes until the root causes are defined.

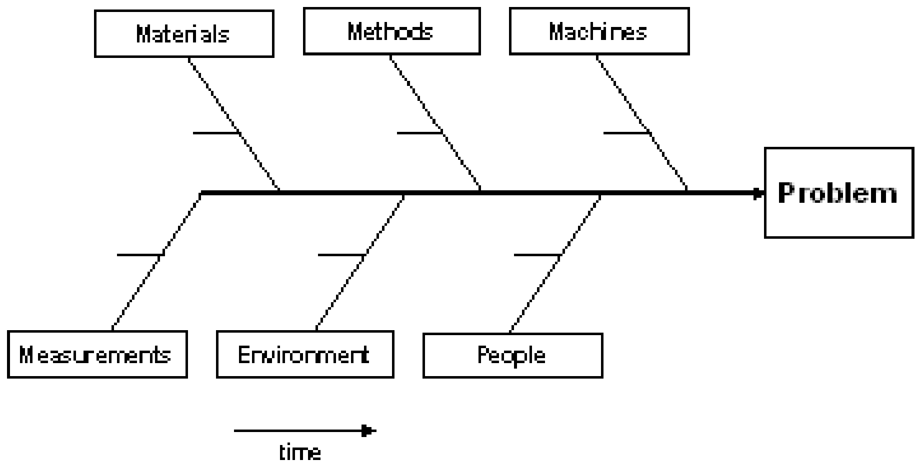


Figure 2.2: Illustration of a basic Ishikawa diagram

Source (http://www.fishbonerootcauseanalysis.com accessed 2011)

2.2.3 The 5 Whys / Root Cause Analysis (RCA)

The 5 Whys is a simple question-asking method aimed at discovering root causes (Borris, 2006). It can result in very specific root causes if combined with an Ishikawa diagram. Despite its simplicity it should not be taken too lightly, as it has to be used properly and without jumping to conclusions or assumptions.

This is a simple example, but it shows how steps should be taken one at a time. Also, this could be expanded to more steps, but in most cases five Whys can be enough to find the root cause.

2.3 Maintenance

Traditionally, the word maintenance has been considered as just a support function or a non-productive act. However, through Wireman's (1991) research, it was estimated that the cost for maintenance for a number of selected companies spiked from $200 billion in 1979 to $600 billion in 1989. This number has identified the importance of maintenance in manufacturing. Further research revealed that corrective maintenance cost is about three times than preventive maintenance (Mobley, 1990). By keeping the role of maintaining the performance of all equipment, improving the efficiency, availability, and safety requirements, maintenance has always been one of the most important things in manufacturing firms (Alsyouf and Al-Najjar, 2003).

Maintenance is the act of preserving the prime condition of a physical system to its proper function. Maintenance activity is often divided into two parts which are Reactive Maintenance (RM) and Preventive Maintenance (PM).

RM deals only when an equipment stops functioning or is in a failure state. However, if this is the only activity assimilated into manufacturing or production, there will be probably a big possibility for a production downtime. It is also important to use this approach because there are possibilities for unplanned equipment failure, frequent problem repetition, and erroneous problem repetition.

On the other hand, PM aims to keep all equipment in mint condition to make production go smoothly without any delays. Through PM, a greater control and confidence in the availability of machinery and equipment can be achieved. PM also provides scheduling of maintenance tasks in conjunction with production, scheduling of maintenance resources to give the most effective use of labour, and avoidance of premature deterioration of machinery and the need for capital investment.

Figure 2.3 shows their relationship in manufacturing. In PM, there are four forms of maintenance practices which are time based, work based, opportunity based, and condition based maintenance. Time based maintenance is the kind of maintenance where equipment is being serviced in a certain period of time, while work based maintenance is an act of maintenance after the production has gone through a certain amount of work hours or production. Opportunity based maintenance is carried out during a break, in holiday, or when there is no production activity. Lastly, condition based maintenance is carried out according to the machine inspection by the person in charge of the designated equipment.

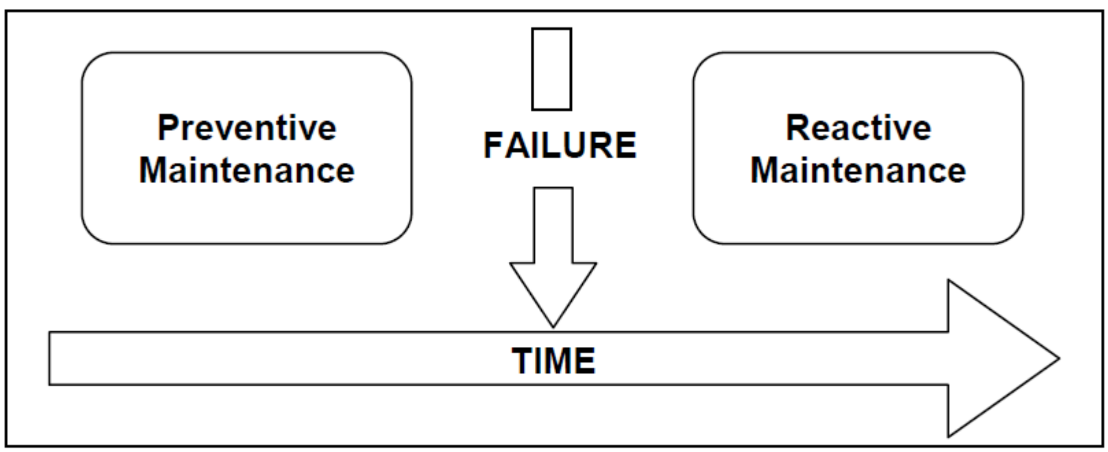


Figure 2.3: Relationship between Preventative Maintenance and Reactive Maintenance according to (Sweetman, 1997)

According to Sweetman (1997), TPM was categorised in maintenance hybrid alongside with Reliability Centred Maintenance (RCM). These two practices were considered as hybrid as they emerged from the combination and application of the maintenance practices before. TPM is the manufacturing improvement method that focuses on eliminating waste and boost productivity with continuous observation on the condition of the equipment involved. Meanwhile, RCM is maintenance practice which only focuses on designated machine over others to increase reliability and optimise financial resource as a system to prevent any kind of loss and aims at building up a company that thoroughly pursues production system improvement.

2.4 TPM – Total Productive Maintenance

The two words that come closest to describing TPM's effects are availability and reliability (Garampon, 2009). Availability refers to the ability of a machine to be in a state to perform a required task under given conditions at a given instant of time over a given time interval, whereas reliability refers to the ability of an apparatus, machine, or system to consistently perform its intended or required function or mission, on demand and without degradation or failure (businessdictionary). TPM has the power to increase effectiveness and create a more rewarding production environment both for management and shop floor staff. This section on TPM starts with outlining its development history, then the pillars it's built on and finally, the impact it has on the applying company.

2.4.1 History and Development

TPM is mainly based on the American methods of Preventive and Productive Maintenance. Seiichi Nakajima, the acknowledged father of TPM, started studies of these methods in 1950 with the intention in mind to perfect and adapt the methods to a Japanese standard. Through years of research and multiple visits to American as well as European companies, he finally developed Total Productive Maintenance and introduced it for the first time in 1971 in Japan (Nakajima, 1995). Another key player in the popularisation of TPM is Edward H. Hartmann, who in 1986 visited Seiichi Nakajima to study a number of applications in the Japanese industry. Hartmann was instantly convinced that this was a vital technology, able to let any company dramatically improve productivity (Hartmann, 2001). In 1987, Hartmann organised the TPM Executive Conference and invited Nakajima to present TPM to the American industry. That venue basically started the crusade of TPM throughout the industries of the world and it has since left its birthplace, the automobile industry, and begun to successfully branch out into various trades like for example semi-conductors, pharmaceuticals, food and the oil industry (Nakajima, 1995).

2.4.2 The Definition of TPM

Total Productive Maintenance is based on a combination of the concepts of Productive Maintenance (PM), Maintenance Prevention (MP) and Maintainability Improvement (MI). This shows where it's coming from and the direction it is supposed to take. It could be explained as being Productive Maintenance with the complete involvement of all parties (Nakajima, 1995).

To understand the principle of TPM and to avoid misinterpretation, a more detailed explanation is necessary. Nakajima uses five main points to define TPM:

- The goal of TPM is the maximisation of overall effectiveness. This serves the purpose of achieving machines running at their intended capacity without unplanned interruptions.
- TPM establishes a system for productive maintenance during the entire lifespan of the equipment. As reason would suggest, a machine tends to break down more towards its later days. Therefore, TPM aims to continuously keep machines in good shape and even facilitate maintenance.

- Also TPM should be realized in all divisions of a company, so that Engineering, Maintenance, Management divisions as well as the workers on the shop floor pull together.
- TPM is designed to promote Productive Maintenance through motivational management in minor, autonomous groups.

2.4.3 TPM Principles

There are five major TPM principles:

- Improving OEE by identifying possible losses of facilities and equipment, and monitoring all of them in case of speed losses, defect losses and down-time losses.
- Making front-line asset care as a part of the job: Front-line asset care (Autonomous Maintenance) is carried out by the operator, with support from the maintenance department. The operator should be able to fulfill at least some maintenance tasks including simple repairs, preventive actions and improvements e.g. corrective actions and proposing ways to prevent drawbacks to recur.

- Having a systematic approach toward maintenance activities; This could be done by:

    - Defining preventive maintenance for each piece of equipment (Time Based Maintenance- TBM)
    - Creating standards for running Condition-Based Maintenance (CBM)
    - Defining maintenance responsibilities for operators and maintenance staff
    - Operators' responsibilities: General care
    - Maintenance staff responsibilities: General breakdown activities, supporting operators by training them, problem diagnosis, devising and assessing

maintenance practice, developing maintenance actions and continuous up grading of equipment

- In order to thoroughly fulfill their duties and perform all their tasks, the employees need to receive continuous and appropriate training to develop their abilities like hand and operational skills, team working and problem solving.
- Early equipment management: Zero maintenance is a concept inducing that failure causes and maintainability of the equipment should be considered during early stages of equipment life span like designing, manufacturing, installation and commissioning.
- Therefore, any problem can be tracked back and eliminated at the above-mentioned
- stages. (Thomas R. Pomorski, 2004; Imants BVBA, 2009)

2.4.4 Departments Involved

TPM involves everyone in the organization from operators to senior management (in the improvement of equipments). TPM must be led by the manufacturing department and encompasses all other departments including Planning, Maintenance, Operations, Design Engineering, Project Engineering, Construction Engineering, Inventory and Stores, Purchasing, Accounting and Finance, Plant and Site Management and Administrative affairs

2.4.5 The Eight Major Losses

TPM strives to increase productivity, through minimizing input while maximising the output in form of better quality, lowered costs, maintaining punctual deliveries and in the meantime increasing morale, safety and health conditions (Nakajima, 1995). This ought to be achieved through eliminating waste weighing down on the overall equipment effectiveness. According to Nakajima there are six major mechanical losses, meanwhile (Reitz, 2008) has expanded it further to include the following eight losses:

1. Failure or Break down loss.
2. Change-over and setup loss – changing production from part A to part B. Time from last produced to first new part.
3. Tool change loss – Switching the processing tool during the production cycle.
4. Start up loss – until steady speed is achieved the warm-up phase slows production.
5. Micro-stops and idling loss – caused by short disturbance, usually less than ten minutes.
6. Speed loss – when operating at low speeds, due to bottlenecks or unresolved issues.
7. Defects and rework loss – time spent producing defects or repairing parts.
8. Shutdown loss – the equivalence to start up losses due to shut down for maintenance, change-over or the like.

It is then the effort of TPM to reduce above losses and in best case eliminate them in total.

2.4.6 Reasons for Machines Break Down

The four most common root causes for machine breakdown are: operator error; programming error (for computer-controlled tools); inadequate maintenance; and environmental causes or a combination of any of these.

Operator errors can be as simple as improperly placing material or using too much force on a tool.

Numeric-control or computer-guided machines may have program bugs. A simple example would be trying to drill too quickly for a particular type of material.

Regular maintenance operations might be neglected, especially in a busy factory. An operator could forget to add lubricants. The operator might not be trained to perform all the necessary steps.

Many environmental conditions can take their toll on equipment: heat, humidity, vibration, or airborne chemicals.

In some instances, these conditions may combine.

2.4.7 How Lean Maintenance Differs from Lean Manufacturing

Lean Manufacturing uses customer orders to pull production from raw materials. It is most successful when the company has a fairly reliable mix of orders coming in at a steady pace.

It is, indeed, possible to set a maintenance schedule so that the schedule pulls the maintenance activity. However, by itself, a schedule cannot prevent unexpected breakdowns. Such breakdowns are equivalent to casting the manufacturing schedule aside because the most important customer has placed a rush order that pre-empts all others.

On the production side, a new customer order may trigger purchasing new raw material. This lead time should be built into the customer’s delivery schedule. However, a machine breakdown that requires an expensive, out-of-stock replacement part immediately harms the schedule. It is uneconomical to stock every possible replacement part to avoid this situation.

The performance parameters of the machines are more readily available than the likelihood of breakdowns for those machines. This type of analysis requires research into the maintenance and repair histories.

Lean Maintenance differs from Lean Manufacturing because the maintenance must be planned, where the manufacturing can be "pulled" by customer orders:

- Machine breakdowns cannot be fitted into a schedule; instead they pre-empt the schedule
- Breakdowns may require ordering replacement parts on a "rush" basis
- Simply scheduling maintenance does not guarantee the absence of breakdowns

There is one similarity: both require careful planning based on the actual capabilities of the machines, whether to produce or to require preventive maintenance.

2.4.8 Overview of the Approach to Lean Maintenance

From the primary concept for Lean Manufacturing to reduce several types of waste, for Lean Maintenance, the equivalent "waste" concepts to be avoided are:

- Wasted Maintenance: maintenance or repair that does not add value, that is, maintenance that does not improve the availability of the machine
- Inefficient Maintenance, even if it does add value
- Sporadic Maintenance, with cycles of low versus frantic activity, it is better to smooth out the schedule

2.4.8.1 Wasted Maintenance

Many of the experts advocating Lean Maintenance point to blindly scheduled maintenance as a waste, especially if it involves replacing expensive components or incurring high labour costs or lengthy downtime.

Note the word “blindly”, however. Their advice is to measure, say, the wear of a part or the viscosity of the lubricant. This is “condition-based maintenance”, which defers maintenance until there truly is a need. Two requirements for condition-based maintenance are: measure the critical indicators that will change before the machine fails; and measure with enough lead time to schedule the maintenance and procure any required parts.

Refer to the repair history as a guide for how long a machine actually did run before a breakdown. This can provide a rough plan for scheduling maintenance. Also use that repair history as a guide to what should be tested in order to implement condition-based maintenance.

2.4.8.2. Inefficient Maintenance

Good planning also ensures that the right parts and tools are available, along with people who have the appropriate skills.

A “Lean” approach would also examine how efficiently the actual work is performed. Are there extra trips back to a storeroom for supplies? Would it help to invest in a maintenance trolley? Would better tools help the employees do a better job? What about training session from the manufacturer?

2.4.8.3 Sporadic Maintenance

Clearly the “frantic hurry” phase of maintenance comes during an unscheduled breakdown. In this situation, the repair person has a higher possibility to make mistakes due to time pressures. This has the least likelihood of having all the necessary tools and parts.

Many maintenance managers aim to keep their maintenance crew scheduled to about an 80% load. This leaves some time for emergency repairs but the crew still is busy throughout the shift.

Another example of sporadic maintenance is a maintenance blitz. Beyond the obvious problems of overloading the maintenance team’s schedule, this blitz also means that skills may have become rusty in the intervening time.

2.4.9 The Guiding Precepts for Lean Maintenance

The following precepts help guide the planning for Lean Maintenance:

Each machine, or at least each model of machine, has its own maintenance needs. In the best maintenance environments, a significant portion of the work schedule involves training and mentoring the operators to take on regular maintenance work. (Oskar Olofsson, 2011)

Each operator should perform regular inspections and maintenance on their machines. These people should know the machines well, and can take part in minor maintenance. A company should invest in training them for the tasks.

One example of making maintenance easy is an automobile's dipstick: bright yellow handle like the other two things the driver is encouraged to check; only one place to put it in; has markings for "too low", "in range" and "overfull". For motors for example a heat stamp can be stuck onto the bearing sides of the motor to act as an indicator of possible overheating of the motor and thus take intervening steps to avoid failure Post a schedule for the maintenance activities, with boxes for the employee to initial and date, beside the instruction sheet.

Train the operators how to write work orders or how to report trouble verbally. This helps the repair people, and their schedulers, know what is wrong or where to start looking. If less than 10% of maintenance activity is "repairs", you might ease back on the preventive measures. If it is more than 20%, put more work into preventing the worst breakdown and repair situations. If your maintenance people can get everything done in the regular day shift, you're doing well.

Without a computerized maintenance management system (CMMS), it becomes difficult to log, track, and report on patterns of maintenance and repair activity. What do you use to determine the right frequency for preventive maintenance? How do you determine how many spare parts you need to keep a machine going without making emergency orders to your supplier?

2.4.9.1 Requirements for Every Lean Maintenance Program

Every Lean Maintenance Program needs:

- Information
- Goals

- Implementation
- Evaluation

Here are more details on these requirements:

2.4.9.2 Information

This may be the largest hurdle in planning a Lean Maintenance program. To address the needs of the factory, an inventory of each machine will be needed. For each, we need to know:

- The manufacturer’s recommended maintenance schedule
- History of actual maintenance activities
- History of past breakdowns and repairs
- Knowledge of the key components to test for “condition-based” maintenance planning

All this information includes both labour and parts requirements.

2.4.9.3 Goals

The ultimate goal for Lean Maintenance is to minimize the cost of performing preventive maintenance while also minimizing the risk of an unscheduled breakdown. The cost of maintaining one machine is usually much less than the cost of its breakdown, because that might shut down operations altogether.

The usual goals for scheduling the maintenance crew are:

- Time spent on scheduled maintenance should be gradually improved to 80% of and allow 20% for unscheduled repairs or maintenance that takes longer than scheduled.

- Gradually increase the time spent training production operators to do routine maintenance, and in monitoring their efforts; then increase the percentage for the most highly skilled maintenance work
- Expect that 90% of the activities, or work orders, are for maintenance

The goals for containing costs in spare-parts inventory are:

- Should not run out of critical replacement parts
- Time standard replacement parts are in inventory be gradually be decreased.

Critical replacement parts are those that are necessary for a machine to operate, and have a long lead time for purchasing. These are too expensive to keep in stock, but highly valuable in that they are needed to keep the machine running.

On the other hand, the Lean Manufacturing approach is to procure raw materials “just in time” for production. The same principle should apply to replacement parts: purchase them “just in time” for the next maintenance activity, rather than just after the last one. This drives the need for accurate historical information on the intervals between failures of a critical replacement part.

2.4.9.4 Implementation

To implement Lean TPM, it is required to make a separate plan for maintaining each model of machine. You may need to engage experts to analyze the causes of each machine’s past failures, and the values of the components to test for “condition-based” maintenance planning.

Part of the process is to meticulously log the maintenance and repair history. Applying root-cause analysis to every failure (or every need for maintenance under condition-based maintenance) should lead to important clues for extending the useful life of the machine. As an example: let's say that lubricating oil begins to break down, triggering an oil change as maintenance. Why is the oil breaking down? Let's say it is dust getting past a filter. The long-term solution is either to replace the filter more frequently or to find another way to prevent dust from getting there (by adding a fan to blow the particulates in a different direction or by adding a filter to trap dust where material is being cut).

2.4.9.5 Evaluation

As you acquire data, you need to evaluate the effectiveness of the Lean Maintenance program, by comparing various metrics between the "before" and "after" time periods:

- Hours of unscheduled downtime per month
- Cost of unscheduled downtime per month, as lost productivity
- Labor cost of planning and scheduling maintenance activities
- Labor cost of testing
- Labor cost of scheduled maintenance
- Labor cost of unscheduled repairs
- Cost of materials for testing, maintenance and repairs

Most factories see a significant reduction in overall cost, because unscheduled repairs are extremely expensive due to lost productivity.

2.4.10 The Eight Pillars of TPM

The principles allowing TPM to eliminate losses and maximise productivity are described in the TPM House (figure 2.3). It is based on the eight pillars of TPM, defined by the Japan Institute of Plant Maintenance (JIPM)(JIPM Solutions Co., Ltd., 2009).

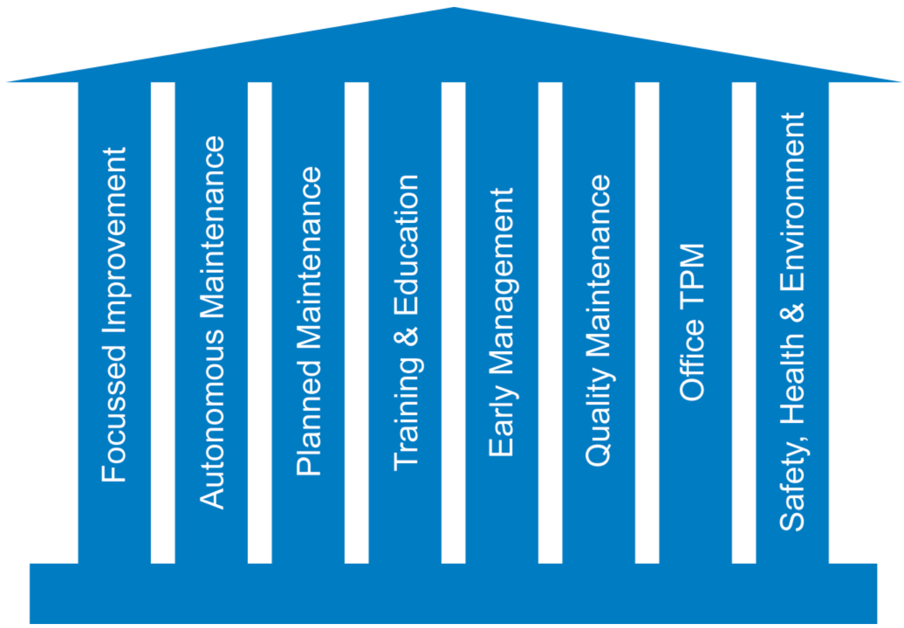


Figure 2.4: The TPM House, based on the eight pillars of TPM defined by JIPM.

- **5S**

This method tries to make work environment well organized, clean and efficient in order to increase productivity and maintenance quality. 5S like other improvement techniques requires both employees' involvement and management commitment. 5S must be separately tailored to each department and needs to be implemented gradually to reach the best results. The most common pitfall in 5S implementation is that companies fail to teach 5S to the employees in the beginning. Top management and steering group members should have the practical knowledge of 5S implementation. A thorough review of 5S, the principles of 5S implementation, the team working concepts and the role of management are important subjects that should be presented. Practical exercises or some pilot projects must be included in the training program as well.

If top management and steering group start 5S from their office, they will have the chance to get more familiar with the issues that should be addressed during implementation of 5S. Another benefit is that it will show commitment of the management toward a company-wide 5S program (EMS Consulting Group, 2003).

The following S's constitute 5S:

● Sort (Seiri): Put everything right in order. Get rid of not needed things

The aim is organization. This process requires employees to remove all items, which are not needed for work. In the beginning, it seems very difficult for employees to get rid of such items .They get used to keep things for just in case purposes. Red tagging is one solution that helps employees find out the frequency of using items and their usefulness.

Then employees can decide to return, store elsewhere, sell, give away or throw away the items. The optimum time for red tagging is one or two days.

Benefits of red tagging:

- Problems, disturbances and confusions are reduced
- Improves communication among the employees
- Product quality is increased
- Enhances productivity (EMS Consulting Group, 2003; Siliconfareast.com, 2000; Six Sigma community, 2000)

● Set in order (Seiton) - Proper Arrangement: Organize things in such a way that they are easily at your disposal.

The goal is maximizing efficiency. The effect of the first two S's will be strengthened when they are implemented together. By putting everything in the right place and labeling, everyone can find what he/she needs in the area, thus, the result is less human energy and time consumed to find things and less inventory. (EMS Consulting Group, 2003; Siliconfareast.com, 2000)

● Shine (Seiso): Clean and polish things regularly in the workshop

If this work becomes a daily habit, tools could be kept in top condition and they will be ready for use at any time. The goal is having a bright place in which everyone enjoys working. Reviewing the previous S's and finding sources of dirt, litter and their elimination are other results. (EMS Consulting Group, 2003; Siliconfareast.com, 2000)

● Standardize (Seiketsu): Standardize the way of maintaining cleanliness.

This part is a simultaneous work with the first 3 steps in order to check and plan continuous improvements. It consists of defining some procedures and daily check lists. The purpose of checklists is to monitor whether 5S requirements are daily met. Standardization integrates Sort, Set in order and Shine into a whole. (EMS Consulting Group, 2003; Siliconfareast.com, 2000)

● Sustain (Shitsuke) – it also means commitment: Be enthusiastic about what you have done and maintain it. All employees in the organization should be motivated to follow the rules of 5S. This could be achieved by sharing values. Shared values are gained by coaching and employees participation. Achievements in 5S cannot be kept sustainable by any authoritarian activity and penalties imposed on the employees. (EMS Consulting Group, 2003; Siliconfareast.com, 2000)

● AUTONOMOUS MAINTENANCE (JISHU HOZEN)

This pillar stresses on performing simple maintenance tasks by the operators- Activities like lubrication, tightening of loosened bolts, visual inspection, cleaning- This will help more experienced maintenance staff to take care of more important maintenance tasks, which create more added values. The aim is keeping machines in good condition.

Benefits:

- Elimination of root causes of many defects

- Operators' flexibility to work and maintain other pieces of equipment

- Equipment's function with the least shot-downs

- Oil consumption reduction

- Process time reduction (Venkatesh, 2009)

● FOCUSED IMPROVEMENT (KOBETSU KAIZEN)

This pillar states that small improvements are more effective than just one big improvement if they are continuous and encourage all employees to be involved. The pillar aims to reduce losses that can lower efficiency. Kaizen is applicable in both production and administrative areas.

Kaizen Emphasis

- Finding the ways of achieving zero loss in all activities

- Elimination of losses by means of using results of PM analysis widely

- Commitment toward cost reduction for resources

- OEE and OPE improvements

Kaizen strives to make substantial improvements in productivity in forms of efficient equipment, operators and material in addition to energy utilization. Kaizen tries to eliminate six losses, which are described below:

- Equipment failure: Causes production downtime. By cooperation between the maintenance and production departments, equipment failures can be prevented by using, predictive and preventive maintenance, developing operation practices and design changes. Root Cause Failure Analysis (RCFA) is a technique that is used after a failure occurrence. RCFA aims to eliminate failures and mitigate their impact.
- Time for Setup and adjustments: It includes the time for the warming-up of a machine after its changing over.
- Small stops: These stops last between 5-10 minutes and include minor adjustments and cleaning.
- Speed losses: Several items may result in a machine working at a lower speed than what is determined before. These items can be no matching between machine and its application, inefficiency of the operator, unsuitable machine wear-parts and substandard materials.
- Losses during warming-up: This includes losses in a quality point of view for products produced during the time of warming-up. (J. Venkatesh, Reliabilityweb.com, 2009)

● PLANNED MAINTENANCE (KEIKAKU HOZEN)

In order to reach customer satisfaction, the products must be defect free. Defect free product requires machinery without trouble.

Planned maintenance focuses on reducing spares inventory, optimum maintenance cost, higher reliability and maintainability of machines, achieving and sustaining machine availability. The role of an information system is undeniable therefore; an information management system like Computerized Maintenance Management System (CMMS) should be established. The information system collects data relevant to time and parts of equipments for maintenance planning. (J. Venkatesh, Reliabilityweb.com, 2009)

Planned maintenance is comprised of four parts:

- ***Breakdown Maintenance:*** This type is based on the philosophy which says:" let it fail then fix it" and is applicable where failure does not impose any significant effect on production and any cost except the cost of repair.
- ***Preventive Maintenance*****:** Maintenance actions like inspection, lubrication, cleaning, tightening to prevent machines from failures through periodic inspection and recognition of equipment condition. It is divided into two parts:
- ***Periodic Maintenance (Time Based Maintenance - TBM):*** Periodic inspection, servicing, cleaning, lubrication, adjustments and replacing worn out parts to prevent sudden failures
- ***Predictive Maintenance: (Condition Based Maintenance - CBM):*** After diagnosing the current condition of critical parts of equipment, optimum remaining of their lifetime should be determined .It uses condition monitoring through surveillance system. Some of the tests are: Vibration, oil analysis, Thermograph test, sound test, Ultrasonic test, performance test.

- **Corrective Maintenance:** To increase the reliability, productivity and improving maintainability, root causes of equipment failures should be removed. Root causes may originate from the design, manufacturing, installation or external factors.
- **Maintenance Prevention:** After checking current equipments and data gathering about their weaknesses, failure records and safety, new equipments are re-designed and installed. Easier maintenance, failure prevention, better safety, defects prevention and ease of manufacturing are some consequences. (J. Venkatesh , 2009).

● QUALITY MAINTENANCE (HINSHITSU HOZEN)

Through defect-free manufacturing, higher quality and customer satisfaction are accessible respectively.

This pillar focuses on the equipment parts, which are critical for product quality. The trend of quality maintenance starts from elimination of current quality problems, which are reactive measures, and in form of Quality Control. The trend is continued with consideration of potential quality problems, which results in proactive measures and in form of Quality Assurance. Quality Maintenance focuses on prevention of defects at source, in-line detection and segregation of defects, effective implementation of Operator Quality Assurance and Poka-yoke. (J. Venkatesh, Reliabilityweb.com, 2009)

● TRAINING AND EDUCATION

The aim of this pillar is making employees multi-skilled with high eagerness to come to work and fulfill their duties completely and independently. The knowledge and skills of the employees should be improved; also, the training environment must be in such a way that employees want to learn by themselves based on their felt needs as well as making work more enjoyable. It is not sufficient that knowledge of the employees is limited to "Know-How". They should also be aware of "Know-Why" to recognize the root causes of problems. All employees should gain knowledge and skills relevant to their duties.

Basically employees are classified in 4 categories in skills point of view: Do not know, know the theory but cannot do, can do but cannot transfer their knowledge, can do and teach.

- **EARLY MANAGEMENT**

To establish the system to launch the production of new product & new equipment in a minimum run up time.

- **OFFICE TPM**

Office TPM should be implemented in administrative and logistic parts in order to increase efficiency and productivity in addition to identification of losses and elimination. Logistics and support functions have significant impact on the production and manufacturing. The effectiveness and productivity of a production system can be increased by improving any activity that supports the production. Many administration losses are unmeasured and remain hidden.

Some important kinds of office losses:

- Administrative process losses
- Office equipment break-downs
- Communication channels' cut-offs
- Accuracy loss
- Idle loss

- Communication loss
- Customer complaints about logistics
- Expenses due to emergency dispatches and purchases
- Time spent on information retrieval
- Correct on-line stock status is not available (J. Venkatesh, Reliabilityweb.com, 2009)

Benefits of Office TPM

- Better plant performance by involvement of the employees in supportive activities
- Clean and tidy work environment
- Reduced labor
- More creativity and productivity of personnel
- Less equipment breakdowns
- Reduction of administrative and overhead costs namely non-production and noncapital equipment
- Less inventory of documents and files
- Reduced repetitive work
- Higher efficiency through better utilization and organization of the office
- Reduced inventory in supply chain
- Reduction of customer complains about logistics (Pomorski, 2004; J. Venkatesh, Plant Maintenance Resource Center, 2007)

● SAFETY, HEALTH AND ENVIRONMENT

This pillar plays an important role in all of the other pillars. TPM program is not meaningful without focusing on health and environmental issues because some policies of TPM are Equipment reliability, human error prevention, eliminating accidents and pollutions. The objectives of this pillar are:

- Zero accidents
- Zero injuries
- Zero environmental impact

Unreliable and faulty equipment is a threat to the operator and the environment. Autonomous maintenance helps the operator get more familiar with the equipment, its potential hazards, and ways of safe and effective working. In addition, TPM will increase commitment of the operators towards health and environmental issues.

With using 5S techniques like cleaning and setting the work place (Seiton and Seiso), the risks of accidents will be reduced. (Thomas R. Pomorski, 2004; J. Venkatesh, Plant Maintenance Resource Center, 2007)

Other Pillars Like: Tools Management - To increase the availability of Equipment by reducing Tool Resetting Time, To reduce Tool Consumption Cost & to increase the tool life.

TPM success measurement - A set of performance metrics which is considered to fit well in a lean manufacturing/TPM environment is overall equipment effectiveness, or OEE. For advanced TPM world class practitioners, the OEE cannot be converted to costs using Target Costing Management (TCM) OEE measurements are used as a guide to the potential improvement that can be made to equipment and by identifying which of the 6 losses is the greater, then the techniques applicable to that type of loss. Consistent application of the applicable improvement techniques to the sources of major losses will positively impact the performance of that equipment.

Using a criticality analysis across the factory should identify which equipments should be improved first, also to gain the quickest overall factory performance. The use of Cost Deployment is quite rare, but can be very useful in identifying the priority for selective TPM deployment

2.4.11 Categorization of Machine Idle Time

Machine idle time is characterized into the following groups.

- Statutory idle time – this includes state holidays, company holidays or times when there are no volumes to produced and thus are included in the yearly machine calendar.
- Planned idle time - this include maintenance, machine clean outs, meetings and/or trainings, sensory and/or trials and breaks.
- Un-planned idle time – include breakdowns, short stops and other external stops like lack of power, operator, etc.

2.5 Overall Equipment Effectiveness (OEE)

Overall equipment effectiveness allows visualization of machine-related losses. This might seem easy at first, because with a machine theoretically able to run 24 hours a day and 365 days each year we get an amount of products representing the maximum capacity. Due to holidays and managerial decisions as not working on most weekends and so on, the maximum capacity is mostly never exploited (Reitz, 2008).

Therefore, the quotient of the actual numbers of produced units put up against the maximum capacity yields the effectiveness of the equipment during the chosen time period; the overall equipment effectiveness(Reitz, 2008). It is important to keep in mind that the OEE is only a measurement of mechanical components. Therefore all losses, even those influenced by human aspects, such as change-overs, should be considered as the only interest in the OEE is to see whether the equipment runs according to its capability (Reitz, 2008). The basic requirement for a correct calculation of the OEE is precise data. All mechanical losses need to be recorded for best results.

2.5.1 General Model of OEE Calculation

The formula for the calculation of OEE was developed by JIPM and is a factor from three different rates; namely availability, performance and quality.

OEE = AR x PR x QR x 100%..2.1

Where,

AR is the availability rate

PR - the performance rate

QR - Quality rate.

$$AR = \frac{AT}{PPT} = \frac{PPT - DT}{PPT} \quad \ldots\ldots 2.2$$

AT - is the Total available time for production = PPT-DT

PPT - Planned production time

DT - Downtime loss

$$\boldsymbol{PR} = \frac{ICT \times PP}{AT} \quad \ldots\ldots 2.3$$

Where; ICT - Ideal cycle time, is the quickest time at which the machine could produce a single part.

PP - Total parts produced inclusive of defective parts

$$QR = \frac{GP}{PP} \quad \text{..} 2.4$$

Where; GP - Good parts produced.

2.6 Reducing Breakdowns the TPM Way

There are four phases of implementing lean TPM for breakdown reduction, this are:

1. Stabilize Failure Intervals
2. Improve Equipment Productivity
3. Maintenance Excellence
4. Predict Equipment Life

These four phases will be applied in the project implementation phase to attain results as well as develop a model that can be replicated to other similar industries.

2.7 Previous Studies

Many previous studies were conducted in order to see if TPM implementation does make a change in companies. Some of the studies were successful and there are some of them do not achieve the maximum potential of a TPM should have. However, all of the researchers use different ways to portray their study on these companies. This is just because all of these companies have their own company background and profile, so they would implement TPM suited for their company best. Finally, according to these studies, success factors alongside with its implementation issues or difficulties can be identified. These identified cause and factors can be used in further research or improvements.

1. Ireland and Dale (2001) had carried out a study on three different companies to determine the effectiveness of TPM implementation in real situations. The three companies consist of a UK plant with a wide range of rubber products (Company A), a packaging company (Company B), and motorized vehicles manufacturing company (Company C). These companies were selected due to differences in their background such as number of employers, machinery used, organisational structure, and strategic objectives. These differences will affect the TPM method of implementation in each company.

2. Chan, et. al. (2005) also studied an electronic manufacturing company to see whether TPM implementation is worth a move for any company. The general aim of this project is to know effectiveness and difficulties in TPM implementation.

3. Eti et. al (2004) only focuses on how manufacturing industries in Nigeria can implement TPM by researching on their problems and shortcomings with the old traditional ways of maintenance. This way, the manufacturing industries can used this recommendation and suggestion as prerequisites before implementing TPM in their company.

4. Friedli et al. (2010) recorded that a pharmaceutical manufacturing company increase their OEE from 36% in 2004 to 51% in 2009. In Friedli et al. (2010) case study, the main problem was the result of direct stoppage and breakdowns in the production. This unplanned maintenance work proves that TPM implementation

was not in its full potential as the autonomous maintenance activity should reduce on this kind of losses.

5. Daniel Ottosson(2009), studied the initiation of TPM in a pilot line of German automobile company. The study showed remarkable improvements in OEE and the productivity per man hour.

2.8 Summary

The literature review has shown that lean manufacturing obviously benefits manufacturer that properly implement lean manufacturing application. Lean manufacturing is seen as an operation that focused on reducing waste and losses in a manufacturing in order to maximize the revenue.

The next chapters will link machine breakdown levels vis-a-vis energy consumption and produce a relationship using lean TPM methodologies.

CHAPTER THREE

METHODOLOGY

3.1 Gum Manufacturing Process Map For PK 1.8g Pellets

Described below in figure 3.1 is the gum manufacturing process for pellets 1.8g as used in Wrigley East Africa.

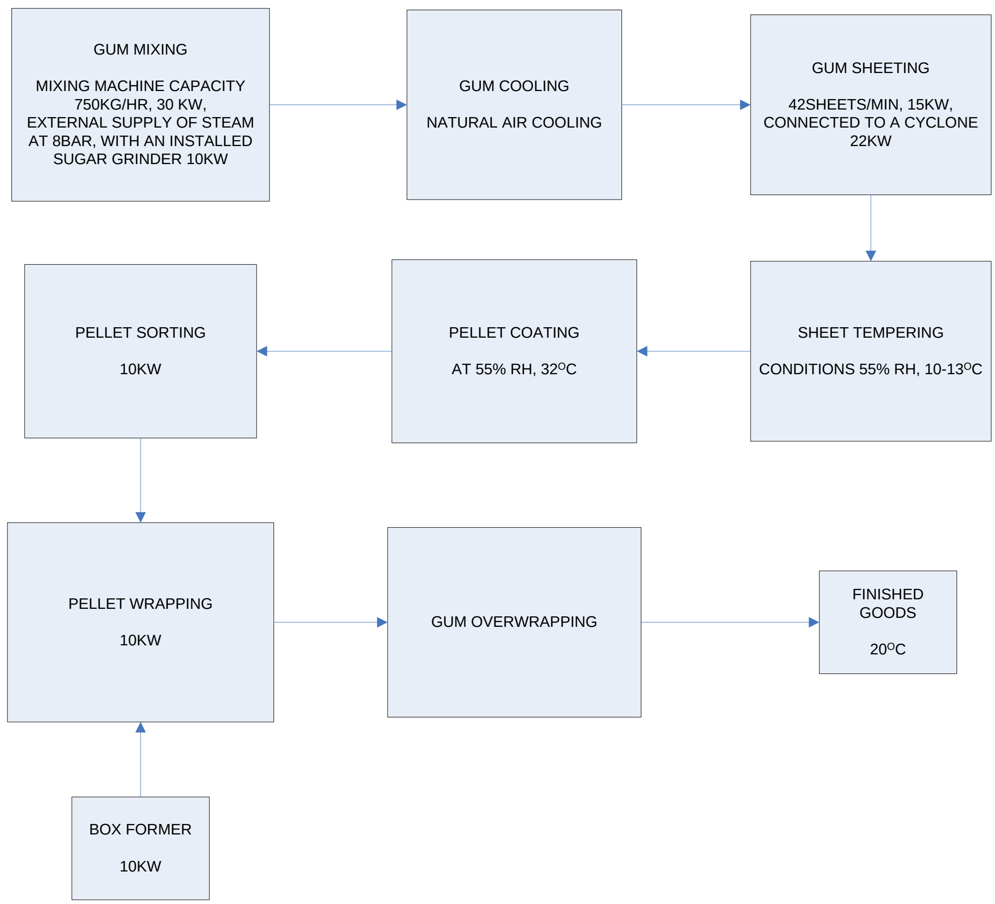


Figure 3.1: Gum Manufacture Process

3.1.1 Gum Mixing and Cooling

In the gum mixing process, the gum base and sugar ground to more than 95% fineness are mixed together in a rotary mixer that has steam connection to supply the requisite heat necessary to ensure proper mixing of the ingredients. Once the requisite consistency has been attained the gum is offloaded into a cooling trolley, where they are cut into loaves of 10kg each and allowed to cool in ambient conditions.

3.1.2 Gum Sheeting

The now cold gum loaves are transported to sheeting area. They are now fed into the sheeting machine hopper, which delivers them into the gum extruder that extrudes the gum as sheet. The even sheet is reduced to the required thickness through a set of reduction rollers before it is formed into a sheet of barely severed pellets through scoring rollers and delivered to cooling trays, where each tray takes four sheets.

The sheeting machine has a Miyakojima gearbox for the extruder and is powered by a 15KW motor. The machine is further fitted to a cyclone of 22KW, for the purpose of extracting sheeting sugar and maintain sugar dust at permissible levels as per OSHA 22000 requirements.

3.1.3 Sheet Tempering

The sheeted gum is then taken to the tempering room. The tempering room is maintained at 55% Relative humidity and 10-13^{o}C by a bryair dehumidifier and a 110KW chiller. The gum is left here for upto 12 hours until it passes the break-test. The break-test shows that the gum is fully tempered and is ready for coating.

3.1.4 Pellet Coating

The coating process is undertaken in a coating machine called the Ipial™, and supplies a mixture of ingredients that include the flavor and coating sugar. The control parameters are the temperature at 33^{o}C, and relative humidity of 50%. To maintain temperature, a process heat exchanger connected to steam supply is installed with a air handling unit to supply the drum. The flow of coating syrup is through a metering system and sprayed into the pellets. The average cycle time of each batch of pellets is 4.5 hours.

3.1.5 Pellet Sorting

Once the pellets are coated they are then delivered to the sorting machine that ensures that only the pellets that meet specifications are allowed to move to the next process. The rejects from the machine are taken back to mixing as scrap for rework.

3.1.6 Pellet Wrapping and Overwrapping

The product from sorting is now taken to the PK machine that wraps the product in brick pack form. The machine works on the knock off principle, where the product from the hopper are fed through the delivery chute to the band drum assembly, through the heater gun assembly, glue pot assembly and finally to the box off. The finished product is then overwrapped in a PMC overwrap machine in trays of twenty per carton and taken to the finished goods store for shipment.

The choice of the selection of PK 1.8g line as a lean-TPM study was guided by the fact that there is a production constraint upstream at pellet wrapping, therefore any breakdown at that stage leads to line stoppage as well as increased energy consumption with no products outflow at the end of the line. This is clear from fig 1.1 showing the case fill rate at below 60%, against a target of over 85%. The OEE as shown in fig 4.1 is below 65%, showing that the downtime losses are high.

3.2. Data Collection

Data on equipment history, Spare parts, operator skills, mechanic skills and the Original equipment manufacturer data were sought and are contained in the appendix. During this period the initial conditions were noted, so that they could be compared with the final conditions. An information database as well as reporting system was set up.

A data collection sheet is attached as appendix iv.

A database for collecting all the machine breakdown and productivity was created whose menu is showed in the plate below.

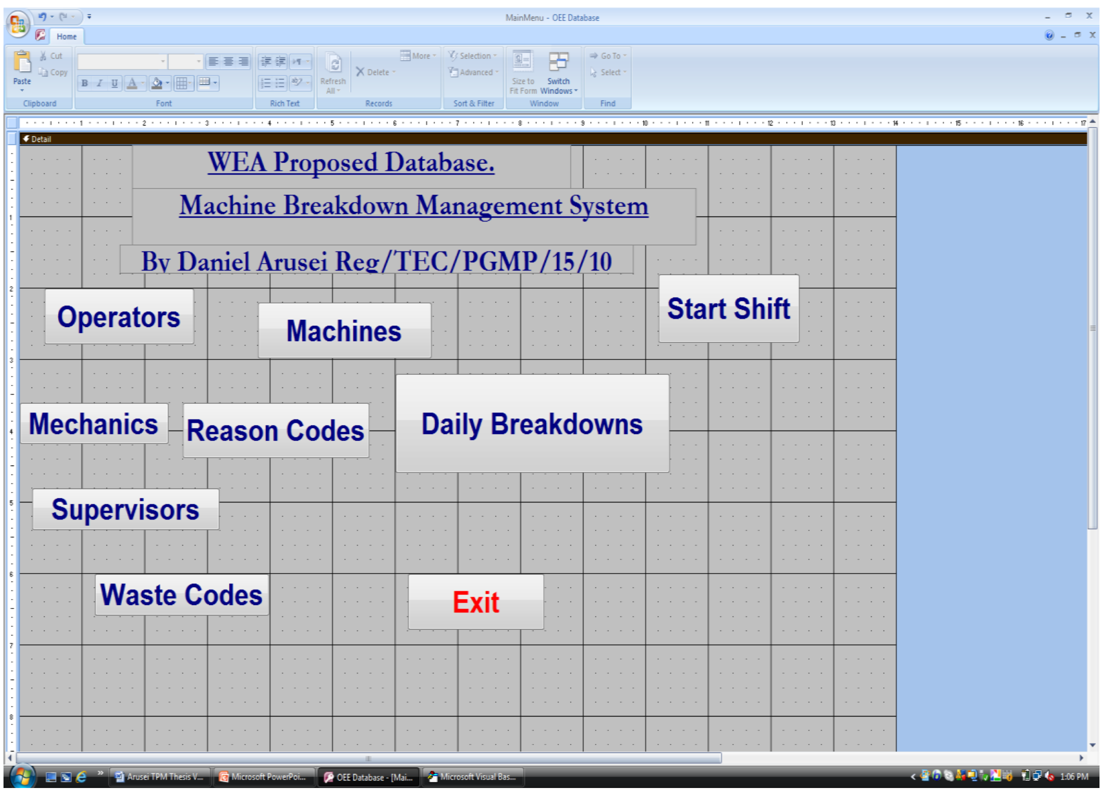


Plate 3.1: Menu for the Breakdowns Database

The database was created in Microsoft access database and has the following tables:

i. A table of all the operators

ii. A table of machine and their codes

iii. A table of all mechanics

iv. A table of all shift supervisors

The reason codes describe any stoppage during production time that has to be conveniently logged into the production sheet. The stoppage could be due to a breakdown in clutch assembly and therefore has to be coded as MB10, with the respective mechanic countersigning on the time into the log sheet. Other reason codes are provided in appendix vi.

The waste codes which describe the amount of product in kilograms that go to waste either during manufacturing or repair process, were incorporated to allow for computation of the quality rate, which is a component in OEE calculation.

Once the log sheet had been signed out for the shift by the shift supervisor it was send to the production clerk who logged all the data into the database using the button, daily breakdowns in plate 3.1 to provide an interface shown below in plate 3.2.

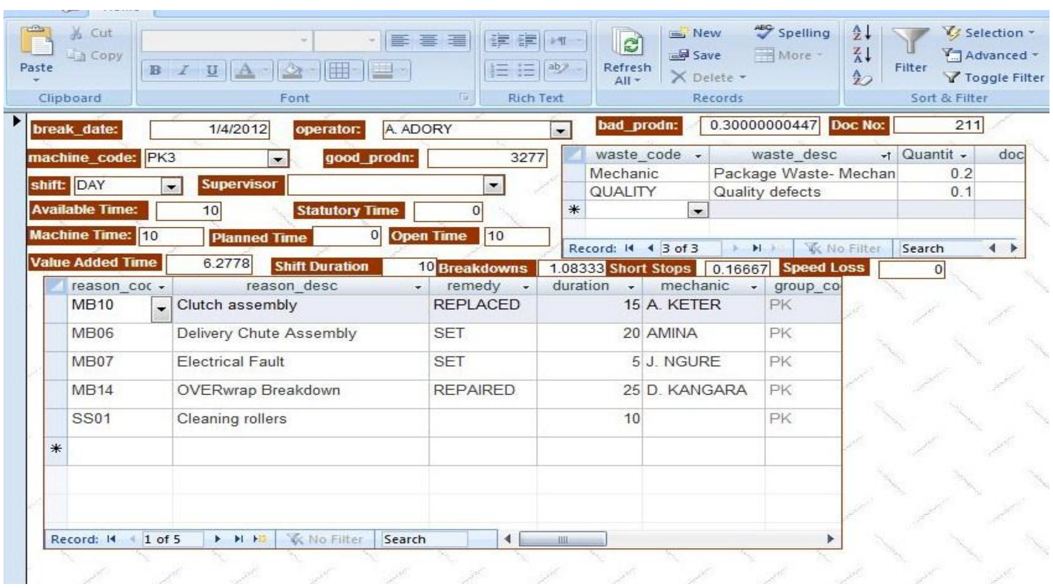


Plate 3.2: User Interface for Data Entry

3.3. Materials and Equipment

The machine used for the pilot study was PK 3, and in order to conduct a time study on the machine, three mechanical counters were used to ascertain the standard time for each of the short stops experienced in the PK machine as shown in table 3.1

Table 3.1: Short Stops Standard Time

Short Stops				
Reason_code	**reason_desc**	**reason_type**	**report_group**	**std_time**
SS01	Cleaning rollers	UNPLANNED DOWNTIME	SHORT STOP	1
SS02	Paper Jam	UNPLANNED DOWNTIME	SHORT STOP	1
SS03	Paper Jam in chute	UNPLANNED DOWNTIME	SHORT STOP	0.25
SS04	Jointed Paper Wax	UNPLANNED DOWNTIME	SHORT STOP	1
SS05	Pellet Jam in Tipping Drum	UNPLANNED DOWNTIME	SHORT STOP	0.3333
SS06	Unwind jammed Prelam foil	UNPLANNED DOWNTIME	SHORT STOP	2
SS07	Smashing	UNPLANNED DOWNTIME	SHORT STOP	1

Electrical power meters were also fitted on the product line to allow for measurement of usage of energy along the product line. During the first step of implementation on the restoration of basic conditions, food grade cleaning materials, equipment to reach hard to access areas and lubricants were used.

Fast moving Spare parts were identified during the restoration of basic machine conditions and arranged in a rack A in the spare parts store for easy retrieval. The parts were also categorized per assembly and modular parts developed. The catalogue of confusing parts was also developed, all these are included in appendix vii.

3.4 Adaptation of Theories

In a gradual process, the theories and methods from both literature study and workshop were adapted to the circumstances in the pilot lines and one after the other introduced into production.

However, due to the short time span of a master thesis, not all methods and steps were adapted in this study, as the introduction of TPM is a process over several years. The focus is set on creating a transparent production with a solid stepping stone to start an overall TPM-conversion.

3.5 Development of the Productivity Model

The main purpose of the model is to understand the process and to give codes to the various losses, for the purpose of developing checklists for data collection.

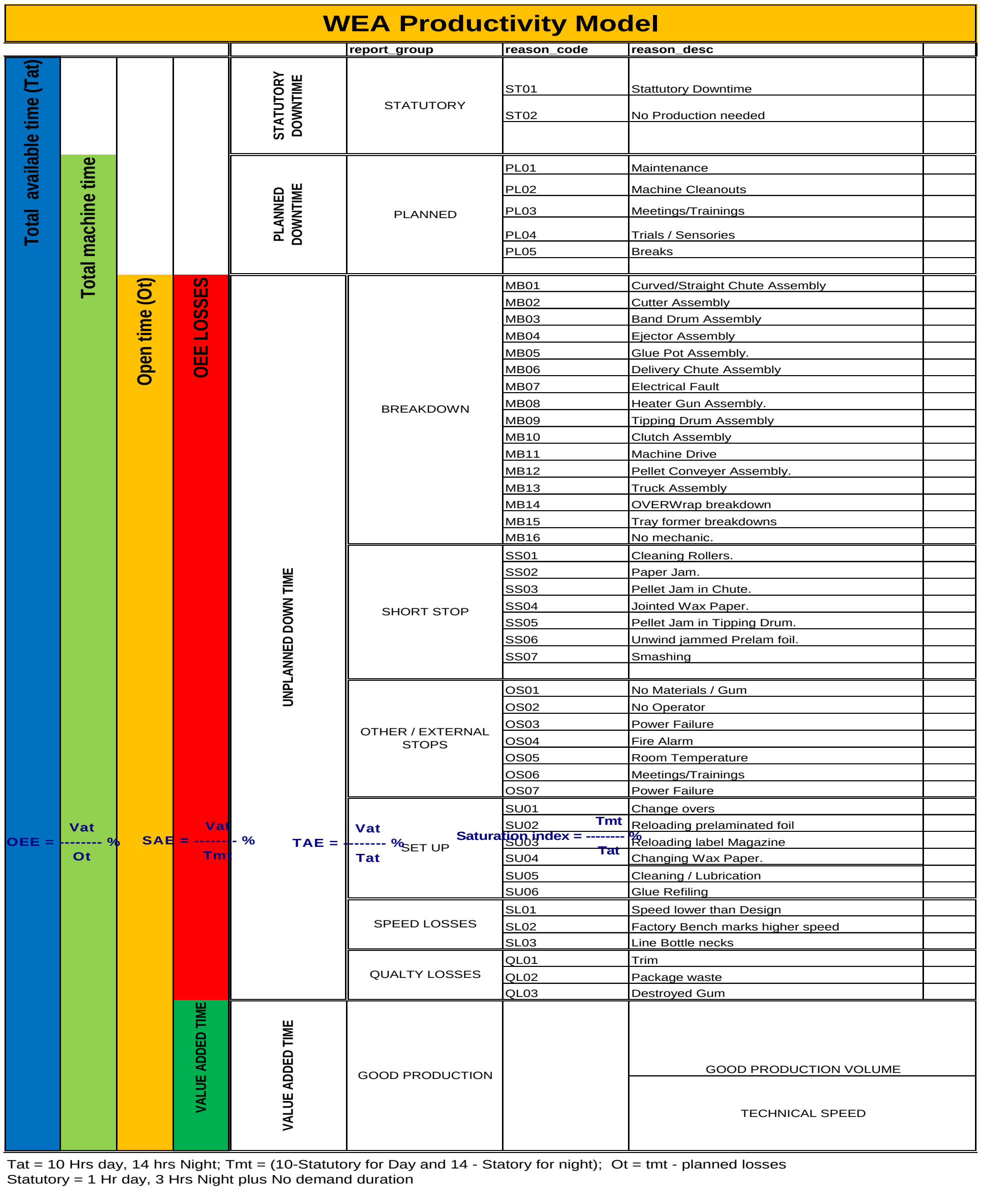


Figure 3.2: PK 1.8 Productivity Model

Figure 3.2 shows the productivity model for which the performance characteristics of the PK line were based. It picks data from the database as per the codes described in plate 3.2.

In order to represent OEE properly, report groups were developed as described below.

1. Total available time (Tat)

This refers to the total clock hours available in a shift. For example the day shift in WEA runs from 0800hrs to 1800hrs, giving Tat of 10 hours, whereas night shift starts at 1800hrs to 0800hrs giving Tat of 14 hours. In this case the Total available time is equivalent to total machine time (Tmt), this is because there is no break between shifts.

2. Open time (Ot)

This is the total time available for production and is normally expressed as Ot=Tmt-planned losses.

3. Statutory Time.

This includes all gazetted holidays, planned offs and scheduled shutdowns.

4. Planned downtime

These are times planned into the production schedule, for example meetings, planned maintenance, machine cleanouts, breaks and trials.

5. Unplanned downtimes.

These include breakdowns, short stops, external stops (like power outages, Fire incidents, sick offs and others), Set up times necessitated by product change, speed losses and quality losses.

6. Value added time.

This time constitutes the total open time less planned and unplanned downtimes.

3.5.1 Performance Metrics

1. OEE = Vat ÷ Ot ……………………………………………………………eqn 3.1

2. Standard Asset Effectiveness (SAE) = Vat ÷ Tmt …………………………....eqn 3.2

3. Total Asset Effectiveness (TAE) = Vat ÷ Tat ………………………… ……..eqn 3.3

4. Saturation Index = Tmt ÷ Tat …………………………………………………eqn 3.4

The report expected from the model is of the format shown in table 3.2, a complete report is shown in appendix III.

5. Mean Time to Repair

MTTR was calculated using the formula shown in equation 3.5 below.

$$MTTR = \frac{Total\ Machine\ Breakdown\ \ Downtime}{Total\ number\ \ of\ breakdowns}$$ ………………………………………….eqn 3.5

6. Mean Time Before Failure

MTBF was calculated using the formula shown in equation 3.6 below.

$$MTBF = \frac{Total\ Machine\ Production\ \ time}{Total\ number\ \ of\ breakdowns}$$ ……………………………………………………..eqn 3.6

Table 3.2 Report Format Showing all the Metrics

PK 1.8	Technical speed	OEE Goal	PRODUCTION	Machine OT	SI	TAE	SAE	OEE	1.1 STATUTORY LOSSES		1.2 PLANNED LOSSES		1.3 BREAKDOWN LOSSES		1.4 CHANGE OVER LOSSES		1.5 SET UP LOSSES	
	ppH	%	(Cases / Kgs)	Hrs	(Tmt/Tat), %	(Vat/Tat), %	(Vat/Tmt), %	(Vat/Ot), %	Hrs	%	Hrs	%	Hrs	8.0%	Hrs	0.3%	Hrs	8.5%
PK1	522	52.0%	909	223.5	36.9%	9.5%	25.8%	28.1%	415.0	63.1%	19.5	3.0%	42.1	7.0%	0.0	0.0%	17.7	7.9%
PK2	522	52.0%	1,114	265.0	43.5%	11.7%	26.9%	29.0%	372.0	56.5%	21.0	3.2%	38.3	8.0%	0.4	0.2%	20.9	7.9%
PK3	522	52.0%	1,572	288.5	47.5%	16.5%	34.7%	37.6%	345.5	52.5%	24.0	3.6%	32.5	5.9%	0.3	0.1%	26.0	9.0%
TOTAL PK		52.0%	3,596	777.0	42.6%	12.6%	29.1%	31.6%	1132.5	57.4%	64.5	3.3%	112.9	7.0%	0.7	0.1%	64.5	8.3%

PK 1.8	1.6 LACK OF MATERIAL LOSSES		1.7 LACK OF OPERATOR LOSSES		1.8 OTHER UNPLANNED LOSSES		1.9 SHORT STOP LOSSES		2.0 UTILITY LOSSES		2.1 SPEED LOSSES		2.2 QUALTY LOSSES		2.3 UNKNOWN LOSSES	
	Hrs	0.5%	Hrs	0.2%	Hrs	0.4%	Hrs	29.0%	Hrs	0.1%	Hrs	0.0%	Hrs	0.0%	Hrs	1.0%
PK1	11.1	5.0%	0.0	0.0%	0.5	0.2%	88.2	39.5%	0.0	0.0%	0.0	0.0%	0.0	0.0%	1.3	0.6%
PK2	14.6	5.5%	2.0	0.8%	0.5	0.2%	111.1	41.9%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.3	0.1%
PK3	13.8	4.8%	1.0	0.3%	1.0	0.3%	102.1	35.4%	0.2	0.1%	0.0	0.0%	0.0	0.0%	3.2	1.1%
TOTAL PK	39.5	5.1%	3.0	0.4%	2.0	0.3%	301.5	38.9%	0.2	0.0%	0.0	0.0%	0.0	0.0%	4.7	0.6%

3.6 Breakdown Reduction Route through Lean-TPM

The plan adopted for breakdown reduction is stipulated in Fig 3.3

3.6.1. Step 1: Identify Breakdown Types

Activities undertaken in step one were:

a. Develop a model of the machine showing all the possible breakdown areas (assemblies and sub-assemblies)

b. Categorize all the possible breakdowns and other losses into the OEE tree and code them accordingly.

c. Do a time study for the major short stops, and code them.

d. Develop a log sheet for the machine with all the codes.
e. Develop a database for the information
f. Develop a program to run the data and produce a daily/shiftly, monthly or yearly report.

All these have been covered in section 3.2.

3.6.2 Step 2: Restoration of Machine Basic Conditions

In this step areas susceptible to dirt accumulation, and wear were identified. An inspection, cleaning and lubrication checklist was developed and implemented. An example of the checklist developed is annexed as appendix viii.

BREAKDOWN REDUCTION MASTER PLAN																				
						2011			2012											
Step	Step Description	Sub-step	Sub-step description	Status	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1	Identify Breakdown types	1	Set up data collection System																	
		2	Analyse historical data and Set performance indicators																	
		3	Deploy breakdowns and carry out Pareto Analysis																	
2	Restore basic conditions on critical areas and set standards	1	Identify Critical areas																	
		2	Perform initial Cleaning and Tagging																	
		3	Manage the tags																	
		4	Define and Implement cleaning, inspection and Lubrication																	
		5	Restore all the operating Standards																	
3	Attack Repetitive breakdowns	1	Define the Failure Modes in important areas																	
		2	Carry out 5why analysis on Failure modes																	
		3	Define Countermeasures																	
		4	Implement Countermeasures																	
		5	Establish a monitoring system for re-occurencences																	
4	Highlight the causes of Sporadic Breakdowns	1	Introduce new breakdown defination to improve the data collection system																	
		2	Introduce the breakdown analysis sheet																	
		3	Define the system to support it																	
		4	Train all relevant operators an maintenance technicians																	
		4	Implement the system and continuously follow up analysis and results																	
5	Define Preventive Maintenance Plans	1	Summarize causes and countermeasures from breakdown analysis																	
		2	Implement actions and countermeasures																	
		3	Set the Planned maintenance system																	
		4	Set the machine board																	

Planned Activities   Pending Activities

Figure 3.3 Breakdown Reduction Master Plan

3.6.3 Step 3: Attack Repetitive Breakdowns.

In order to track repetitive breakdowns, a breakdown recurrence matrix was developed as shown in table 3.3

Table 2.3: Breakdown Recurrence Matrix

group_code	PK			
Count of frequency	Break_month			
Row Labels	1	2	3	Grand Total
MB01		**1**		**1**
Curved/Straight Chute Assembly		1		1
MB02	**10**	**14**	**12**	**36**
Cutter Assembly	10	14	12	36
MB03	**82**	**67**	**49**	**198**
Band Drum Assembly	82	67	49	198
MB04	**4**	**7**	**2**	**13**
Ejector Assembly	4	7	2	13
MB05	**9**	**8**	**4**	**21**
Glue Pot Assembly	9	8	4	21
MB06	**4**	**5**	**1**	**10**
Delivery Chute Assembly	4	5	1	10
MB07	**5**	**4**	**1**	**10**
Electrical Fault	5	4	1	10
MB08	**2**	**1**	**2**	**5**
Heater gun Assembly	2	1	2	5
MB09	**11**	**4**	**4**	**19**
Tipping Drum Assembly	11	4	4	19
MB10	**7**	**5**	**1**	**13**
Clutch assembly	7	5	1	13
MB11	**4**	**3**		**7**
Machine drive	4	3		7
MB12	**1**		**2**	**3**
Pellet Conveyor Assembly	1		2	3
MB13			**1**	**1**
Truck assembly			1	1
MB14		**3**		**3**
OVERwrap Breakdown		3		3
MB15			**11**	**11**
Tray former Breakdowns			11	11
MB16	**70**	**56**	**34**	**160**
No mechanic	70	56	34	160
Grand Total	**209**	**178**	**124**	**511**

The breakdown recurrence matrix is acquired through a data transfer from the breakdowns database developed earlier and using a pivot table to give the frequency of recurrence of each breakdown periodically.

Once the recurrent problems are identified a root cause analysis is undertaken and countermeasures defined into the engineering loss report shown in table 3.4.

Table 3.4: Engineering Loss Report

Engineering Loss Report							
Date	Machine Name	Breakdown Duration		Breakdown Reason (s) (In "Engineering Terms")	Action Plan (s)	Due Date	Responsibility
8/Sep	PK 3	45.00%	9	Clutch mechanism ...extended PPM to overhaul the mechanism	Root cause investigated		
28/Sep	PK 3	16.30%	3.26	Ceased bearing at cutter assembly	Introduce bearing CBM tools	30-Oct	
4/Oct	PK 3	27.20%	5.168	Band drum plunger sticking on dead end of drum bore.	Other PK machines be checked to pre-emnt this kind of failure.	11-Oct	
18/Oct	Pk 3	11.00%	2.09	Replacing a failed clutch pin, timing on first kicker, cutters to offset packet tearing and registration loss.	Other PK machines be checked to pre-emt this kind of failure.	18-Oct	
22/Oct	PK 3	8.80%	1.672	Band box guide re-set to arrest tilted and off-track labels.	Other PK machines checked in the same area and found okay.	22-Oct	
25/Oct	Pk 3	11.80%	2.242	Working to arrest leakage at the glue pot, timing the glue pot cam.	Other PK machines examined and found okay in this area. Daily checks to closely monitor.	25-Oct	
3/Nov	PK 3	9.40%	1.504	Repairing and Replacing of one stationer cutter	Weekly inspections to monitor this area kind of parts deterioration.	6-Nov	
5/Nov	PK 3	9.60%	1.824	timing of pusher position and setting of guide rails to offset pellet smashing.	to do a why why analysis to find why and how these rails and pushers ofen loses settings.	13-Nov	
12/Nov	PK 3	46.40%	3.248	Replaced cracked paper cutter mounting with one from PK6 and modified to suit the slot to offset the issue of failed cutter.	Weekly inspections to monitor this area kind of parts deterioration.	19-Nov	
16/Nov	PK 3	25.90%	4.921	Setting of cutter trucks and replaced rubber spal on track 3 & 5 to offset cutter failure.	Weekly inspections to monitor this area kind of parts deterioration.	19-Nov	
19/Nov	PK 3	9.60%	1.824	Secured loose lower draw roller drive coupling and re-built a worn band drum plunger on track 2 to offset smashing of pellets and prelam foil not being pulled.	Other PK machines to be examined in the same area.	24-Nov	
22/Nov	PK 3	16.70%	3.173	Secured loose lower draw roller drive coupling and re-built a worn band drum plunger on track 2 to offset smashing of pellets and prelam foil not being pulled.	Other PK machines to be examined in the same area.	24-Nov	
29/Nov	PK 3	13.60%	2.584	Adjusting gliue pot stroke to be able allow well spread of the same on wrapper	Daily inspections to monitor this area kind of such looseness.	4-Dec	

3.6.4 Step 4: Highlight Causes of Sporadic Breakdowns

Once the basic conditions of the machine have been restored, the standard operating procedure of each an assembly of the machine is developed in the form of one point lessons. These one point lessons are then used as training materials to train mechanics and operators on standard settings of the machine. Failure modes of equipment are also noted in this step, and therefore defect cards are developed for subsequent training of mechanics and operators. The One point lessons and defect cards are annexed as appendix II.

Step 5: Define Preventive maintenance plans.

Preventive maintenance plans are developed using computations from the database of the Mean time before failure (MTBF) of each an assembly, so that the equipment is scheduled for maintenance before failure. Standard procedures such as lubrication and setting have already been captured under the daily inspection, cleaning and lubrication checklists. A sample of a preventive maintenance plan has been annexed as appendix viii.

3.7 Mathematical Model of Energy Consumption versus Breakdown Levels

Assumption: Breakdowns occur only while a station is giving Service.

This mode of breakdown and repair is very often encountered in manufacturing. It is typical for machines, which show no wear during idle times. Only during machining time a breakdown may occur.

For a continuous production flow like the one at WEA, a breakdown of a PK machine causes a downtime in the upstream activities in the mixing, sheeting, tempering and coating lines. This when aggregated leads to a major power usage with minimal production.

Using the notations:

i – PK operation

j- for mixing operations

k- Sheeting operations

l- Tempering operations

m- Coating operations, to refer to the number of operations a model for energy usage during machine breakdown on the PK can be developed:

If when the machine stands idle, it consumes $Power_{idle}$*(P.i).* and, the power consumed while processing a part is $Power_{processing}$ *(P.p).* Then when the machine is turned off and then turned on (i.e., a setup occurs), it consumes $Energy_{setup}$ *(P.s).* This setup operation takes at least T_{setup} duration. The tip power, which is the marginal power utilized to process a part, must also be determined. That is,

$Power_{tip} = P.p - P.i$ ……………………………………………………….….……..eqn 3.7

Finally, the breakeven duration (T_B) is defined as the least amount of duration required for a turn off/turn on operation (i.e., time required for a setup) and the amount of time for which a turn off/on operation is logical instead of running the machine at idle. Mathematically,

$T_B = \max\left(\frac{Energy\ setup}{Power\ idle}; Tsetup\right)$ ……………………………………………….eqn 3.8

The relationship between breakdowns and energy usage will thus be:

$E = \Omega * \sum_i MTTR * R + \sum_j^m (P.i + P.s)$…….…………………………………… 3.9

Where E – total energy consumption

R- rated power consumption of the machine.

Ω - a factor that takes into account the amount of power is consumed during repair as well as the residual power usage during repair.

Equation 3.9 gives a generic relationship between breakdown levels and energy consumption for a flow type of a manufacturing process. The first part of the equation gives the energy consumption on the specific machine that causes delay on the upstream processes and computes usage using the mean time to repair for the machine and the rated power usage, the assumption here is that while the machine is under repair, energy is used in pretest and post test operations.

The second part of the equation gives the total energy consumed by the upstream operations j-m when the machines are idle and need to be setup after clearance of breakdown downstream. For lines operating independently then the equation reduces to:

E $=\Omega * \sum_i MTTR * R$ ………………………………..……………………eqn 3.10

The general objective function for energy reduction is thus:

Min $\{ \Omega * \sum_i MTTR * R + \sum_j^m (P.i + P.s)\}$ ……………………………………eqn 3.11,

Options:

- Minimize Mean time to repair (% breakdowns)
- Minimize machine set ups thereby increasing MTBF.
- Minimize machine idle times.

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction:

This chapter demonstrates the results obtained from implementing the methodology which has been developed in the previous chapter in order to implement lean-TPM within the Wrigley company. The main objectives of this research are: maximizing the throughput to satisfy the market demand, and identifying and minimizing breakdown times. These objectives are obtained through implementing the research methodology steps.

4.1 Results of the Research Steps:

4.1.1 Step one: Data Collection

The research has used mixed method of the both quantitative and qualitative techniques in order to collect the required data. The collected data has been utilized to develop the TPM model for the WEA factory and to validate the obtained results.

Table 4.1: PK lines Data Sheet

machine_code	machine_name	prodn_capacity	ssu_factor	kg_factor	report_group	Prodn Target	case_factor	Active
PK1	PK1	522	1.3334	0.36	PK		0.027778	TRUE
PK2	PK2	522	1.3334	0.36	PK		0.027778	TRUE
PK3	PK3	522	1.3334	0.36	PK		0.027778	TRUE
PK4	PK4	522	1.3334	0.36	PK		0.027778	TRUE
PK5	PK5	522	1.3334	0.36	PK		0.027778	TRUE
PK6	PK6	522	1.3334	0.36	PK		0.027778	TRUE
PK7	PK7	522	1.3334	0.36	PK	3942	0.027778	TRUE

Legend:

- Production capacity is in parts per hour.
- SSU - standard stocking unit, and is the conversion of machine speed from parts per hour to a uniform stocking unit SSU by multiplication with the ssu factor.
- Case factor – is a conversion factor from ssu to cases, sixteen trays of parts make up a case, and one tray takes up twenty four parts.
- Active – is whether machine is in use, True means machine is active.

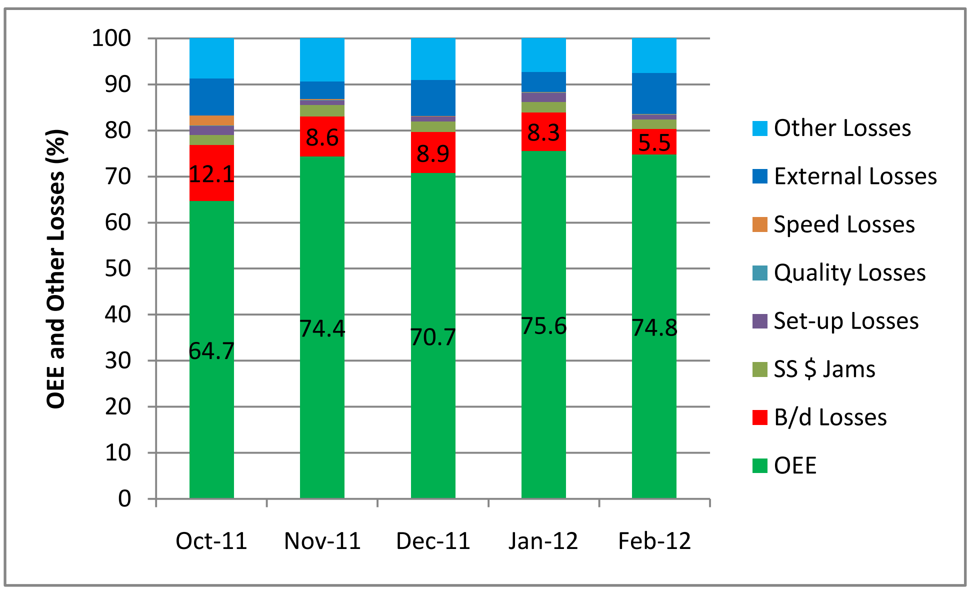


Figure 4.1: Trending OEE and other Losses from Oct 2011 to Feb 2012

From figure 4.1 we can deduce that the OEE is significantly increasing from 64.7% in October to 74.8% in February. The main contributor to OEE increase is the reduction in breakdowns and Speed losses. The reduction in speed losses is attributed to the use of modular parts which ensured that the pulley running the drive was changed from the initial one of 160mm diameter to the one of 180mm, to match the original equipment manufacturer standards.

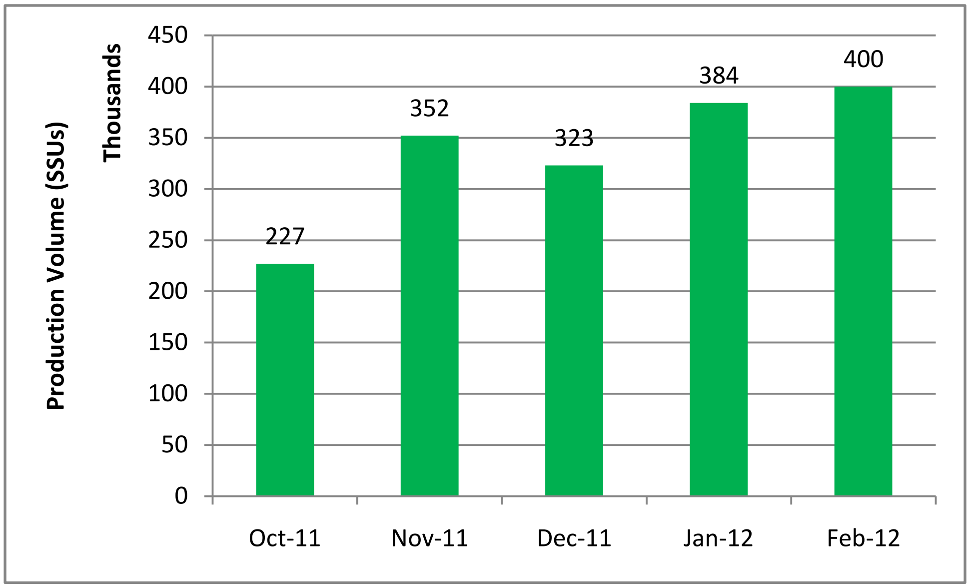
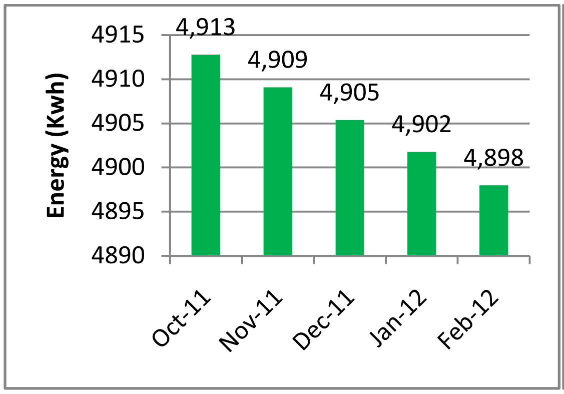


Figure 4.2: Production Volumes October 2011 to Feb 2012

Production Volumes gradually increased from the initial 227,000 SSUs to 400,000 SSUs within a span of four months. This is attributed to the fact that there was an increase in value added time and therefore higher machine uptime due to reduction in non value adding time, like breakdowns and speed losses. From figure 4.2, there was a drop in volumes in December, this is because during this time the production schedule was stopped on 19th December for scheduled shutdown to allow for plant overhaul.



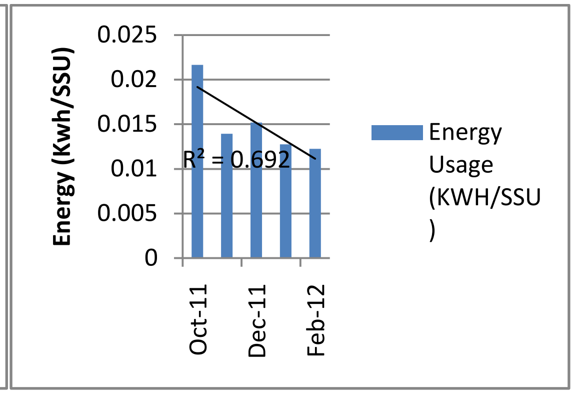


FIG 4.3 a

FIG 4.3 b

Figure 4.3: Energy Consumption Trend October 2011 to Feb 2012

The energy consumption is generally on a downward trend. This is expected because with reduced breakdowns upstream, the need to run auxiliary equipments like the cyclones, the boiler, the chillers and the dehumidifiers reduced. It is imperative to note that in the event of a breakdown in PK machine, all the downstream equipments have to continue running to ensure that the gum is kept at standard conditions, otherwise the gum gets spoilt and necessitates rework. Note that even if rework is allowed, a batch of spoilt gum has to be mixed into 40 batches of new gum according to the Wrigley quality management standards. From figure 4.3 b, the energy consumption per SSU went up in December, whereas it was expected to go down, this is because even during shutdown there was a base load to be supplied, for example for testing of equipment under repair and steam supply for cleaning.

4.2 Step two: Analysis of Results

4.2.1 Variation of OEE with Production Levels

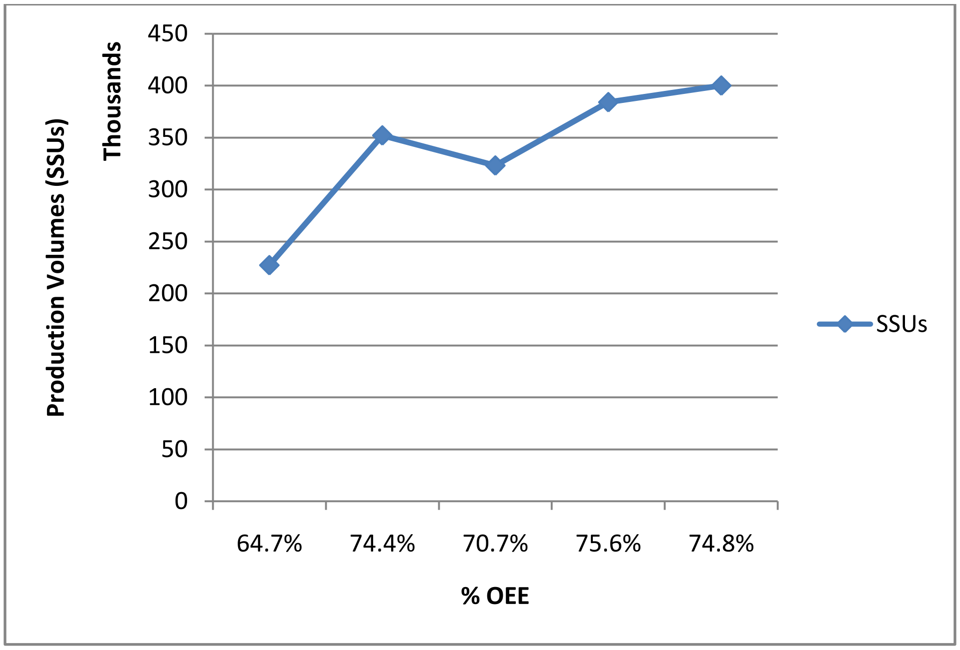


Figure 4.4: Variation of OEE with Production Volumes (SSUs)

4.2.2 Variation of Breakdowns with OEE

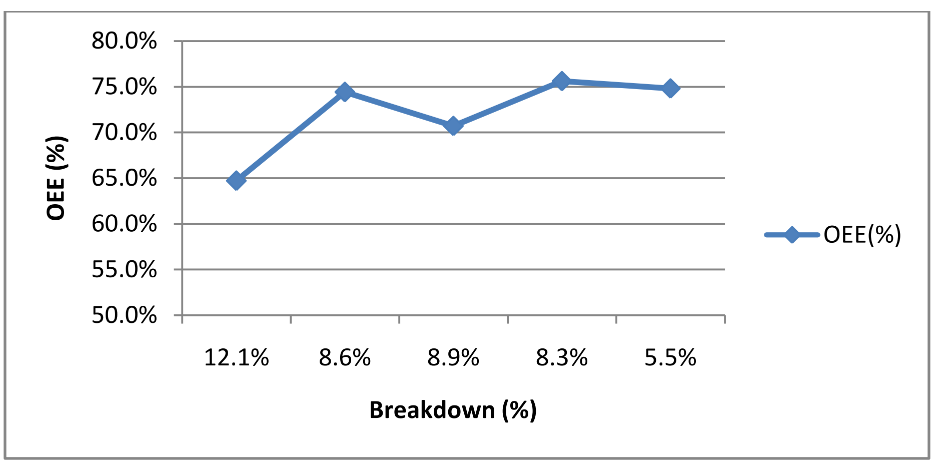


Figure 4.5: Variation of Breakdowns with OEE

From fig 4.5, it is clear that as breakdowns decrease there is an equivalent increase in OEE, this is expected if other OEE losses are kept constant.

4.2. 3 Variation of Energy Consumption with Production Volumes

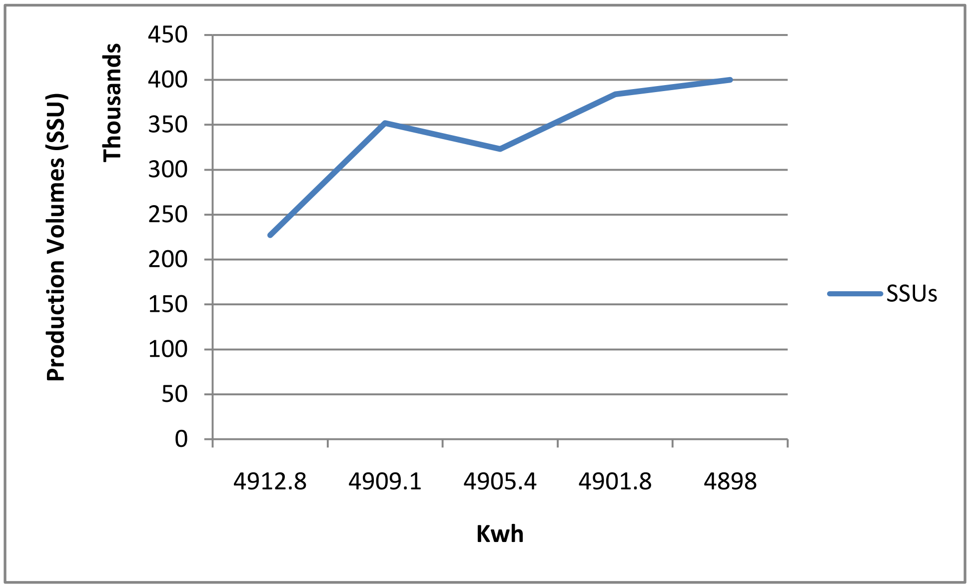


Figure 4.6: Variation of Breakdown Levels with Energy Consumption

It is common knowledge that the input is directly proportional to the output if losses are neglected. The case is the same here; if more product is required then more energy is required in the upstream and downstream operations. The more realistic view to energy consumption is the per unit of product consumption, naturally this should be lower as shown in figure 4.3b.

4.2.4. Variation of Energy Consumption with Breakdowns

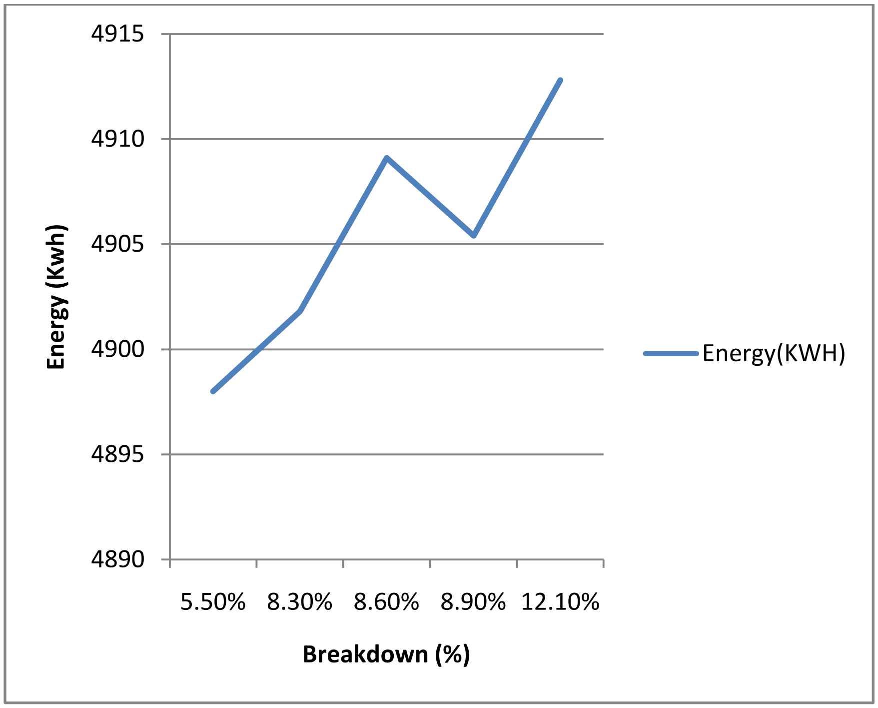


Figure 4.7: Variation of Energy Consumption vis-à-vis Breakdown Levels

Energy Consumption and breakdowns are positively related. This implies that the higher the breakdowns the higher the energy consumption; a fact that can only be explained by the power requirements by the machine during testing, setup, idling and the upstream and downstream support processes. It is therefore necessary to move equipment from the breakdown regime to the planned preventive maintenance regime, because in preventive maintenance the upstream and downstream are preplanned to stop operations, thus negating the use of energy for this support operations.

4.2.5. Variation of MTTR with Time

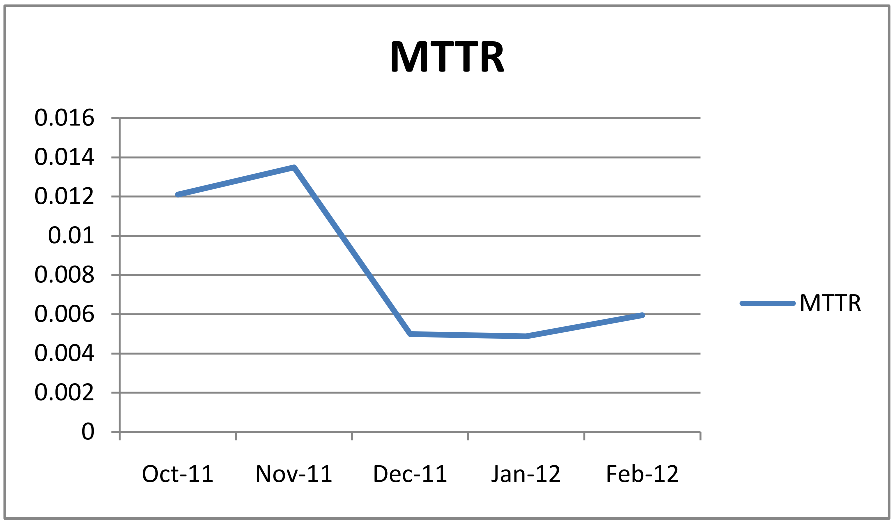


Figure 4.8: MTTR Variations with time

The mean time to repair is on the downward trend as the TPM effort increases in the machine. The major contributors to the reduction in mean time to repair are:

1. The rearrangement of the spare parts store according to the movement of parts as well as cataloging parts per assembly greatly reduced the time spent by mechanics to find a part in the store.
2. Development of one point lessons for standard setting of the major assemblies of the machine and tools to use assisted in ensuring a standard way of repair.
3. Training of both mechanics and operators on machine standards.
4. The Cleaning, inspection and Lubrication checklists assisted in noting possible breakdowns before hand, hence allows for time to prepare to correct the problem. Which agrees with the works of Kamran (Kamran Shahanaghi, 2009).

4.2.6. Variation of Mean time before Failure (MTBF) with time

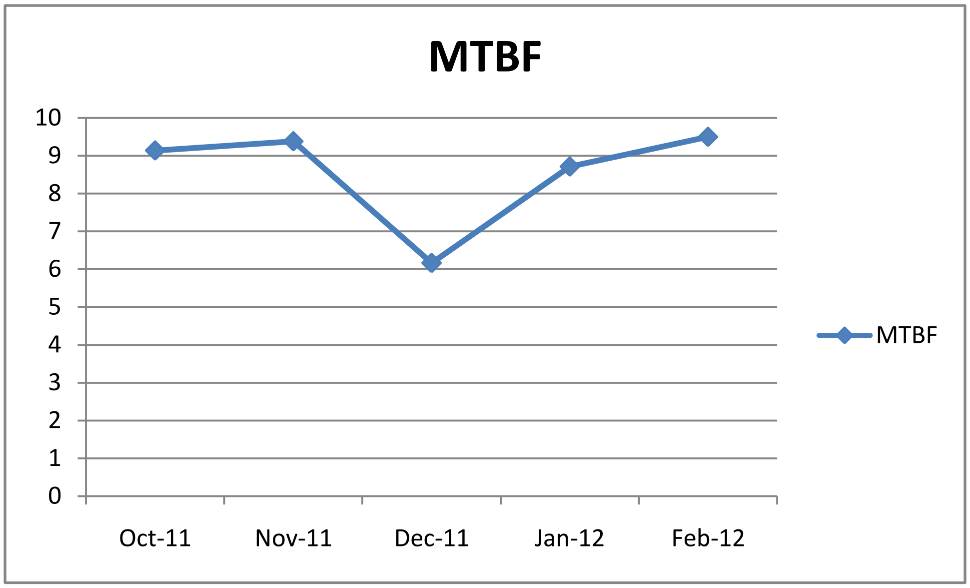


Figure 4.9: MTBF Variation over time

The mean time between failures initially reduced then increased from the third month onwards. The initial reduction is attributed to the restoration of basic machine conditions in step one and two. This is because during this period, the non standard parts were removed and the original setting of the equipment restored, lubrication, cleaning and inspection checklists had not been introduced into the system and many mechanics and operators had not been trained in the new standards.

4.3 Discussion of Results

4.3.1 OEE and Breakdown Percentage.

At the start of the research, the OEE stood at 64.7%, but with the introduction of breakdown reduction strategies by use of TPM methods as stipulated in the PM pillar master plan fig 3.3, the OEE improved to 74.8% at the end of February 2012. The first four steps of the PM route were successfully covered; however the remaining steps are on schedule. The implementation of TPM is therefore a sure way to bring down machine downtimes related to machine failures.

4.3.2 Energy Usage

Energy usage on the PK line reduced from 0.021KWH/SSU to 0.012KWH/SSU, this is attributed to the reduction in breakdown levels. This is because during machine repair, the line still consumes energy from the upstream feeder processes such as sheeting, tempering, mixing and conveyance systems. It is therefore clear that for a line process, breakdown of one unit causes far more cost implications than for stand-alone units.

4.3.3 Machine Breakdowns KPIs.

MTBF took a dip in December; this is because machine standards and production of modular parts was still in progress coupled with the training of mechanics on the new standards and the TPM way, however it stabilized at 9.5 hours, an equivalent of a single breakdown per shift. The root cause analysis for failure which every mechanic was required to duly fill at the end of every breakdown greatly assisted in eliminating recurring breakdowns, as well as identifying gaps in spare parts inventory.

MTTR reduced by 50%, to settle at 0.005hrs, this is as a result of the development of one point lessons (OPLs) that acted as a guidance towards repairing any machine breakdown. A database for OPLs was created and machine boards installed on site for displaying these OPLs.

4.4 Economic Impact

Table 4.2 Cost Benefit Analysis Table

Cost Benefit Analysis					
Item	**Costs**	**Cost Per Unit**	**No. of Units**	**Total per month**	**Total for 5 months**
1	Cost Of Special Cleaning and Lubrication Equipment	30,000	1	30,000.00	30,000.00
2	Cost of modular Parts	354,000	1	354,000.00	504,000.00
3	Mechanic Tools Jigs and fixtures	75,000	1	75,000.00	75,000.00
4	External Consultant	500,000.00	1	500,000.00	1,000,000.00
				-	
				-	
	TOTAL COST			959,000.00	1,609,000.00
				-	
				-	
	Benefits				
1	Increase in Product Throughput by average 8.52 tons per month.	833.3333	8520	7,099,999.72	
2	Using the finacial benchmark of 20% net profit (Wayne 1996)			1,419,999.94	7,099,999.72
3	Reduction in energy Usage per unit from 0.021Kwh to 0.012Kwh and average monthly production of 369000 SSU, therefore total energy saving will be = 369,000* (0.021-0.012)Kwh	7	3321	23,247.00	116,235.00
				-	
				-	
	TOTAL BENEFIT			1,443,246.94	7,216,234.72

From Table 4.2 the simple pay back can be computed as

$$\text{Pay back period} \quad = \frac{\text{Savings}}{\text{Investment}} = \frac{7216234 - 1609000}{160900} = 0.29 \text{ months}$$

Which means the investment is recouped within the month. This thus is a viable project. It is important to note that this cost-benefit analysis does not take into account benefits such as reduction in loss of manhours, quality losses during machine testing and the high staff morale attributed to weekend offs.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

The purpose of this thesis is to develop a model for breakdown reduction in industrial machines based on lean TPM principles. In order to do so four specific objectives were formulated and were aimed at grasping the key objective and also function as guidance along the way in developing a model for similar industries in their quest to achieve operational excellence.

The Conclusions from the research work are highlighted below

1. To develop an information system of the company, all intrinsic features of each machine are supposed to be well documented, including machine history with modifications if any are well collated and stored in the machine card. This is well covered under the early equipment maintenance pillar under the TPM pillars. Each of the assemblies and sub-assemblies are to be defined and well coded into the system.
2. When calculating the performance metrics of a machine, a properly defined productivity model of the same must first be developed. The essence of this is that different machines have different loss types that have to be defined. This can be done through a time study at the shop floor.
3. In reducing machine breakdowns, a proper systematic way of loss reduction has to be followed as described in Fig 3.3. The strategy encompasses all aspects of the four *Ms*, (Man, Machine, Method and Material).

   In dealing with man the strategy has training by utilizing a skill gap analysis for both mechanics and operators and defining standard operating procedures for the roles additionally from the root cause analysis, one point lessons are developed to be used as training material.

To reduce time wastage in spare parts management an inventory of all parts was done, and the parts classified according to consumption. A parts catalogue was developed showing pictures for the most confusing parts with their bin numbers in the store.

4. Standard reports were developed. The reports from the data collected could be generated shiftly, daily, weekly, monthly and yearly. The reports include: OEE report, Waste report, Engineering losses report, breakdown recurrence report, team reports and others. The variation of the report depends on the query sent to the dbase. The production of these reports has aided in team management and encourages competition between teams.
5. It has been shown from the research that indeed there exists a relationship between energy usage and breakdown levels as summarized by equation 3.9, which is a general function for a line of machines. It is therefore imperative for management not to consider the breakdowns *perse* but also the effect of breakdowns on facility energy usage. Maintenance is therefore not just a cost center but can also be a profit center if one considers the energy usage during this period.

Recommendation

This research was carried out on equipments that had been in operations for over twenty years after commissioning, therefore the general principles applied here may not apply to a new facility. It is proposed that a similar study be carried out on a newly installed facility so that the general principles of early equipment maintenance under the TPM pillar are applied so as to trend breakdown levels with the maintenance function. At the end of the study a master plan for such conditions should be developed so as to reduce breakdowns and keep energy consumption at optimum, thus avoiding deterioration of equipment.

With a simple payback period was 0.29 months the project is considered viable and is therefore an encouragement to other companies willing to pursue the TPM route in achieving operational effectiveness and improving their bottom line.

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APPENDIX I: PROGRAM CODE

```
Private Sub cmdOEE_Click()
    Dim dbs As Database
    Dim strSql As String, strShift1 As String, strShift2 As String, strDesc As String
    Dim prvCode As String
    Dim qdfSql As QueryDef
    Dim qdfDtl As QueryDef, qdfPrd As QueryDef
    Dim r As Integer, n As Integer
    Dim rstSql As Recordset
    Dim rstDtl As Recordset
    Dim available_time, statutory_time, planned_downtime, machine_time, open_time,
valueAdded_time
    ' Clear contents of DBDATA
    Worksheets("DBDATA").Cells.ClearContents
    Set dbs = OpenDatabase("C:\Thesis work\OEE Database\Breakdowns.mdb")
    If cmbShift.Value = "DAY" Then
        strShift1 = "DAY"
        strShift2 = "DAY"
        strDesc = "DAY SHIFT"
    Else
        If cmbShift.Value = "NIGHT" Then
            strShift1 = "NIGHT"
            strShift2 = "NIGHT"
            strDesc = "NIGHT SHIFT"
        Else
            strShift1 = "DAY"
```

```
        strShift2 = "NIGHT"
        strDesc = "BOTH SHIFTS"
    End If
End If
Set qdfSql = dbs.QueryDefs("qryOEEINT")
qdfSql.Parameters("[OEEStartDate]") = DtpStart.Value
qdfSql.Parameters("[OEEEndDate]") = DtpEnd.Value
qdfSql.Parameters("[OEEShift1]") = strShift1
qdfSql.Parameters("[OEEShift2]") = strShift2
         r = 1
Set rstSql = qdfSql.OpenRecordset
Do While Not rstSql.EOF
    available_time = 0
    statutory_time = 0
    planned_downtime = 0
    machine_time = 0
    open_time = 0
    valueAdded_time = 0

    Sheets("DBDATA").Cells(r, 1).Value = rstSql!machine_code
    Sheets("DBDATA").Cells(r, 2).Value = rstSql!good_prodn
    Sheets("DBDATA").Cells(r, 3).Value = rstSql!ssu_factor
    Sheets("DBDATA").Cells(r, 4).Value = rstSql!kg_factor
    Sheets("DBDATA").Cells(r, 5).Value = rstSql!case_factor
    Sheets("DBDATA").Cells(r, 6).Value = rstSql!prodn_capacity
```

```
available_time = rstSql!available_time * 60
Sheets("DBDATA").Cells(r, 7).Value = available_time
valueAdded_time = rstSql!valueAdded_time * 60
Sheets("DBDATA").Cells(r, 12).Value = valueAdded_time

Set qdfDtl = dbs.QueryDefs("qryOEEINTDtl")
qdfDtl.Parameters("[OEEStartDate]") = DtpStart.Value
qdfDtl.Parameters("[OEEEndDate]") = DtpEnd.Value
qdfDtl.Parameters("[OEEMc]") = rstSql!machine_code
qdfDtl.Parameters("[OEEShift1]") = strShift1
qdfDtl.Parameters("[OEEShift2]") = strShift2

Set rstDtl = qdfDtl.OpenRecordset
Do While Not rstDtl.EOF
  If rstDtl!report_group = "STATUTORY" Then
     Sheets("DBDATA").Cells(r, 13).Value = rstDtl!Duration
     statutory_time = statutory_time + nz(rstDtl!Duration)
   End If
   If rstDtl!report_group = "PLANNED" Then
     Sheets("DBDATA").Cells(r, 14).Value = rstDtl!Duration
     planned_downtime = planned_downtime + nz(rstDtl!Duration)
   End If
   If rstDtl!report_group = "BREAKDOWN" Then
     Sheets("DBDATA").Cells(r, 15).Value = rstDtl!Duration
   End If
```

```
If rstDtl!report_group = "SET UP" Then
   Sheets("DBDATA").Cells(r, 16).Value = rstDtl!Duration
End If
If rstDtl!report_group = "OTHER/EXTERNAL" Then
   Sheets("DBDATA").Cells(r, 17).Value = rstDtl!Duration
End If
If rstDtl!report_group = "SHORT STOP" Then
   Sheets("DBDATA").Cells(r, 18).Value = rstDtl!Duration
End If
If rstDtl!report_group = "SPEED" Then
   Sheets("DBDATA").Cells(r, 19).Value = rstDtl!Duration
End If
If rstDtl!report_group = "QUALITY" Then
   Sheets("DBDATA").Cells(r, 20).Value = rstDtl!Duration
End If
If rstDtl!report_group = "CHANGE OVER" Then
   Sheets("DBDATA").Cells(r, 21).Value = rstDtl!Duration
End If
If rstDtl!report_group = "LACK OF MATERIAL" Then
   Sheets("DBDATA").Cells(r, 22).Value = rstDtl!Duration
End If
If rstDtl!report_group = "LACK OF OPERATOR" Then
   Sheets("DBDATA").Cells(r, 23).Value = rstDtl!Duration
End If
If rstDtl!report_group = "OTHER UNPLANNED" Then
```

```
            Sheets("DBDATA").Cells(r, 24).Value = rstDtl!Duration
        End If
        If rstDtl!report_group = "POWER" Then
            Sheets("DBDATA").Cells(r, 25).Value = rstDtl!Duration
        End If

        rstDtl.MoveNext

    Loop
    rstSql.MoveNext
    machine_time = available_time - statutory_time
    open_time = machine_time - planned_downtime
    Sheets("DBDATA").Cells(r, 8).Value = statutory_time
    Sheets("DBDATA").Cells(r, 9).Value = planned_downtime
    Sheets("DBDATA").Cells(r, 10).Value = machine_time
    Sheets("DBDATA").Cells(r, 11).Value = open_time
    r = r + 1
Loop


' Update planned losses per shift
Set qdfSql = dbs.QueryDefs("qryOEEINTGrp")
qdfSql.Parameters("[OEEStartDate]") = DtpStart.Value
qdfSql.Parameters("[OEEEndDate]") = DtpEnd.Value
qdfSql.Parameters("[OEEShift1]") = strShift1
```

```
    qdfSql.Parameters("[OEEShift2]") = strShift2

    Set rstSql = qdfSql.OpenRecordset

    r = 1

    Do While Not rstSql.EOF

        Sheets("DBDATA").Cells(r, 30).Value = rstSql!report_group & rstSql!Shift

        Sheets("DBDATA").Cells(r, 31).Value = rstSql!good_prodn

        Sheets("DBDATA").Cells(r, 32).Value = rstSql!theo_capacity

        Sheets("DBDATA").Cells(r, 33).Value = rstSql!Duration

        r = r + 1

        rstSql.MoveNext

    Loop

    Set qdfSql = dbs.QueryDefs("qryOEEINTPrd")

    qdfSql.Parameters("[OEEStartDate]") = DtpStart.Value

    qdfSql.Parameters("[OEEEndDate]") = DtpEnd.Value

    qdfSql.Parameters("[OEEShift1]") = strShift1

    qdfSql.Parameters("[OEEShift2]") = strShift2

    Set rstSql = qdfSql.OpenRecordset

    r = 1

    Do While Not rstSql.EOF

        Sheets("DBDATA").Cells(r, 36).Value = rstSql!report_group & rstSql!waste_code &
rstSql!Shift

        Sheets("DBDATA").Cells(r, 37).Value = rstSql!qty

        r = r + 1

        rstSql.MoveNext

    Loop
```

```
' Update planned losses by team
Set qdfSql = dbs.QueryDefs("qryOEEINTGrpPLT")
qdfSql.Parameters("[OEEStartDate]") = DtpStart.Value
qdfSql.Parameters("[OEEEndDate]") = DtpEnd.Value
qdfSql.Parameters("[OEEShift1]") = strShift1
qdfSql.Parameters("[OEEShift2]") = strShift2
Set rstSql = qdfSql.OpenRecordset
r = 1
Do While Not rstSql.EOF
   Sheets("DBDATA").Cells(r, 40).Value = rstSql!report_group & rstSql!team
   Sheets("DBDATA").Cells(r, 41).Value = rstSql!good_prodn
   Sheets("DBDATA").Cells(r, 42).Value = rstSql!theo_capacity
   Sheets("DBDATA").Cells(r, 43).Value = rstSql!Duration
   r = r + 1
   rstSql.MoveNext
Loop

Set qdfSql = dbs.QueryDefs("qryOEEINTPLT")
qdfSql.Parameters("[OEEStartDate]") = DtpStart.Value
qdfSql.Parameters("[OEEEndDate]") = DtpEnd.Value
qdfSql.Parameters("[OEEShift1]") = strShift1
qdfSql.Parameters("[OEEShift2]") = strShift2
Set rstSql = qdfSql.OpenRecordset
r = 1
Do While Not rstSql.EOF
```

```
        Sheets("DBDATA").Cells(r, 45).Value = rstSql!report_group & rstSql!waste_code &
rstSql!team
        Sheets("DBDATA").Cells(r, 46).Value = rstSql!qty
        r = r + 1
        rstSql.MoveNext
    Loop


    Sheets("OEE").Cells(1, 14).Value = strDesc & " " & DtpStart.Value & " To " & DtpEnd.Value
    'Sheets("OEE").Cells(1, 15).Value = DtpStart.Value & " To " & DtpEnd.Value


    MsgBox "Completed Update"
End Sub
Private Sub DtpStart_CallbackKeyDown(ByVal KeyCode As Integer, ByVal Shift As Integer, ByVal
CallbackField As String, CallbackDate As Date)
End Sub
Private Sub CommandButton1_Click()
End Sub
```

APPENDIX II: ONE POINT LESSON FOR MECHANICS AND OPERATORS

DEFECT NAME	SMASHED/CRUSHED PACKAGE		
DEFECT CLASS			
CRITICAL	MAJOR	MINOR	STANDARD
			

STEP	DATE	CAUSE	CLASS	DESCRIPTION OF ACTION	BY WHO	SOP/OPL
1	18-02-12	Improper Gum Size	MAJOR	Change the product to better quality Gum as per Operator Gum Quality reccommendations	Operator	
2	18-02-12	Trapped trash on the heater gun	MAJOR	Clean the heater gun	Operator	PK 1.8 0005
3	18-02-12	Glue molds on the band drum	CRITICAL	Clean the band drum	Operator	PK 1.8 0006
4						
5						
6						
7	18-02-12	Improper second ejector timing	MAJOR	Do proper second ejector machine settings.	Mechanic	PK 1.8 0024
8	18-02-12	Incorrect timing of Heater/Band drum	MAJOR	Proper machine settings Timing	Mechanic	PK 1.8 0023
9	18-02-12	Wrongly aligned band drum axis	MAJOR	Properly align the band drum axis as per procedure	Mechanic	
10	18-02-12	Excessive glue application	MAJOR	Set the correct glue application rate.	Mechanic	
11	18-02-12	Improper setting of the delivery chute cover top folders	MAJOR	Do proper Delivery chute cover top folder settings.	Mechanic	
12						
13						
14						

MECHANICS TRAINING MATRIX

OPLs FOR MACHINE SETTINGS AND SS REDUCTION										
CARD	CARD NAME	SOP / OPL	D. KANGARA	W. NGUNE	S. CHEMONGES	K. MWAURA	G. MBUGUA	E. ONYIEGO	A. KETER	R. NDIRANGU
Card 1	STANDARD PROCEDURE FOR SETTING OF CUTTERS	PK 1.8 001								
Card 2	STANDARD PROCEDURE FOR SETTING OF DETECTOR BLOCK	PK 1.8 002								
Card 3	STANDARD PROCEDURE FOR SETTING OF TIPPING DRUM ASSEMBLY	PK 1.8 003								
Card 4	STANDARD PROCEDURE FOR SETTING OF CURVED CHUTE ASSEMBLY	PK 1.8 004								
Card 5	STANDARD PROCEDURE FOR SETTING OF PELLET BRAKES	PK 1.8 005								
Card 6	STANDARD PROCEDURE FOR SETTING OF PELLET DETECTION WITH VARYING PELLET SIZES	PK 1.8 006								
Card 7	STANDARD PROCEDURE FOR SETTING OF THE VIBRATOR	PK 1.8 007								
Card 8	STANDARD PROCEDURE FOR SETTING OFGLUE POT	PK 1.8 008								
Card 9	STANDARD PROCEDURE FOR SETTING OF BAND DRUM	PK 1.8 009								
Card 10	STANDARDS CONDITIONS FOR BUSHINGS	PK 1.8 010								
Card 11	LUBRICATING STANDARDS ON PK MACHINES.	PK 1.8 011								

APPENDIX III: SAMPLE REPORT FROM DATABASE FOR PK LINES

FACTORY OPERATIONS REPORT													BOTH SHIFTS 10/27/2011 To 10/27/2011													
EQUIPMENT			GOOD PRODUCTION		EFFICIENCY MEASURES				SHUTDOWN LOSSES				OEE LOSSES													
BIG G		OEE Goal	PRODUCTION	Machine OT	SI	TAE	SAE	OEE	1.1 STATUTORY LOSSES		1.2 PLANNED LOSSES		1.3 BREAKDOWN LOSSES		1.4 SET UP LOSSES		1.5 OTHER /EXTERNAL LOSSES		1.6 SHORT STOP LOSSES		1.7 SPEED LOSSES		1.8 QUALTY LOSSES		1.9 UNKNOWN LOSSES	
	ppH	%	(Cases / Kgs)	Hrs	(Tmt/Tat), %	(Vat/Tat), %	(Vat/Tmt), %	(Vat/Ot), %	Hrs	%	Hrs	%	Hrs	5.0%	Hrs	%	Hrs	1.5%	Hrs	5.0%	Hrs	0.5%	Hrs	0.1%	Hrs	5.0%
BIG G1	25000	80.0%	229	19	85.4%	57.2%	67.0%	72.2%	3.5	14.6%	1.5	7.3%	0.2	0.9%	0.4	2.3%	1.5	7.9%	0.4	2.0%	1.9	10.0%	0.0	0.0%	-4.4	-21.4%
BIG G2	35000	80.0%	307	19	85.4%	54.8%	64.2%	69.3%	3.5	14.6%	1.5	7.3%	0.0	0.0%	0.9	4.5%	1.5	7.9%	0.9	4.5%	0.0	0.0%	0.0	0.0%	-3.2	-15.6%
BIG G3	35000	80.0%	-	0	0.0%	0.0%	0.0%	0.0%	24.0	100.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
BIG G4	25000	80.0%	97	8	37.5%	24.3%	64.9%	73.0%	15.0	62.5%	1.0	11.1%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.4	4.7%	0.0	0.0%	0.0	0.0%	-0.4	-4.2%
TOTAL BIG G		80.0%	634	46	52.1%	34.1%	49.0%	71.5%	7.3	30.6%	1.3	8.6%	0.1	0.3%	0.4	2.3%	1.0	5.3%	0.5	3.7%	0.6	3.3%	0.0	0.0%	-2.7	-13.7%
THEEGARTEN	Technical speed	OEE Goal	PRODUCTION	Machine OT	SI	TAE	SAE	OEE	1.1 STATUTORY LOSSES		1.2 PLANNED LOSSES		1.3 BREAKDOWN LOSSES		1.4 SET UP LOSSES		1.5 OTHER /EXTERNAL LOSSES		1.6 SHORT STOP LOSSES		1.7 SPEED LOSSES		1.8 QUALTY LOSSES		1.9 UNKNOWN LOSSES	
	ppH	%	(Cases / Kgs)	Hrs	(Tmt/Tat), %	(Vat/Tat), %	(Vat/Tmt), %	(Vat/Ot), %	Hrs	%	Hrs	%	Hrs	4.0%	Hrs	%	Hrs	0.9%	Hrs	%	Hrs	5.0%	Hrs	0.1%	Hrs	5.0%
BIG G6	54000	75.0%	560	19	85.4%	64.7%	75.8%	81.8%	3.5	14.6%	1.5	7.3%	0.4	2.2%	0.7	3.4%	0.3	1.8%	0.1	0.7%	1.0	5.4%	0.0	0.0%	-2.6	-12.5%
BIG G7	54000	75.0%	547	19	85.4%	63.3%	74.1%	79.9%	3.5	14.6%	1.5	7.3%	0.3	1.8%	0.9	4.7%	0.3	1.8%	0.3	1.4%	1.0	5.4%	0.0	0.0%	-2.8	-13.9%
TOTAL THEEGARTEN		75.0%	560	19	85.4%	64.7%	75.8%	81.8%	7.0	14.6%	3.0	7.3%	0.8	2.0%	1.6	4.1%	0.7	1.8%	0.4	1.1%	2.0	5.4%	0.0	0.0%	-5.4	-13.2%
PK	Technical speed	OEE Goal	PRODUCTION	Machine OT	SI	TAE	SAE	OEE	1.1 STATUTORY LOSSES		1.2 PLANNED LOSSES		1.3 BREAKDOWN LOSSES		1.4 SET UP LOSSES		1.5 OTHER /EXTERNAL LOSSES		1.6 SHORT STOP LOSSES		1.7 SPEED LOSSES		1.8 QUALTY LOSSES		1.9 UNKNOWN LOSSES	
	ppH	%	(Cases / Kgs)	Hrs	(Tmt/Tat), %	(Vat/Tat), %	(Vat/Tmt), %	(Vat/Ot), %	Hrs	%	Hrs	%	Hrs	8.0%	Hrs	%	Hrs	1.5%	Hrs	22.0%	Hrs	1.0%	Hrs	0.5%	Hrs	4.5%
PK1	522	60.0%	125	22	95.8%	36.0%	37.6%	39.3%	1.0	4.2%	1.0	4.3%	0.3	1.1%	2.3	10.5%	0.0	0.0%	6.8	30.9%	0.0	0.0%	1.0	4.5%	-10.3	-45.0%
PK2	522	60.0%	-	0	0.0%	0.0%	0.0%	0.0%	24.0	100.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
PK3	522	60.0%	123	19	85.4%	35.3%	41.4%	44.6%	3.5	14.6%	1.5	7.3%	0.7	3.5%	4.1	21.4%	0.2	0.9%	5.3	28.0%	0.0	0.0%	0.0	0.0%	-10.2	-49.8%
PK4	522	60.0%	94	16	85.4%	27.1%	31.8%	40.7%	3.5	14.6%	4.5	22.0%	1.8	11.5%	1.7	10.9%	0.4	2.6%	4.8	30.1%	0.0	0.0%	0.0	0.0%	-8.8	-43.0%
PK5	522	60.0%	123	19	85.4%	35.4%	41.5%	44.8%	3.5	14.6%	1.5	7.3%	1.9	10.1%	1.7	9.0%	0.3	1.3%	6.0	31.4%	0.0	0.0%	0.0	0.0%	-9.8	-48.0%
PK6	522	60.0%	-	0	0.0%	0.0%	0.0%	0.0%	24.0	100.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
PK7	522	60.0%	101	19	85.4%	29.0%	33.9%	36.6%	3.5	14.6%	1.5	7.3%	3.8	19.7%	2.0	10.4%	0.0	0.0%	6.4	33.7%	0.0	0.0%	0.0	0.0%	-12.1	-59.2%
TOTAL PK		60.0%	567	95	62.5%	23.3%	26.6%	41.2%	3.0	12.5%	2.0	9.7%	1.7	9.2%	2.4	12.4%	0.2	1.0%	5.9	30.8%	0.0	0.0%	0.2	0.9%	-10.3	-49.0%
FLEX	Technical speed	OEE Goal	PRODUCTION	Machine OT	SI	TAE	SAE	OEE	1.1 STATUTORY LOSSES		1.2 PLANNED LOSSES		1.3 BREAKDOWN LOSSES		1.4 SET UP LOSSES		1.5 OTHER /EXTERNAL LOSSES		1.6 SHORT STOP LOSSES		1.7 SPEED LOSSES		1.8 QUALTY LOSSES		1.9 UNKNOWN LOSSES	
	ppH	%	(Cases / Kgs)	Hrs	(Tmt/Tat), %	(Vat/Tat), %	(Vat/Tmt), %	(Vat/Ot), %	Hrs	%	Hrs	%	Hrs	5.0%	Hrs	%	Hrs	1.5%	Hrs	%	Hrs	1.0%	Hrs	0.5%	Hrs	2.0%
FLEX1	12000	82.0%	111	20	85.4%	69.3%	81.1%	83.2%	3.5	14.6%	0.5	2.4%	1.0	5.0%	0.2	0.8%	0.0	0.0%	1.8	9.0%	0.0	0.0%	0.0	0.0%	-3.0	-14.5%
FLEX2	12000	82.0%	76	20	85.4%	47.4%	55.4%	56.8%	3.5	14.6%	0.5	2.4%	7.4	37.1%	0.1	0.7%	0.0	0.0%	0.9	4.4%	0.0	0.0%	0.0	0.0%	-8.4	-41.2%
FLEX3	12000	82.0%	116	20	85.4%	72.7%	85.1%	87.2%	3.5	14.6%	0.5	2.4%	1.5	7.5%	0.2	1.0%	0.0	0.0%	1.2	5.8%	0.0	0.0%	0.0	0.0%	-2.9	-13.9%
FLEX4	12000	82.0%	118	20	85.4%	73.5%	86.0%	88.2%	3.5	14.6%	0.5	2.4%	1.0	5.0%	0.3	1.3%	0.0	0.0%	0.9	4.7%	0.0	0.0%	0.0	0.0%	-2.2	-10.8%
FLEX5	12000	82.0%	117	20	85.4%	73.1%	85.6%	87.7%	3.5	14.6%	0.5	2.4%	1.0	5.0%	0.2	1.1%	0.0	0.0%	0.9	4.3%	0.0	0.0%	0.0	0.0%	-2.1	-10.1%
FLEX6	12000	82.0%	116	20	85.4%	72.5%	84.9%	87.0%	3.5	14.6%	0.5	2.4%	1.2	5.8%	0.2	1.1%	0.0	0.0%	1.5	7.4%	0.0	0.0%	0.0	0.0%	-2.9	-14.0%
FLEX7	9000	82.0%	82	20	85.4%	67.9%	79.5%	81.5%	3.5	14.6%	0.5	2.4%	2.0	10.0%	0.3	1.7%	0.0	0.0%	1.2	5.8%	0.0	0.0%	0.0	0.0%	-3.5	-17.0%
TOTAL FLEX		82.0%	#NAME?	12710	#NAME?	#NAME?	#NAME?	#NAME?	3.5	14.6%	0.5	2.4%	2.2	10.9%	0.2	1.0%	0.0	0.0%	1.2	5.9%	0.0	0.0%	0.0	0.0%	-3.6	-17.4%
COATING	Technical speed	OEE Goal	Production (Kgs)	Machine OT	SI	TAE	SAE	OEE	1.1 STATUTORY LOSSES		1.2 PLANNED LOSSES		1.3 BREAKDOWN LOSSES		1.4 SET UP LOSSES		1.5 OTHER /EXTERNAL LOSSES		1.6 SHORT STOP LOSSES		1.7 SPEED LOSSES		1.8 QUALTY LOSSES		1.9 UNKNOWN LOSSES	
	ppH	%	(Cases / Kgs)	Hrs	(Tmt/Tat), %	(Vat/Tat), %	(Vat/Tmt), %	(Vat/Ot), %	Hrs	%	Hrs	%	Hrs	2.0%	Hrs	%	Hrs	2.5%	Hrs	%	0.0	%	Hrs	0.0%	Hrs	1.0%
ZONE A	192	88.0%	2,256	16	87.5%	49.0%	56.0%	73.5%	3.0	12.5%	5.0	23.8%	0.0	0.0%	1.6	9.9%	1.7	10.4%	0.0	0.0%	0.0	0.0%	0.0	0.0%	-3.3	-15.5%
ZONE B	199	88.0%	3,102	20	87.5%	64.8%	74.1%	77.8%	3.0	12.5%	1.0	4.8%	0.0	0.0%	2.1	10.4%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	-2.1	-9.9%
ZONE C	90	88.0%	1,044	16	85.4%	48.3%	56.6%	72.5%	3.5	14.6%	4.5	22.0%	0.0	0.0%	1.0	6.3%	0.7	4.2%	0.0	0.0%	0.0	0.0%	2.8	17.7%	-4.5	-22.0%
ZONE D	192	88.0%	3,136	21	86.8%	68.1%	78.4%	78.4%	3.2	13.2%	0.0	0.0%	0.0	0.0%	1.3	6.4%	0.8	3.6%	0.0	0.0%	0.0	0.0%	0.0	0.0%	-2.1	-10.0%
DRIAM A	64	88.0%	-	0	0.0%	0.0%	0.0%	0.0%	24.0	100.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
DRIAM B	64	88.0%	-	0	0.0%	0.0%	0.0%	0.0%	24.0	100.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
IPIAL	201	88.0%	2,400	15	91.7%	49.7%	54.2%	82.3%	2.0	8.3%	7.5	34.1%	0.5	3.4%	2.2	14.9%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	-2.7	-12.1%
DUMOULIN	122	88.0%	1,440	15	85.4%	49.0%	57.4%	79.8%	3.5	14.6%	5.8	28.0%	0.0	0.0%	1.3	9.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	-1.3	-6.5%
OTAL COATING		88.0%	13,378	102	65.5%	41.1%	47.1%	58.0%	8.3	34.5%	3.0	14.1%	0.1	0.4%	1.2	7.1%	0.4	2.3%	0.0	0.0%	0.0	0.0%	0.4	2.2%	-2.0	-9.5%
SHEETING	Technical speed	OEE Goal	PRODUCTION	Machine OT	SI	TAE	SAE	OEE	1.1 STATUTORY LOSSES		1.2 PLANNED LOSSES		1.3 BREAKDOWN LOSSES		1.4 SET UP LOSSES		1.5 OTHER /EXTERNAL LOSSES		1.6 SHORT STOP LOSSES		1.7 SPEED LOSSES		1.8 QUALTY LOSSES		1.9 UNKNOWN LOSSES	
	ppH	%	(Cases / Kgs)	Hrs	(Tmt/Tat), %	(Vat/Tat), %	(Vat/Tmt), %	(Vat/Ot), %	Hrs	%	Hrs	%	Hrs	4.0%	Hrs	%	Hrs	3.0%	Hrs	%	Hrs	11.8%	Hrs	1.0%	Hrs	4.0%
SHEETING M	1350	65.0%	12,393	14	72.6%	38.2%	52.7%	65.2%	6.6	27.4%	3.3	19.1%	1.0	7.1%	0.8	5.7%	0.0	0.0%	0.0	0.0%	2.7	19.3%	0.0	0.0%	-4.5	-25.9%
10'S MACHINE	Technical speed	OEE Goal	PRODUCTION	Machine OT	SI	TAE	SAE	OEE	1.1 STATUTORY LOSSES		1.2 PLANNED LOSSES		1.3 BREAKDOWN LOSSES		1.4 SET UP LOSSES		1.5 OTHER /EXTERNAL LOSSES		1.6 SHORT STOP LOSSES		1.7 SPEED LOSSES		1.8 QUALTY LOSSES		1.9 UNKNOWN LOSSES	
	ppH	%	(Cases / Kgs)	Hrs	(Tmt/Tat), %	(Vat/Tat), %	(Vat/Tmt), %	(Vat/Ot), %	Hrs	%	Hrs	%	Hrs	15.0%	Hrs	%	Hrs	5.0%	Hrs	%	Hrs	10.0%	Hrs	1.0%	Hrs	1.5%
10 PC machine	681	40.0%	-	0	0.0%	0.0%	0.0%	0.0%	24.0	100.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
PACKAGING MACHINES																										
MTG	3600	82.0%	-	24	100.0%	1533.3%	1533.3%	1566.0%	0.0	0.0%	0.5	2.1%	1.6	6.7%	0.3	1.4%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	-1.9	-8.0%
BOSCH M/C	0	82.0%	-	0	0.0%	0.0%	0.0%	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
.4 OVERWRAF	0	82.0%	-	0	0.0%	0.0%	0.0%	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
.8 OVERWRAF	0	82.0%	-	0	0.0%	0.0%	0.0%	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
FACTORY OVER ALL PERFORMANCE	Technical speed	OEE Goal	PRODUCTION	Machine OT	SI	TAE	SAE	OEE	1.1 STATUTORY LOSSES		1.2 PLANNED LOSSES		1.3 BREAKDOWN LOSSES		1.4 SET UP LOSSES		1.5 OTHER /EXTERNAL LOSSES		1.6 SHORT STOP LOSSES		1.7 SPEED LOSSES		1.8 QUALTY LOSSES		1.9 UNKNOWN LOSSES	
	ppH	%	(Cases / Kgs)	Hrs	(Tmt/Tat), %	(Vat/Tat), %	(Vat/Tmt), %	(Vat/Ot), %	Hrs	%	Hrs	%	Hrs	6.50%	Hrs	%	Hrs	2.80%	Hrs	%	Hrs	3.50%	Hrs	0.60%	Hrs	4.10%
		71.4%						#NAME?																		

APPENDIX IV: SAMPLE DATA COLLECTION FORM

Expected Production			*12,000*	*21,000*	*33,000*	*45,000*	*48,000*	*57,000*	*69,000*	
BREAKDOWNS										
MB01	Disc Assembly	XXX		/ X			/ XXXX	X /		X /
MB02	Vibrator Assembly	XXX		/ X			/ XXXX	X /		X /
MB03	Pusher chain	XXX		/ X			/ XXXX	X /		X /
MB04	Sealing rollers	XXX		/ X			/ XXXX	X /		X /
MB05	Crimp knives	XXX		/ X			/ XXXX	X /		X /
MB06	Registration system	XXX		/ X			/ XXXX	X /		X /
MB07	Folders/Guides	XXX		/ X			/ XXXX	X /		X /
MB08	Pellet sensors	XXX		/ X			/ XXXX	X /		X /
MB09	Electrical Fault	XXX		/ X			/ XXXX	X /		X /
MB10	MTG break down	XXX		/ X			/ XXXX	X /		X /
MB11	No mechanic	XXX		/ X			/ XXXX	X /		X /
MB12	No Electrician	XXX		/ X			/ XXXX	X /		X /
PLANNED										
PL01	Maintenance	XXX		/ X			/ XXXX	X /		X /
PL02	Machine Cleanouts	XXX		/ X			/ XXXX	X /		X /
PL03	Meetings/Trainings	XXX		/ X			/ XXXX	X /		X /
PL04	Trials / Sensories	XXX		/ X			/ XXXX	X /		X /
PL05	Breaks	XXX		/ X			/ XXXX	X /		X /
OTHER /EXTERNAL STOPS										
OS01	No Materials/gum	XXX		/ X			/ XXXX	X /		X /
OS02	Meeting/Training	XXX		/ X			/ XXXX	X /		X /

APPENDIX V: 5 Y TEMPLATE

Leader: Zone: Theme: Start: team:

WRIGLEY
A Subsidiary of Mars, Incorporated

REF Nº

1-Do we have a problem? (current Vs Standard situation)?

2-Do we know the root cause?

2.1- Understanding the problem

a- Who was involved?

b- What happened?:

c- Where?:

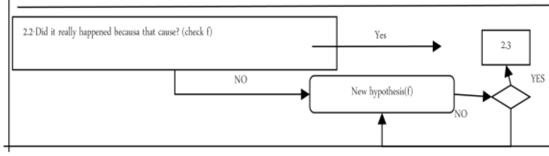
d- When did it happen?:

e- Why do you think it happened?:

f- How do you think it happened (1st evident cause):

g- Losees /time lost/time to repair

Show point f with schemas or drawings:



2.3-Define the root cause

Real cause (f)	WHY?	WHY?	WHY?	WHY?	WHY?
MEN					
MACHINE					
METHOD					
MATERIALS					

3.- Is it really the root cause? What countermeasure we can put in place?

Root Cause				
Checked?How?				
Countermeasure				
Who/when				
Temporary or permanent				

4.- Did you confirmed the countermeasures?

Who check efficiency and application?				
When?				
Result/ date				

APPENDIX VI: REASON CODES FOR PK MACHINE

FrmSubReasonGroup				
reason_code	**reason_desc**	**reason_type**	**report_group**	**std_time**
MB01	Curved/Straight Chute Assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB02	Cutter Assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB03	Band Drum Assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB04	Ejector Assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB05	Glue Pot Assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB06	Delivery Chute Assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB07	Electrical Fault	UNPLANNED DOWNTIME	BREAKDOWN	1
MB08	Heater gun Assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB09	Tipping Drum Assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB10	Clutch assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB11	Machine drive	UNPLANNED DOWNTIME	BREAKDOWN	1
MB12	Pellet Conveyor Assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB13	Truck assembly	UNPLANNED DOWNTIME	BREAKDOWN	1
MB14	OVERwrap Breakdown	UNPLANNED DOWNTIME	BREAKDOWN	1
MB15	Tray former Breakdowns	UNPLANNED DOWNTIME	BREAKDOWN	1
MB16	No Mechanic	UNPLANNED DOWNTIME	BREAKDOWN	1
OS01	No Material/Gum	UNPLANNED DOWNTIME	LACK OF MATERIAL	1
OS02	No operator	UNPLANNED DOWNTIME	LACK OF OPERATOR	1
OS03	Power Failure	UNPLANNED DOWNTIME	POWER	1
OS04	Fire Alarm	UNPLANNED DOWNTIME	OTHER UNPLANNED	1
OS05	Room Temperature	UNPLANNED DOWNTIME	OTHER UNPLANNED	1
OS06	Meeting/Training.	UNPLANNED DOWNTIME	OTHER UNPLANNED	1

FrmSubReasonGroup				
reason_code	**reason_desc**	**reason_type**	**report_group**	**std_time**
OS08	Any Other.	UNPLANNED DOWNTIME	OTHER UNPLANNED	1
OS09	Logistics(Spares/Water)	UNPLANNED DOWNTIME	OTHER UNPLANNED	1
OS10	Safety Projects	UNPLANNED DOWNTIME	OTHER UNPLANNED	1
OS11	lack of gum due to sugar mill	UNPLANNED DOWNTIME	LACK OF MATERIAL	1
OS12	Incident	UNPLANNED DOWNTIME	OTHER UNPLANNED	1
OS13	Lack of Trays	UNPLANNED DOWNTIME	LACK OF MATERIAL	1
PL01	Planned Maintenance	PLANNED DOWNTIME	PLANNED	1
PL02	Planned Machine Cleanouts	PLANNED DOWNTIME	PLANNED	1
PL03	Planned Meetings/Trainings	PLANNED DOWNTIME	PLANNED	1
PL04	Trials/Sensories	PLANNED DOWNTIME	PLANNED	1
PL05	Breaks	PLANNED DOWNTIME	PLANNED	1
PL06	Backlog	PLANNED DOWNTIME	PLANNED	1
Pl07	Planned Shutdown	PLANNED DOWNTIME	PLANNED	1
QL01	Trim	UNPLANNED DOWNTIME	QUALITY	1
QL02	Package waste	UNPLANNED DOWNTIME	QUALITY	1
QL03	Destroyed gum	UNPLANNED DOWNTIME	QUALITY	1
SL01	Speed slower than design	UNPLANNED DOWNTIME	SPEED	1
SL02	Factory Bench Marks higher speed	UNPLANNED DOWNTIME	SPEED	1
SL03	Line bottle necks	UNPLANNED DOWNTIME	SPEED	1
SS01	Cleaning rollers	UNPLANNED DOWNTIME	SHORT STOP	1
SS02	Paper Jam	UNPLANNED DOWNTIME	SHORT STOP	1
SS03	Paper Jam in chute	UNPLANNED DOWNTIME	SHORT STOP	0.25
SS04	Jointed Paper Wax	UNPLANNED DOWNTIME	SHORT STOP	1
SS05	Pellet Jam in Tipping Drum	UNPLANNED	SHORT STOP	0.3333

FrmSubReasonGroup				
reason_code	**reason_desc**	**reason_type**	**report_group**	**std_time**
		DOWNTIME		
SS06	Unwind jammed Prelam foil	UNPLANNED DOWNTIME	SHORT STOP	2
SS07	Smashing	UNPLANNED DOWNTIME	SHORT STOP	1
ST01	Statutory downtime	STATUTORY DOWNTIME	STATUTORY	1
ST02	No Production needed	STATUTORY DOWNTIME	STATUTORY	1
SU01	Change overs	UNPLANNED DOWNTIME	CHANGE OVER	1
SU02	Reloading prelaminated foil	UNPLANNED DOWNTIME	SET UP	0.5
SU03	Reloading Label Magazine	UNPLANNED DOWNTIME	SET UP	1
SU05	Machine Cleaning/lubrication	UNPLANNED DOWNTIME	SET UP	1
SU06	Glue Filling	UNPLANNED DOWNTIME	SET UP	3

APPENDIX VII: PLANNED PREVENTIVE MAINTAINANCE SCHEDULE.

PLANNED PREVENTIVE MAINTAINANCE - PK № 3

PK

Equipment	Unit	Description	Comment	Date	Mechanic`s signature
PK	Infeed conveyor	Check drive shaft, idlers, bearings (if backlashes more than acceptible or irregular wear - change)			
		Check bushings , rods, fasteners			
		Check transport belt			
	shute	Check bushings, spring-loaded sectors			
		Check of correct working 1/2 pellet sensor			
	3d drum	Check bushings , bolts, folders			
		Free-run testing - outrun checking			
	2d drum	Check bushings , bolts, folders			
		Free-run testing - outrun checking			
	1st drum	Free-run testing - outrun checking			
	Pushers	Check pushers for wear			
		Check bolts, bearings of bar - pusher carrier for wear and backlashes			
		Check eccentric bearing			
	High speed section	Check bearings			
		Check bushings			
		Tight fasteners			
	Package transport	Check transport belts (if wear - change)			
		Check bearings, idlers			
	Foil cutter	Check driving shafts,idlers, bearings ,blades (if backlashes more than acceptible or irregular wear - change)			
		Check rollers, bearings, shafts - if necessary - change			
	CTB cutter	Check driving shafts,idlers, bearings ,blades (if backlashes more than acceptible or irregular wear - change)			
		Check rollers, bearings, shafts - if necessary - change. Replace rubber o-rings			
	Wax applicator	Check for leakages			
		Check scrapers , set gaps			
		Check bushings			

APPENDIX VIII: CATEGORIZED SPARE PARTS.

PK 1.8 CATEGORIZED SPARE PARTS

PK 1.8 Machines

	Part #	Parts Description	# of parts in assembly	Stock in Hands	needed for the ssembley	Stock material unit @		QTY To order	Kiesta	Manufacturer/ machinist Standard Engineering Nairobi	Manufacturer/ machinist mechanical Eng	
LOWER CORK ROLLER AND CUTTER ASSEMBLY	PK 14-1	Paper cutter head	1		To use old		1	0				
	PK 14-2	Cork roller bearing bracket RH	1		available		1	0				
	PK 14-3	Cork roller bearing bracket LH	1	3	available	48.28		48.28				
	PK 14-4	Cork roller bearing mounting shaft	1		available		1	0				
	PK 14-5	Coork roller spare sleeve	3		available		3	0				
	PK 14-6	Cork roller link space collar	2	2	available	277.4		554.8				
	PK 14-7	Cork roller link end space	1				1	0		2,500.00		
	PK 14-8	Cork roller angle link	3		available	468.75		1406.25		3,800.00		
	PK 14-9	Cork roller plain link	3				3	0		2,800.00		
	PK 14-10	Cork roller bushing	6	47	available	186.12		1116.72				
	PK 14-11	Cork roller spring bar	3		available		3	0				
	PK 14-12	cork roller shaft (Short)	3	43	available	14,008.50		42025.5				
	PK 14-13	Cork roller shaft screw	3	2	available	274.5	1	823.5				
	PK 14-14	Cork roller (Recessed)	3		available		3	0				
	PK 14-15	Cork roller driven gear	3	12	available	2,000.00		6000				
	PK 14-16	Cork roller coil spring	3	15	available	425.35		1276.05				
	PK 14-17	Cork roller shaft (Long)	1	8		10,186.01		10186.01				
	PK 14-18	Cork roller bearing (RH)	1		available		1	0				
	PK 14-19	Cork roller bearing (LH)	1	4	available	4,297.50		4297.5				
	PK 14-20	Paper feed stop reverse ratchet	1	5	available	3,800.00		3800				
	PK 14-21	Cork roller sub-assembly	1	16		46,911.18		46911.18				
	PK 14-22	Cork roller end driving gear	2	10		225.4		450.8				
	PK 14-23	Cork roller centre driving gear	1	15		3,411.47		3411.47				
	PK 14-24	Cork roller lange spacer	1		available		1	0				