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Analysis of Failure Modes and Selection of Maintenance Strategy for Vital Machines in a Tea Industry

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Abstract

The aim of this paper is to find out the maintenance strategy for vital machines in a tea industry. Firstly various failure modes and the potential causes and effects of failure are identified using failure mode and effect analysis (FMEA).Risk priority number of failure modes are calculated. VED analysis is combined with FMEA in order to find out vital machines with very high RPN number. Maintenance plan for each of the vital machines are find out using Analytical Hierarchy Process (AHP) and VIKOR, and Preventive maintenance interval is scheduled using Monte Carlo simulation.
Keywords: FMEA, VED, AHP, VIKOR, Monte Carlo Simulation

I. INTRODUCTION

The reliability analysis of industrial systems is very important, in order to guarantee their functional behaviour. Therefore the analysis of the system as whole unit is not enough in order to estimate the system reliability. The increasing complexity of industrial systems is mainly due to the variety of technologies involved in their implementation. Performance of each machine depends on the type of maintenance strategies employed on it. Machines used in industries need proper maintenance because failure of machine may result in the production loss. Use of inappropriate maintenance strategy may result in the increase of the maintenance cost. Increase in maintenance cost will result in the increase of the production cost. Selection of a maintenance strategy to a particular machine is a problem of decision making and it is always a challenging task.

II. NEED FOR MAINTENANCE STRATEGY SELECTION

Most of the machines in the company are aged. Currently corrective maintenance strategy is used in the company. According to corrective maintenance strategy, machines are repaired only after the complete failure of it. This will lead to very high machine downtime loss and maintenance cost. The machine downtime loss will lead to production loss and company cannot meet it demand. Therefore company need an appropriate maintenance strategy to reduce machine downtime loss. Maintenance strategy differs from machine to machine based on the nature, technology used and type of machine.

III. LITERATURE SUMMARY

Rakesh.R, Bobin Cherian Jos, George Mathew (2013) [1] explains that FMEA is a systematic method of identifying and preventing system, product and process problems before they occur. It is focused on preventing problems, enhancing safety and increasing customer satisfaction. According to Sheng-Hsien (Gary) Teng and Shin-Yann (Michael) Ho(1995)[2] ,There are two phases in the FMEA process. The first phase is to identify the potential failure modes and their effects. The second phase is to perform criticality analyses to determine the severity of the failure modes. Chandrahas, Santosh Kumar Mishra and Deepak Mahapatra(2015)[3] ,says that Maintenance strategy plays a very important role in all kind of manufacturing industries. Each maintenance strategy has their characteristics, importance and drawbacks. According to, Jureen Thor ,Siew-Hong Ding , Shahrul Kamaruddin(2013)[4], The five main types of maintenance policies are : corrective maintenance, preventive maintenance, predictive maintenance, autonomous maintenance, and design out maintenance. Traditionally, the original maintenance alternative implemented in the industry is corrective maintenance (CM). CM or failure-based maintenance corresponds to actions employed when functionality fails. Rakesh Kumar Singh & Makarand S. Kulkarni (2013) [5] explains AHP (Analytic Hierarchy Process) is one of the very popular and widely used MCDM methods. It assumes that a problem can be structured as a hierarchy of an overall goal and a set of conflicting information. In this a typical decision problem is structured in three levels. The goal is at the top level of the AHP decision hierarchy, while the criteria are placed on the second level. These criteria are used to judge the alternatives on the lowest level. These are used to evaluate a predetermined number of alternatives.

Fereshteh Jaderi, Elham sa'idi, Bagher Anvaripour and Nader Nabhani[6] , says that Critically analysis for a particular industry means the degree of importance of a certain piece of equipment to that industry . This kind of analysis generally can be achieved by determining the consequences of failure. Thus, the decisions of the businesses are made by taking the damage of a certain amount of risk into account. According to Siew-Hong, Ding and Shahrul Kamaruddin(2012)[7],

In order to maintain their competitiveness capability in the market, higher productivity with minimum production cost becomes the main target. Either productivity or production cost, it cannot be apart from maintenance issues. Productivity cannot be achieved without proper maintenance on production system. At the mean time, maintenance expenditure can achieve 15 to 70 percent of production costs in different industry. R. Tavakkoli-Moghaddam and S.M. Mousavi (2011)[8] explains that a new integrated methodology can be used to solve the selection problem. Two well-known decision making methods, namely analytic hierarchical process (AHP) and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), are combined in order to make the best use of information available, either implicitly or explicitly. The aim of using the AHP is to give the weights of the selected criteria. Finally, the VIKOR method is taken into account to rank potential alternatives. Mohamed F. El-Santawy1 and A. N. Ahmed (2012)[9], says that The merit of MCDM techniques is that they consider both qualitative parameters as well as the quantitative ones. As the decision maker tries to maximize or minimize outcomes associated with each objective depending on its nature, so a Multi-Criteria Decision Making (MCDM) problem arises. It should be noticed that evaluation criteria could be of various nature. According to Tsu-Ming Yeh and Jia-Jeng Sun(2011)[10] Reliability and maintainability play a crucial role in ensuring the successful operation of plant processes as they determine plant availability and thus contribute significantly to process economics and safety. Maintenance and maintenance policy play a major role in achieving system's operational effectiveness at minimum cost.

IV. PROBLEM IDENTIFICATION AND PROBLEM STATEMENT

The case study is done at GEMRAJ tea factory. The company cultivates tea, manufacture; sell and export blended and packed tea. The factory is located in Pattumudy near Peermade. Currently the company use corrective maintenance strategy. Lack of preventive maintenance activities lead to severe machine downtime loss and production loss.
The main problems identified in the company are:

- Machine breakdowns are increasing
- Machine downtime loss
- Production loss due to machine downtime
- Company cannot meet demand
- Money loss due to machine downtime

The problem statement is "machine downtime loss are increasing due to frequent failure of machines"

V. PROBLEM DEFINITION

The major problem faced by the company is the high downtime for many of its equipment. The frequent failure of equipment results in high machine downtime. Most of the failed equipment needs much time for maintenance. The production process is stopped until the failed equipment retains its function. The data which helps to prove this problem is expressed in the table below:

Table - 1
Machine downtime loss

YEAR	*MACHINE DOWNTIME IN HOURS*
2010-11	*437*
2011-12	*419*
2012-13	*454*
2013-14	*486*
2014-15	*513*

The table shows the total machine downtime in hour for the last five years. From the table, it is clear that the total machine downtime in the GEMRAJ tea is increasing in the recent years.

Another problem faced by the company is insufficient production. The company cannot attain the demand. This is due to frequent failure of equipment. Here the production process is continuous and the unavailability of any equipment seriously affects the production process. So the production depends on the reliability of the equipments. The data which helps to prove this problem is expressed in the table below:

Table - 2
Yearly demand and production

YEAR	*DEMAND (TONNES)*	*PRODUCTION (TONNES)*
2010-2011	*1388*	*1095*

2011-2012	*1423*	*1141*
2012-2013	*1343*	*1043*
2013-2014	*1306*	*986*
2014-2015	*1261*	*918*

The table shows the total production and demand in tonne for the last five years. The company cannot attain the demand.

The machine downtime loss will lead to unavailability of damaged machines for production process. The unavailability of damaged machines will results in production stoppage. As a result of it, valuable time for the production of black tea is lost and money loss in terms of production loss occurs. The money loss in terms of production loss is shown in the table below:

Table - 3
Money loss in terms of production loss

YEAR	*MONEY LOSS (IN LAKHS)*
2010-11	*41.3*
2011-12	*39.31*
2012-13	*42.9*
2013-14	*45.93*
2014-15	*48.48*

VI. PROCEDURE

A. *Stage 1*

Firstly a failure mode and effect analysis (FMEA) of the machines in the tea factory is done. Various failure modes of machines are analysed and causes and effects of failure modes are found out. The risk priority number of each failure modes are identified using the formula RPN = severity×occurance×detectibility. The severity, occurrence and detectibility are found out based on rating scales.

Then machines in the tea factory are classified into vital, very important, important and least important using vital essential and desirable (VED) analysis. A five scale rating is used to classify machines. A machine is classified as vital if it got a rating score equal to or above 80. A machine is classified as very important if it got a score between 60 and 80. A machine is classified as important if it got a score between 40 and 60. A machine is classified as least important if it got a score below 40. Rotor-vane, CTC machine, Fermentation, Drying conveyor and Heat exchanger are vital machines.

The list of the vital machines (machines got a score equal to or above 80) along with RPN number are given in the table below:

Table - 4
Vital machines

SL NO	*VITAL MACHINES*	*RPN NUMBER*
1	*ROTOR VANE*	*288*
2	*CTC UNIT*	*150*
3	*FERMENTATION UNIT*	*140*
4	*DRYING CONVEYOR*	*32*
5	*HEAT EXCHANGER*	*60*

List of vital machines with a risk priority number equal to or greater than hundred are shown in the table below:

Table - 5
Vital machines with higher RPN number

SL NO	*MACHINES WITH RPN > 100*	*RPN NUMBER*
1	*ROTOR VANE*	*288*
2	*CTC UNIT*	*150*
3	*FERMENTATION UNIT*	*140*

B. *Stage 2*

Analytical hierarchy process is integrated with VIKOR in order to select maintenance strategy for vital machines with risk priority number (RPN) greater than hundred. Separate maintenance strategies are selected for Rotor-vane, CTC machine and fermentation unit.

Maintenance strategies are selected based on four criteria's. Data is collected with the help of questionnaire. Data's required for AHP is collected from three experts. Maintenance strategies considered are: Preventive maintenance, Condition based maintenance, Corrective maintenance and Autonomous maintenance. Criteria's used are: Cost, Safety, Value added, Equipment and technology.

Steps of integrated AHP-VIKOR approach for maintenance strategy selection are:
- Form a committee of experts.
- Construct a hierarchical model for the selected criteria's, and use the AHP method to calculate, aggregated weights of criteria's.
- Use pair-wise comparison to find out the degree of importance of each criterion.
- All experts' opinion will be integrated to obtain a weight for every aggregative criterion, by using geometric average.
- By using a heuristic method, arithmetic average, the weight of each criterion is calculated. For that Firstly, sum the arrays in each column. Then, each array in each column is divided by its respective column sum in order to get a normalized matrix. Finally find out average of each raw to get all criteria weights.
- The VIKOR method is used to rank potential alternatives.

The results obtained from AHP and VIKOR are shown in the table below:

Table - 6
Maintenance strategy for vital machines

SL NO	MACHINE	MAINTENANCE STRATEGY
1	ROTOR VANE	CONDITION BASED
2	CTC UNIT	PREVENTIVE
3	FERMENTATION UNIT	PREVENTIVE

C. Stage 3

Finally maintenance interval for Rotor-vane and fermentation unit for the next year is simulated using Monte Carlo Simulation. Time between failure of both machines and frequency of occurrence of each time between failures is collected from the previous year records and their probability of occurrence is calculated using binomial distribution. Cumulative probabilities are found out and broken down into random number range and preventive maintenance interval is simulated for the next year. The simulated maintenance interval for the next year is shown in the table below:

Table - 7
Simulated maintenance interval for next year

MONTH	RANDOM NUMBER	MAINTENANCE INTERVAL
JAN-MAR	25	6
APR-JUN	39	7
JUL-SEP	65	8
Oct-Dec	76	8

VII. RESULT

Maintenance strategies are selected for vital machines with higher RPN number using integrated approach of analytical hierarchy process and VIKOR. Preventive maintenance is suitable for CTC unit and Fermentation unit and condition based maintenance is suitable for Rotor-vane. Preventive maintenance interval is simulated using Monte Carlo Simulation.

VIII. CONCLUSION

Machine downtime results in production loss and money loss. Corrective maintenance strategy is currently used in the company. By analysing the results obtained from the maintenance strategy selection using AHP and VIKOR, it is clear that corrective maintenance strategy is not suitable for vital machines in the tea industry. Implementation of suggested maintenance strategies will result in the decrease in machine downtime loss and thus company can attain the demand.

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