Effective Preventive Maintenance Scheduling: A Case Study

Hasnida Ab-Samat, Livendran Nair Jeikumar, Ernnie Illyani Basri, Nurul Aida Harun and Shahrul Kamaruddin
School of Mechanical Engineering
Universiti Sains Malaysia
Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia

Abstract

Maintenance is an important system in operation. In an era where industries are focusing on 24 hours operation to maximize production, machines are pushed to its absolute limits to cope with this demand. As utilization increases, the rate at which the machine parts get worn out increases thus the frequency of failure increases rapidly. To combat this problem and ensure that machines continue to operate at its optimum, maintenance work is carried out. One of the branches of maintenance technique which is carried out to prevent occurrences of failure before it happen is known as Preventive Maintenance (PM). However, performing PM may not be as easy as it requires great co-operation from the maintenance, production and management departments. This paper is written to study the aspects of effective PM and to analyze the causes of inefficient PM activity in a case study company and its implications. Another important approach taken is to investigate the causes of machine downtime by performing a root cause analysis. Affinity diagram was formed to highlight several issues with implementation of PM and a further analysis using Tree Diagram enabled to generate possible solutions. The findings of this provides prove that separating the machines into critical and non-critical categories, each having a different priority level is a crucial step towards solving the issue at hand and ensuring the reduction in downtime occurrence in addition to reducing the workload of the technicians.

Keywords
Preventive Maintenance, Machine Downtime, Scheduling, Root Cause Analysis, Affinity Diagram, Tree Diagram

1. Introduction

To cope with the tough competition in manufacturing industries, companies have invested in highly automated production system with excellent equipment. In order for the companies to sustain their hold in the global market, full utilization of equipments are vital in order to maintain the production operation thus leading to the economical sustainability as well as maximization of company profit [1]. When an unplanned downtime occurs due to machines or equipment failure, this will disrupt the production operation. It would be very expensive to revise the production plan in an emergency situation, and also causes lower product quality and variability in service level. Therefore, maintenance system plays a crucial role in order to ensure the whole system runs efficiently and effectively [2]. Maintenance is one of the main functions in the manufacturing environment as it more likely to sustain the performance of equipment and improve the operations efficiency in manufacturing plant. Even though maintenance is a non-value added process in industry, it is undeniable that maintenance plays a major role in asset management process. Maintenance has been mostly practiced in industries as it gives benefits in term of profit to the company with customer satisfaction. Maintenance which is also known as a profit generator activity, a method to relate with other operation functions as well as to ensure the availability, reliability and safety of all equipment in the plant [3]. The company will gain higher profits through the safety of the equipment and undisrupted production system which optimizes cost, quality and throughput.

The performance of maintenance operations becomes the crucial issue in company or operation plant. Maintenance operation does not only focus on repairs and spare part replacement activities, is also plays a big role as it influenced the performance of maintenance work. Thus, the scope of maintenance management should cover every stage in the life cycle of technical system including plant, machinery, equipment and facilities such as specification, acquisition, planning, operation, performance evaluation, improvement, replacement and disposal [4]. The main problem faced in this case study is the downtime still occurs even though after maintenance activities are carried out. Therefore, the available schedule of preventive maintenance (PM) needs to be simplified.

The main aim for this paper is to reduce the planned downtime for PM by analyzing and improving the available schedule that is employed in the case study company. Therefore, after identifying the maintenance activities applied in the company and analyzing the failure rates occurring in the production operation, the analysis is performed in terms of management tools and techniques to relate the entire criterion that had been identified before. Thus, the main objective to simplify the PM schedule is achievable. Based on data gathered, the pattern of the failures based on the previous month's downtime can be studied. Hence, more attention is given to the critical downtime machines in the cluster and analysis is done using maintenance management tools and technique. This should help to reduce downtime from recurring in the company's plant.

This paper is written to study the effectiveness of PM and how it functions in manufacturing system. In particular, this paper is structured in few sections and subsections. In the introduction' section, overviews of problems faced in maintenance are firstly elaborated before the maintenance technique is introduced. The implementation of PM is elaborated in the following section. Next section organized and elaborated the PM Planning and Scheduling Framework. The following subsection including data analysis, PM Planning Model and PM Scheduling Model are discussed according to the case study in the company. Maintenance Schedule analysis is discussed in Section 4. To show practical side of PM, suggested improvement are put forward in final section before conclusion.

2. Implementation of Preventive Maintenance (PM)

According to [5], corrective maintenance and (CM) preventive maintenance (PM) at time intervals are the most common maintenance techniques. CM is defined as a fire fighting approach where equipment is allowed to run without interruptions and maintenance activities are conducted only when equipment fails. It requires minimum number of manpower and money spends to monitor the condition of equipments [6]. However, the downside is high maintenance cost will be required when any catastrophic failure happen. On the other hand, PM is a basic maintenance technique which is usually applied in manufacturing environment in order to facilitate the production flow as well as enhancing the equipment efficiency. PM usually relates to schedule with fixed time interval that is done daily, weekly, monthly or some other predetermined intervals. The use of performances interval is to implement preventive task when needed. Usually when applying PM, maintenance activities are planned and scheduled based on equipment's requirement and historical data of failures. The planned activities involves the documented maintenances task, labor resources requirements, parts and material requirements, duration to perform task and also other technical references related to equipment. The activities are organized according to work's priority, the work order, labor resource availability, duration to perform task as well as planning of parts and materials [7].

PM plays a crucial role in planning an effective maintenance schedule which can be incorporated with production scheduling, so that this will lead to the efficiency and effectiveness in manufacturing system. Therefore, it is essential that production planning and PM activities can be carried out in an integrated way in order to avoid the failures which causes the need to do re-planning. Nevertheless, there are a lots of problems occur during implementation of PM. For instance, the overlapping between PM planning and production scheduling. The issue of integrating both areas is highlighted due to its importance in the current highly competitive environment. Thus, this will lead to the other problems that influence in operating system such as production flow, set up times, cause downtime, increase the waste and the deterioration of equipment [8].

"Prevention is better than cure" should be applied in solving maintenance problems in manufacturing environment as PM activities should be done properly to avoid consequences of inefficient production scheduling and PM planning. In particular, the manufacturing data should be employed in implementing PM, thus will help to facilitate the production flow. As PM been carried out with good decision making in manufacturing facilities, this will lead to restore the production line to an 'as-good-as-new' status [9]. A proper PM schedule should be conducted wisely according to the planning, so that, the flow of production and PM activities can be carried out well. Thus, this will enhance the efficiency of production output without having any difficulties regarding equipment failures or downtime.

Based on the facts on PM discussed earlier, a case study was conducted in a semiconductor company situated in Penang, Malaysia. The company which has been established since 1994 is equipped with highly automated state-of-art facilities and leading technologies in manufacturing flexible printed circuit (FPC). The company comprises a full range support and services from circuit design, prototype fabrication and mass production up to flex assembly. Most of the product produce in this company is basically in form of panel or roll. Some of panel and roll produced in either single sided or double sided. The processes of manufacturing of FPC consist of several operations. The production operation of manufacturing high quality of FPC can be divided into four clusters. Those clusters are Circuit Formation (Cluster 1), Circuit Protection (Cluster 2), Finishing (Cluster 3) and Back End (Cluster 4). Each cluster has its own sections according to the associated processes.

For this case study, the improvement of PM was conducted, focusing on the Circuit Formation Cluster which is cluster 1. This cluster comprises three sections known as wet process, imaging and post treatment as shown in

Figure 1. From this figure, it can be comprehended that the processes in this cluster starts with the Imaging process followed by the Wet-Process and ends at Post Treatment.

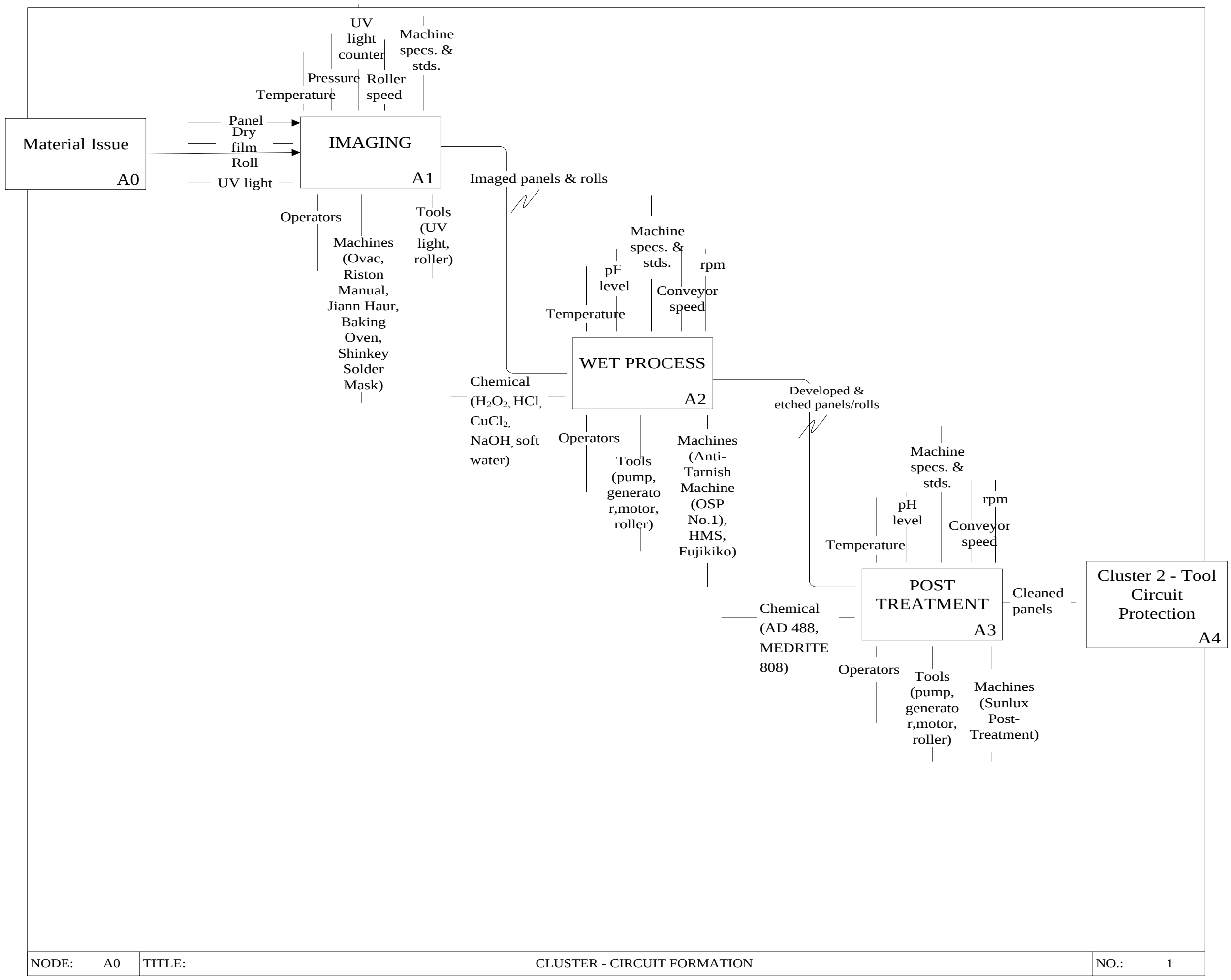

Figure 1: Processes in Circuit Formation Cluster

Basically, PM can be optimized as the machines have been clustered into the group of machines. This will lead to the ease of maintenance activities, and reduce the workload carried by maintenance staff. In the case study company, the production floor of manufacturing FPC board consists of 109 machines with only 8 technicians for maintenance work. The technicians who are responsible according to four clusters are also responsible for the maintenance of company's equipment like air-conditioners and lamps. The working hour for the personnel in the company is 12 hours/day. But, the few number of maintenance staffs that are responsible for each cluster usually lead to inefficient PM planning. Furthermore, the company always faces major and minor problem of breakdown. For major breakdown, most of the machines need to undergo maintenance for more than 2 hours whereas the minor ones take less than 2 hours. This major problem can be the main attention to the PM in order to reduce the breakdown in manufacturing facilities. Thus, this contributes to the improper conducted PM scheduling even though it has been done in predetermined time. Therefore, proper scheduling should be proposed based on the machine's requirement and history data of failures.

3. PM Planning and Scheduling

Preventive maintenance (PM) scheduling is a very challenging task in printed-circuit manufacturing due to the complexity of flexible printed circuit fabrication and systems, the interdependence between PM tasks, and the balancing of work-in-process (WIP) with demand/throughput requirements. In this section, after a discussion of the problem background, PM planning and scheduling in flexible printed-circuit fabrication is proposed.

3.1 Data Analysis

For this research, the PM planning and scheduling are based on major machine downtime where the machine does not operate due to breakdown more than 2 hours. Recently, the PM schedule is separated into four clusters. A total of 109 machines need to be rescheduled in proper way as only 8 technicians are responsible to look after all these machines (six technicians on day-shift and two for night-shift). Data for major machine downtime was collected starting from January 2011 until September 2011. The PM schedule for clusters is very complicated and thick. No proper specification on critical machines is taken into consideration. From January to September 2011, data for total downtime major have been extracted and shown in Figure 2.

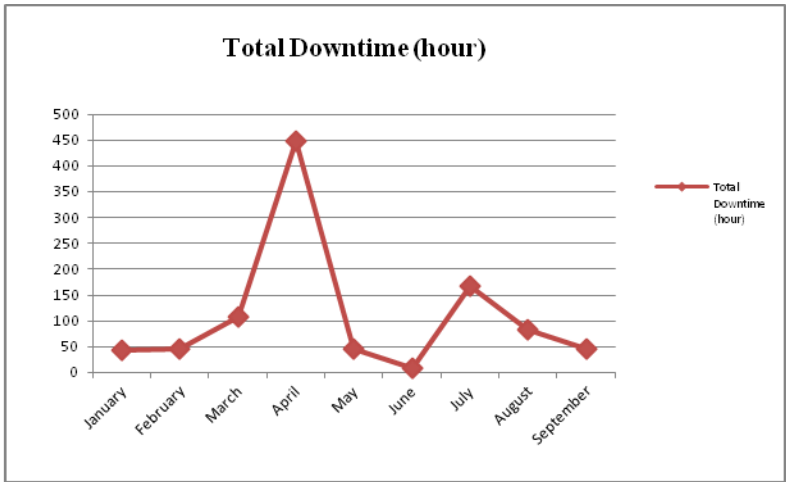

Figure 2: Total downtime from January till September 2011

Figure 2 show how the downtime varies with month. Machine downtime in April seems to be worst among other months with total downtime up to 449.25 hours. Data for April are narrowed down to see causes of machine downtime and are listed in Table 1.

Table 1: Data on machine downtime major in April 2011

Date	Machine	Description Of Problem	Total down time	Root Cause
01.04.11	1	Annual service	146Hrs 10Min	Annual service
04.04.11	2	Motor spoil and bracket broken	7Hrs	Oscillation not running
04.04.11	3	Entrance cover run time over	2Hrs 55Min	Open close shuttle bracket broken
07.04.11	4	Annual service	Until now	Annual service
07.04.11	5	Screen function "hang"	93Hrs 55Min	Touch screen spoilt and PLC no memory data
11.04.11	6	Roller not function	4Hrs 15Min	Chain fall down and encoder broken
11.04.11	7	Can't punch	34Hrs	Safety sensor problem
12.04.11	8	Main Chiller pipe leaking	4Hrs 30Min	Chiller pipe broken
18.04.11	9	Pressure up until 120bar	26Hrs 30Min	2nd Pressure valve not function
18.04.11	10	Water rinsing pump not function	4Hrs 30Min	Pump produces an abnormal sound
21.04.11	3	No power supply	93Hrs 30Min	Transformer burnt
25.04.11	11	Hal dryer not running	10Hrs	PLC no power and power supply card burn
25.06.11	12	Cannot punch	18Hrs	Cylinder sensor wire break & servo motor jammed
27.04.11	13	Roll scratches	4Hrs	Roller scratches

From Table 1, Machine 5 shows the longest downtime among other machines (93hours 55minutes). The cause for this breakdown is the touch screen spoilt no data memory in PLC (Programmable Logic Controller). Actions taken to undergo this problem are by changing the touch screen and download the program. But, these actions cannot be classified as PM actions as technicians done the maintenance after this machine breakdown, not before these problem occurred. Second longest downtime is from Machine 3 (93hours 30minutes). Cause of breakdown is transformer of this machine burnt, thus lead to no power supply. Action taken to overcome this problem is by changing to a new transformer. Not only focusing on these two machines, other machines that lies into major downtime must also be taken into consideration. Data collected from all these ten months is analyzed. Machines which are having longest downtime are classified as critical machines. On the other hand, further causes of ineffective are being analyzed. Various causes can affect the full implementation of effective PM. Figure 3 shows the issues involved to the ineffectiveness on PM that occur in the company.

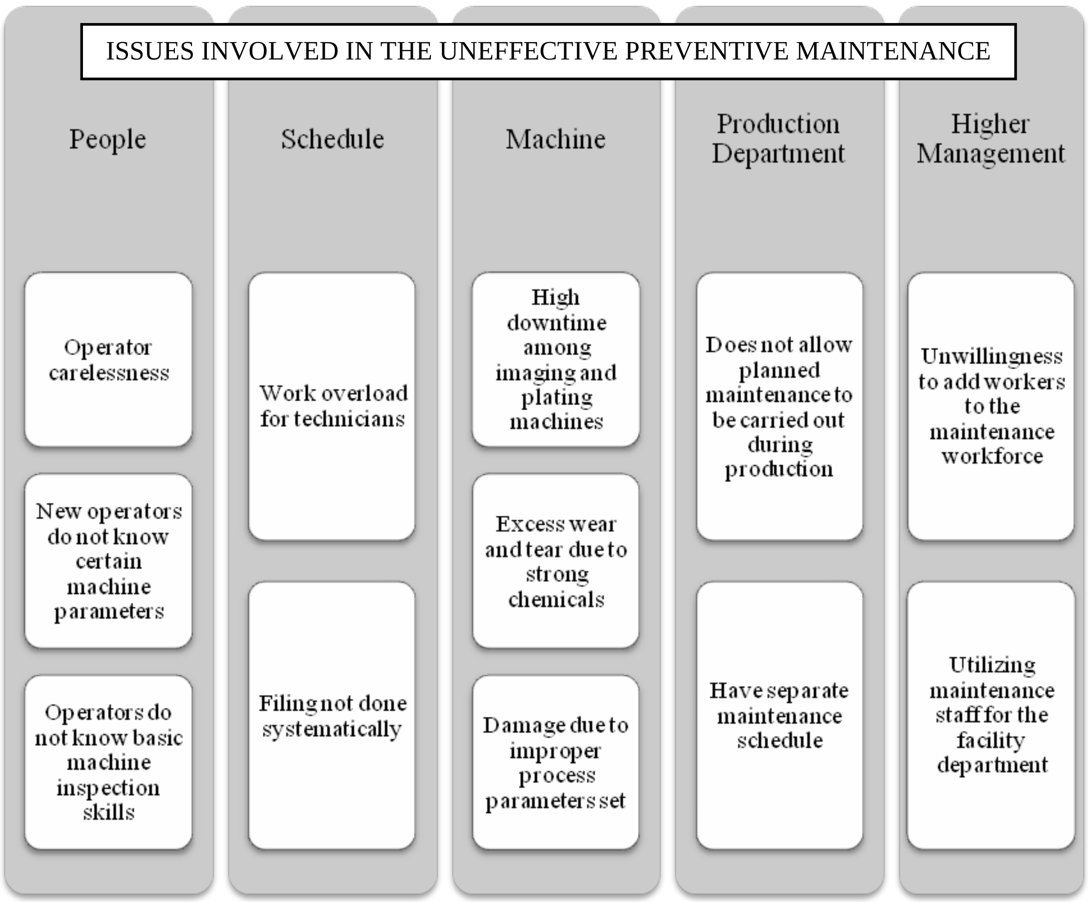

Figure 3: Causes of Ineffective Maintenance

Another method that is used to study the ineffectiveness maintenance consequences on the machines is by using root cause analysis. The aim of performing this root cause analysis is based on a maintenance perspective where emphasis is placed on how proper maintenance can avoid the common problems that cause machine downtime. Root cause analysis is a problem solving process designed for use in investigating and categorizing the root cause of events. It's a useful tool to identify what and how an event occurred and why it happened. Through this, suggestions and prevention steps can be generated to solve the issue. Only through this where the probability of occurrence of the same problem can be minimized.

The case study company currently has 107 machines operating and a clutch of machines crucial to the flow of the production processes are prone to failure. Even after countless repairs done, they are still susceptible to failure. It is notable that many of these machines are involved in processes that involve strong chemicals thus leaves many parts of the machines exposed to excess wear and tear. Based on the data gathering and analysis done, the root causes of the machines were identified and its contributions in terms of downtime are recorded based on Table 3.

Table 3: Machine downtime and their Root Cause

Month	Date	Machine	Description Of Problem	Total down time(hr & mins)	Root Cause	Action Taken	Preventive Plan
July	04.07.11	A	Dryer roller not function	2 hrs 5 mins	Gear broken	Change new gear	Check all the gear every month, if spoil
August	01.08.11	B	Chemical Pressure tank #2 not function	4 hrs 10 mins	Ampler spoil	Change new pump	Check the motor during PM time will
	04.08.11	C	Top roller dent	5hrs	Roller dent	Change new roller top and bottom	Change roller every 3 month
	08.08.11	D	Glass broken	9 hrs 30 mins	Glass broken	Change new glass, do rubber surround the glass	Glass broken at the joining material. Ask vendor(LSP) to fix the sensor
	09.08.11	B	Aqua control error	3 hrs 30 mins	Main MCB trip	Change new MCB & wire	Monthly check on all the MCB
	09.08.11	E	Filter dry film tearing	3 hrs 55 mins	Shelf-life	Change new filter mesh	will monitor the shelf-life and get the standard
September	23.09.11	E	Chemical temp low. Heater problem	2 hrs	Heater spoil ready	Change new heater, heater only run 1 unit	Keep spare two unit heater
	26.09.11	F	Power can't on	2 hours 55 mins	Limit switch shutter spoil	Change new limit switch	NONE
	29.09.11	G	Roller not running	8 hrs	Chain broken	Change new chain and do alignment	NONE

These machines are critical machines that control the overall production flow. Of all the problems that occur, they can all be generally classified as problems that occur mainly due to wear and tear and other electrical or technical problems. Wear and tear is a common problem faced by machines in this factory as they are constantly exposed to strong chemicals such as Hydrochloric Acid (HCL). The developing and etching machines constantly have major problems that cause lengthy downtimes. Due to the nature of this process, these machines have to be constantly inspected to detect any possible signs of wear and tear at the earliest stage possible. This is so that the technicians and operators can be prepared to replace worn out parts at a suitable stage before major problems occur. If this is carried out, major problems with these machines can be minimized thus keeping downtime at a minimum. However it is currently not carried properly due to time constraints.

3.2 PM Planning Model

Based on the collected data, several ideas have been derived in achieving effective PM in this company as illustrated in Figure 4.

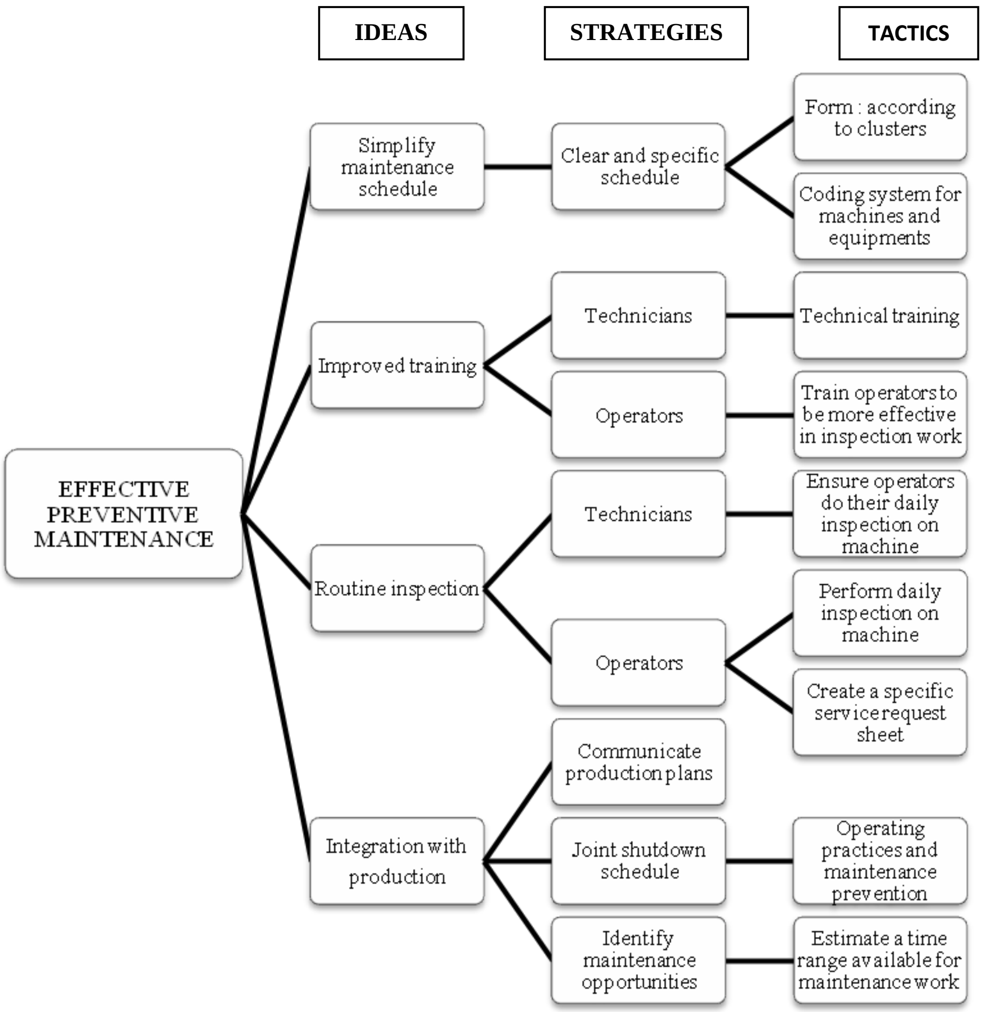

Figure 4: Analysis of effective PM using Tree diagram

Figure 4 shows strategies and tactics evaluated from the proposed ideas in implementing effective PM. Main ideas generated for this PM are to have simple maintenance schedule, do training for technicians and operators in maintaining machines to be in good conditions, do routine inspections and also integrations with production. In terms of integrating with productions, maintenance department must integrate with productions in doing PM periodically. Communicate with productions plans to stop operations for awhile to do PM and joint shutdown schedule. By doing this, machine can be maintained without or less breakdown. Operators also will know how to repair their machines, not only depending on operators.

3.3 PM Scheduling Model

One of main objective in implementing PM in this company is to have simple yet effective PM schedule. In achieving this goal, PM schedule will be classified into clusters and its respective technicians. Critical machines are taken into highest priority where all spare parts must be ready before machine breakdown together with necessary actions to overcome these machines from breakdown. Other than that, the schedule must state clear timeline especially on periodic maintenance (some machines part must be changed or maintained within certain period). Moreover, the PM schedule must be sorted into technicians. Every one of them will focus on their specified machines. Thus, maintenance activity can be done effectively by fully utilizing all technicians. Ensuring this schedule will ease technicians is the upmost characteristics in implementing effective PM.

4. Maintenance Schedule Analysis

Analyzing the preventive maintenance schedule thoroughly, it can be noted that for every machine, there are a few steps of maintenance work to be carried out. A standard machine requires approximately 10 to 15 minutes of maintenance work to be done. Since the maintenance department currently does its weekly maintenance on Monday, there are only three to four technicians who have to be responsible on performing maintenance work on 109 machines. This is a tough task to perform considering time limitations and constraints due to unexpected machine failures to be resolved on the day and other maintenance duties to be done.

From the perspective of production, the machines can be divided into critical and non-critical machines. The critical machines are the major machines that control the flow of the production and may be the bottleneck machine. When these machines fail, the production may have to be stopped, such is the importance of these machines. These machines too are highly susceptible to wear and tear thus constant inspection and weekly preventive maintenance work has to be carried out. The non-critical machines on the other hand are machines that have very low frequency of failure. This can be attributed to the working nature of these machines where they are not susceptible to wear.
Based on downtime analysis taken from a period of July to September 2011, the machines having a regular downtime of over 2 hours can be classified as the critical machines. The rest of the machines are classified as non-critical machines due to their low failure rate. The critical machines are Machine 10 (predictive maintenance already being conducted), B, C, D, E, F and G.

Based on the observation from the technician in charge of the cluster, two things are evident where high downtime machines are given particularly high priority and weekly maintenance is mandatory in addition to the predictive maintenance being carried out and that weekly maintenance is also carried out for low downtime machines but these machines are not critical ones and that the weekly maintenance does not affect its performance or influences the causes of downtime.

5. Suggested Improvement

Based on these observation and analysis, a few solutions can be implemented and its effects examined on the maintenance work:

1. Critical machines has to be given full attention and predictive maintenance work has to be continuously carried out no matter what because these machines influence the overall process flow strongly and downtimes can't be afforded.
2. Machines that are not critical ones have to be scrapped out from the weekly maintenance schedule. This is because the technicians have to balance between maintenance and facility work where a chunk of time is spent on facility work and since first priority is given on the critical machine to allow predictive and weekly maintenance to be carried, it is only sensible that the weekly maintenance of non-critical machines be scrapped to allow more time for the technicians to carry out more important duties.

Based on a simple calculation for Cluster 1, where out of 23 machines currently in operation, 6 machines are deemed as critical ones so if the non-critical machines are scrapped from the weekly maintenance schedule, it is evident that per week, the technicians gain 5.67 hours of time to carry out the weekly and predictive maintenance of critical machines, the monthly maintenance of critical and noncritical machines, corrective maintenance work and also for facility work. From this it is proven that the weekly maintenance of noncritical machines can be eliminated from the master schedule and this enable lesser work load on the technicians.

Conclusion

The implementation of preventive maintenance (PM) has proven that machine failure rates can be greatly reduced; ensuring uninterrupted production. In most companies, PM is not always carried out on schedule due to the circumstances involved and this affects the sole purpose of carrying out PM which requires precise planning on maintenance dates for each machine. However, based on the situation in the company, it was evident why the preventive maintenance work could not be carried out efficiently. A lack of manpower coupled with a hefty maintenance schedule to accomplish is a daunting task. The analysis done on the machine downtime causes turned up technical problems that are generally caused by improper maintenance work further proving how crucial it is to carry out PM on time.

In the case study company, the downtime data and analysis has shown the list of critical machines and the ineffectiveness of the current maintenance schedule that does not distinguish between the critical and non-critical machines. A further root cause analysis has shown that the machines suffer critical breakdowns when maintenance work is not done properly. Thus to prove this, the root cause analysis was done to show how each problem correlates with issues such as wear and tear and the delay to replace worn out components that lead to breakdowns. From the maintenance schedule analysis based on Cluster 1(Circuit Formation), the machines can be grouped into critical and non-critical ones and if the focus is to be given on the weekly maintenance of critical machines whilst sacrificing the maintenance of non-critical machines, the technician gains approximately 5.67 hours of extra time and this time can be used to focus on a wholesome maintenance work and inspection on the critical machines. If this is managed to be done, the downtime of critical machines can be greatly reduced thus ensuring smooth production.

References

1. Parida, A. and Kumar, U., 2006. “Maintenance performance measurement (MPM): issues and challenges”, Journal of Quality in Maintenance Engineering, 12(3), 239-251.
2. Sharma, A., Yadava, G.S. and Deshmukh, S.G., 2011. “A literature review and future perspectives on maintenance optimization”, Journal of Quality in Maintenance Engineering, 17(1), 5-25.
3. Waeyenbergh, G. and Pintelon, L., 2002. “A Framework for Maintenance Concept Development”, International Journal of Production Economics, 77, 299-313.
4. Murray, M., Fletcher, K., Kennedy, J., Kohler, P., Chambers, J., Ledwidge, T., 1996. "Capability assurance: a generic model of maintenance", Maintenance Engineering Society of Australia.,
5. Jonsson, P., 1997. “The status of maintenance management in Swedish manufacturing firms”, Journal of Quality in Maintenance Engineering, 3(4), 233 – 258.
6. Dhillon, B.S., 2006. Maintainability, Maintenance, and Reliability Engineering. Florida: CRC Press Taylor & Francis Group,
7. Smith, R. and Hawkins, B., 2004. Lean Maintenance: Reduce Costs; Improve Quality and Increase Market Share. Massachusetts: Butterworth-Heineman Publication.
8. Sortrakul, N., Nachtmann, H.L., and Cassady, C.R., 2005. “Genetic algorithm for integrated preventive maintenance planning and production scheduling for a single machine”, Computer in industry, 56, 161-168.
9. Aghezzaf, E.H., Jamali, M.A., and Ait-Kadi, D., 2007. “An Integrated Production and Preventive Maintenance Planning Model”, European Journal Operational Research, 181(2), 679-685.