Terbit *online* pada laman web jurnal : https://jes-tm.org/

Journal of Engineering Science and Technology Management

| ISSN (Online) 2828 - 7886 |

JES-TM
Journal of Engineering Science & Technology Management

Article

Implementing Decision-Making Grid Model to Improve Maintenance Strategies in Oil Palm Industries

Emon Azriadi[1]

[1,2,3,4] Department Industrial Engineering, Universitas Pahlawan Tuanku Tambusai

E-mail: eazria10@gmail.com

ARTICLE INFORMATION

Volume 1 Issue 2
Received: 24 Juli 2021
Accepted: 20 Agustus 2021
Publish Online: 26 September 2021
Online: at https:JESTM.org/

Keywords

Maintenance Policy
Downtime
Breakdown Frequency
Mean Time to Repair
Availability and Priority

A B S T R A C T

A typical maintenance organization has the responsibility in keeping the production facility running at the desired level of performance. In order to ensure that condition, necessary decisions should be made. The Decision Making Grid (DMG) model is one of analysis techniques that provides maintenance organization in strategic and tactical level management to determine the appropriate maintenance policy for all individual machinery and equipment within the facility. The analysis identified the performance of the equipment in oil palm mill facility by conducting availability measurements. The machineries and equipment which have breakdown records were analyzed then by the DMG model to propose the appropriate maintenance policy for all individual machinery and equipment within the facility. Implementing the DMG recommendations were proposed to follow the suggested priority order.

1. BACKGROUND

1.1 Introduction

Maintenance of industrial manufacturing can be defined as all necessary activities to keep an equipment or system in, or restore it to, a condition in which it can perform its required function (Monchy, 1991; Pintelon and Gelder, 1992). Similar with the statement, Abazi and Sassine (2001) explained that the main purpose of maintenance in industry is to keep a system's facilities in functioning state, to reduce the adverse effects of breakdown and to increase the availability of the assets.

In the meantime, industrial manufacturing systems are always changing due to the advancement in technology. Many industrial manufacturing are sometimes designed to be operated in critical condition, and the tendency of the failure is likely to continue under the competitive demands of marketplace. An effective maintenance becomes crucial for keeping the reliable production facility and for ensuring the fulfilment of the production target.

To provide a cost effective maintenance strategy, a decision support analysis could be helpful. It can assist the maintenance manager to make certain appropriate decisions to maintain the assets in the state of desired level performance.

One of the decision analysis techniques that can be used is the Decision Making Grid (DMG) model. This technique has been utilised in many industrial sectors to provide the maintenance manager a suitable maintenance strategy for machinery and production equipment. For example, the DMG model was applied in an automotive manufacturing company by Labib (1996) and also in a food processing company by Burhannuddin (2007).

1.2 Research Purposes

In this research purpose is a conventional palm oil company is considered to apply the DMG model as decision support technique in their maintenance organisation.

2. LITERATURE RIVIEW

2.1 Overall Perspective of Maintenance Concept

In the past few decades, maintenance function has evolved from an insignificant issue into one of the most indispensable concern in any industrial organisation. As shown in figure 1, maintenance was only considered as a simply necessary burden, nothing more than an inevitable part of production which its activities costed more money. Later on, after the World War II period until 1970's, maintenance had become a management concern purely as a technical function. It was emphasised on material and technical aspect. Further on, the role of maintenance transforms into one of the main concern as a mature partner in business strategy development and possibly at the same level as production (Pintelon and Puyvelde, 2006)

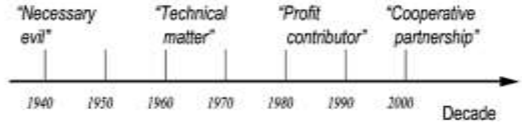

Figure 1 Maintenance Function in a Time Perspective
(Source: Pintelon and Parodi-Herz, 2008)

Nowadays, most industrial organisations acknowledge that maintenance has the critical role in increasing the productivity and profitability. The maintenance iceberg in the figure 2 illustrates the indirect costs of maintenance which lies beneath the direct maintenance costs. It gives the sense that maintenance activities have the critical influences in covering many losses which might occur.

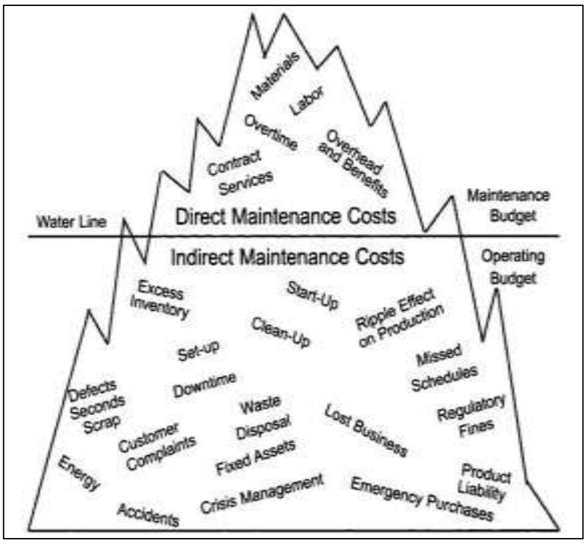

Figure 2 Maintenance Iceberg
(Source: Nyman and Levitt, 2001)

2.2 Maintenance Policy

Maintenance policy is defined as interrelationship between maintenance department and the assets to support the production process in achieving a certain level of availability and reliability at acceptable levels of safety and cost (Marquez, 2007). Pintelon and Parodi-Herz (2008) pointed out several types of maintenance policies can be considered to be applied. The maintenance policies are mainly Failure Based Maintenance (FBM), Time/ Used Based Maintenance (TBM/ UBM), Condition Based Maintenance (CBM), Opportunity Based Maintenance (OBM) and Design-Out Maintenance (DOM).

Maintenance policy optimisation can be defined as the process to attempt the balance of maintenance requirement such as legislative, economic, technical or others. Furthermore, Tahir et al (2008) explained that its objective is to select the appropriate maintenance technique for each piece of equipment in the system and identifying the periodicity which maintenance technique should be conducted to achieve the best requirement and maintenance target, concerning safety, equipment reliability and availability, and also maintenance costs.

Policy	Description
FBM	FBM prescribes maintenance to be carried out only on occurrence of failure or breakdown. Hence, FBM is Corrective Maintenance (CM). In case of purely random breakdowns and low breakdown effects, this may be an effective policy.
TBM/UBM	TBM/UBM prescribes maintenance to be triggered by the event that a specified number of units of use or time is reached. The latter case is also called Fixed Period Maintenance (FPM). TBM/UBM assumes that the failure behaviour of the equipment is predictable (increasing failure rate, IFR type, i.e. the probability of failure increases with the time since last maintenance).
CBM	CBM prescribes maintenance to be activated when the value of a given system parameter reaches or surpasses a preset value. CBM thus assumes that there exists a system parameter that can be used to predict the failure behaviour. Again preventive maintenance is assumed to be more economic than corrective maintenance. The traditional inspection rounds in the plant (inspection-based maintenance, IBM) are in fact a primitive form of CBM. Recently CBM became quite popular.
OBM	When a plant component fails the opportunity may be taken during the ensuing shut down to carry out preventive maintenance on other components which have not yet failed.
DOM	The focus of DOM is on improvements in the equipment design in order to simplify maintenance operations and to increase reliability.

Tabel 1 Generic Maintenance Policies
(sources: Pintelon and Parodi-Herz, 2008)

2.3 Performance Indicator

Pintelon, L. and Gleders, L.F. (1992) mentioned that performance evaluation is an indispensable element of maintenance management. Performance report does not only reveal how well the maintenance actions were carried out, but it also allows problems to be anticipated and treated appropriately in the future.

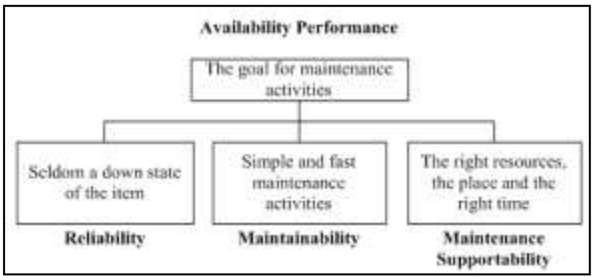

Figure 3 Maintenance Terminology (Source: Labib, 2009).

Similar with the statement above, Wang, H and Pham, H. (2006) also mentioned that to obtain the optimal maintenance policy in a complex system, it is essential to determine system availability. Therefore, a study of system reliability measurement such as availability, mean time between failures (MTBF), mean down time (MDT) would be necessary.

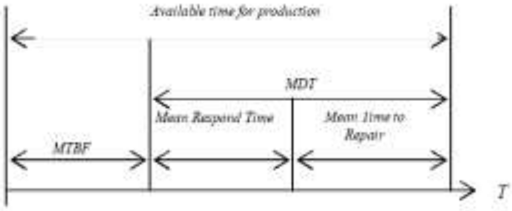

Figure 4 Relationship between MTBF, MDT, MRT, and MTTR (Source: Labib, 2009).

2.4 Maintenance Decision Support Technique

The usual criteria on optimisation of maintenance policies are based on the assets reliability measurement. It includes the availability, average up time and average down time (Wang and Pham, 2006). Variety models have been developed and studied extensively.

Weibull model for reliability application is one of technique that can help maintenance management to make suitable decisions. In general, *Weibull* concept believes that all man-made systems are unreliable in the sense. They degrade with age and/or usage and ultimately fail. The failure is influenced by several factors. These include the usage mode (continuous or intermittent), usage intensity (high, medium, or low), operating environment (normal or abnormal), and operator skills (Murthy et al, 2004).

One of the other techniques that can be utilised as a maintenance optimisation technique and will be proposed in this research is the Decision Making Grid (DMG) model. This model provides decision analysis for maintenance policy selection. It was originally proposed by Labib (1996) and implemented in an automotive company in the United Kingdom. In general, the DMG model uses multiple criteria with the frequency of failures and mean downtimes as parameter.

2.5 Decision Making Grid Model

Labib (2004) proposed the DMG model as a map on which the performances of the worst machines are mapped according to multiple criteria. It defines DMG in control chart on two dimension model. First model is downtime with low, medium and high criterion, and the second is frequency of failure as low, medium and high criterion. The methodology has implemented as follows:

Step 1: Criteria Analysis - Establish a Pareto analysis of the two factors, downtime frequency and machine downtime;

Step 2: Decision Mapping - Those machines that meet both criteria and ranked in step 1, are then mapped in the two dimensional matrix, and;

Step 3: Once mapping been finalised, the decision is developed by comparing the two dimensional matrix developed in step 2 with DMG as shown in figure 5.

Decision Making Grid		Downtime		
		Low	Medium	High
Frequency	Low	(OTF)	(FTM)	(CBM)
	Medium	(FTM)	(FTM)	(FTM)
	High	(SLU)	(FTM)	(DOM)

Figure 5 DMG model mapping (Source: Labib, 2004).

The objectives of this application are to implement appropriate strategies that will lead to the movement of machines towards an improved maintenance stages, complied with respect to the multiple criterion maintenance policies as follows:

- Operate to failure (OTF): Machine is very seldom failed. Once failed, the downtime is short;
- Fixed time maintenance (FTM): Failure frequency and downtime are almost at the moderate cases;
- Skill levels upgrade (SLU): Machine is always failed. But it can be fixed very fast;
- Condition-based maintenance (CBM): Machine is very seldom to fail. But once failed, it takes a long time to bring it back to the normal operation;
- Design out maintenance (DOM): Machine is always failed. Once failed, it takes a long time to bring it back to the normal operation.

Labib (2004) also recommended that Total Productive Maintenance (TPM) approach should be applied for lower triangle of the DMG matrix as shown in figure 6. TPM is applied widely in Japanese factories and one of the TPM concepts is to empower the operators to maintain continuous productions on totally efficient lines. The approach of TPM is the continuous knowledge transfer to operators and maintains the production machines together with the maintenance crew. Hence, slowly it can reduce waiting times for technicians to be in the production plant. Also, it gives the opportunities to operators to eliminate the root causes of machines errors at the small level, before they become big ones.

Furthermore, it is mentioned that Reliability Centred Maintenance (RCM) approach should be applied for upper triangle of the matrix as shown in figure 6. It explained that RCM involved inspections and measurements of the probability that a machine will operate as expected as desired level, for a specific period of time under the design operating conditions without any failures. Once those problematic machines are identified, then maintenance strategy should be adjusted to ensure the longest survival of the machine to complete a mission at specific time. Strategies such as condition-based monitoring or design out maintenance could be executed based on the measurement and estimates.

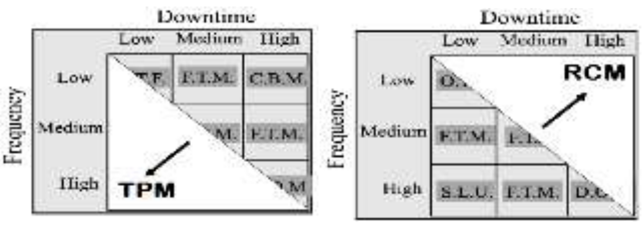

Figure 6 DMG-TPM and RCM Strategy
(Source: Labib, 2004)

The significance of this approach is that rather than treating RCM and TPM as two competing concepts, it unifies them within a single analytical model, fixed time maintenance (FTM). In general, the easy FTM questions are “Who?”, and “When?” (the efficiency questions). The more difficult ones are “What?” and “How?” (the effectiveness questions), as indicated in figure 7 (Labib, 2004).

Decision-Making Grid		Downtime		
		Low	Medium	High
Frequency	Low	(OTF)	When?	(CBM)
	Medium	Who? Easy FTM	Difficult FTM	What?
	High	(SLU)	How?	(DOM)

Figure 7 DMG-Easy FTM and DMG-Difficult FTM Strategy
(Source: Labib, 2004)

One of the advantages of the DMG model is able to address many maintenance decision policies, for example DOM. CBM, FTM, SLU and OTF to individual equipment and machinery in a complex system which were used for analysis.

3. METHODOLOGY

3.1 Prioritising

Bagadia (2006) mentioned that the criticality of the equipment within the system can be indicated by the level of priority. It is important to determine which equipment to be fixed first. Similarly, Mishra and Pathak (2002) also pointed out that prioritising must be established to handle a mixture backlogged which might happen during maintenance activities. The maintenance works could be ordered according to priority system as presented in the following points:

- Priority I. This priority is used for emergency work which special work orders and overtime are allowed.
- Priority II. This priority is usually used for jobs scheduled which should be adjusted to top priority works. Some changes in the schedule are possible due to change of priority.
- Priority III. The jobs can be scheduled depending upon maintenance resources availability. Once the priority I and II are fixed, the jobs should be implemented strictly as the schedules.

To determine the priority of the equipment, some variety techniques have been established. Two of the techniques that would be used to make an appropriate order in prioritising the equipment to be maintained first are Failure Modes and Effects Analysis/ Critical Analysis (FMEA/ FMECA) and NUCREC technique.

McDermott et al (2009) mentioned that the objective of Failure Modes and Effect Analysis is to look for the ways an item fails to perform its functions. The ways in which an item can fail are called failure modes. Each failure mode has a potential effect, and some effects are more likely to occur than others. In addition, each potential effect has a relative risk associated with it. The FMEA process is a way to identify the failures, effects, and risks within a process or product, and then eliminate or reduce them.

Meanwhile, the Failure Modes, Effects and Critical Analysis (FMECA) is possessed of two separate analyses, the Failure Modes and Effects Analysis (FMEA) and the Criticality Analysis (CA). TM 5-698-4 (undated) explained that the FMEA must be completed prior to performing the CA. The FMEA analyses different failure modes and their effects on the system while the CA classifies or prioritises their level of importance based on failure rate and severity of the effect of failure.

Other than FMECA, Higgins and Mobley (2002) and Levitt (2009) proposed the NUCREC technique to determine the priority work type and equipment criticality by multiplying the ratings of the crucial factors. This technique will be proposed in this research to execute the priority of the DMG model suggestions.

NUCREC has three crucial factors: Need Urgency, Customer Rank and Equipment Criticality. Acronym NUCREC is adopted from those three crucial factors. Higgins and Mobley (2002) recommended the rating systems for each crucial factor is given as following points:

- Need urgency ratings:
  1. Emergency; safety hazard with potential further damage
  2. Downtime; facility or equipment is not producing revenue
  3. Routine and preventive maintenance
  4. As convenient, cosmetic
- Customer rank is rated in the following order:
  1. Top management
  2. Production line with direct revenue implication
  3. Middle management, research and development of facilities
  4. All others

- The equipment criticality ratings:
  1. Utilities and safety system with large area effect
  2. Key equipment with no backup
  3. Most impact on morale and productivity
  4. Low uses and little effect on output

The product of the ratings gives the total priority. That number will range from 1 (which is 1x1x1) to 64 (4x4x4). The lower number of the total multiplication rating will have higher priority. The maintenance request of the lowest number should be done first.

4 RESULTS AND DISCUSSION

In order to analyse the data investigated from a conventional palm oil mill of the selected company, the author determines few main production characteristics, and these are given as follows:

1. The available time of production process in period July 2009 - December 2009 is 1720 hours. It is determined from 10 hours operation time a day which 2 days off in every month.
2. Every machinery and equipment has different frequency of failures. Once failed, it has different downtime. The waiting and repairing time which are part of the downtime is considered to be assumed. Most of failures are treated as soon as possible, except for machineries and equipment which need an outsourcing organisation involvement and necessary waiting time to do the maintenance tasks.
3. Machineries and equipment operate in a serial production line.

Availability Measurement

Availability is the ability of an asset to perform its function as required. The previous figure 4 explains the relationship between the concepts of availability from mean time between failures (MTBF), mean downtime (MDT), mean waiting time (MWT) and mean time to repair (MTTR). Therefore, the equation of availability of the asset can be formulated as equation below (Labib, 2009).

$$\text{Availability, A} = \frac{MTBF}{MTBF+MTTR} \times 100\%$$

From the conditions which are given above, the availability of the machinery and major equipment in the palm oil plant can be calculated as shown in table 2.

Table 2 shows the availability of the machinery and major equipment for the period of July 2009 – December 2009. Total production operating times for these 6 months are expected as 1720 hours. Over the period, 130 breakdowns were recorded.

Digester highlighted has the longest downtime (189 hours) with 9 times number of failures. It contributes as the most unreliable machine in the system with 91.90 % availability. It is followed by thresher with 93.87 % availability and boiler in the third place with 93.93 % availability. The Boiler also is experienced the longest in term of mean time to repair (MTTR). Meanwhile, the container is experienced the most frequent number of failures with 41 times during the period. However, the asset only takes the ninth place of the most unreliable machine or equipment in the system with 98.69 % availability. It could be because the container has the shortest MTTR among the assets in the system.

Code	Machineries and Equipment	Frequency	Downtime	MDT	MTBF	MTTR	Availability
A1	Weighing Bridge	0	0.00				100
A2	Loading Ramp	12	38.40	3.20	140.13	2.77	98.06
A3	Container	41	22.55	0.55	41.40	0.55	98.69
A4	Transfer Carriage	2	8.40	4.20	855.80	4.00	99.53
B	Steriliser/ Autoclave	5	110.00	22.00	322.00	18.04	94.69
C1	Crane/ Hoist	6	18.60	3.10	283.57	3.10	98.92
C2	Thresher	4	128.00	32.00	398.00	26.00	93.87
C3	Conveyor	3	9.00	3.00	570.33	3.00	99.48
D1	Digester	9	189.00	21.00	170.11	15.00	91.90
D2	Screw Press	6	138.00	23.00	263.67	17.00	93.94
D3	Cake Break Conveyor	0	0.00				100
E1	Vibrating Screen	2	4.20	2.10	857.90	2.10	99.76
E2	Settling Tank	1	34.00	34.00	1686.00	26.00	98.48
E3	Oil Centrifuge	2	2.60	1.30	858.70	1.30	99.85
E4	Water Centrifuge	4	5.60	1.40	428.60	1.40	99.67
E5	Sludge Centrifuge Decanter	7	11.20	1.60	244.11	1.60	99.35
E6	Vacuum Dryer	4	48.00	12.00	418.00	9.00	97.89
F	CPO Storage Tank	2	36.00	18.00	842.00	10.00	98.83
G1	Nuts and Fibres Separator	1	3.20	3.20	1716.80	3.20	99.81
G2	Core and Shells Separator	0	0.00				100
H1	Boiler	2	112.00	56.00	804.00	52.00	93.93
H2	Turbine Generator	0	0.00				100
H3	Water Treatment	4	16.40	4.10	425.90	4.10	99.05
H4	Steam Piping Installation	5	21.50	4.30	339.70	4.30	98.75
H5	CPO Piping Installation	0	0.00				100
H6	Water Piping Installation	8	9.60	1.20	213.80	1.20	99.44
Total Breakdowns		130					

Table 2 Availability of the Production Assets

DMG Model Analysis

The performance of maintenance organisation in this palm oil company could be improved by implementing the DMG model analysis. The analysis will provide the maintenance organisation to apply the appropriate maintenance policy for every machineries and equipment within the production facility.

- Criteria Analysis

The aim of this step is to establish Pareto analysis of two important criteria, downtime as the main concern of production and the number of failures as the main concern of assets management. The data of the two criteria for all machinery and the equipment is extremely needed for the DMG analysis. However, the downtime and the number of failure data are reciprocal of mean time to repair (MTTR) data and mean time between failures (MTBF) data respectively (Labib, 2004).

The data of the two criteria are then sorted and grouped into high, medium, and low Categories. Burhanuddin (2007) and Tahir et al (2008) mentioned that the groups can be determined by using simple interval as pointed out below, where "*h*" is the highest and "*l*" is the lowest.

- High Boundary = $h \leq$ High $> h-(1/3h)$
- Medium Boundary = $h-(1/3h) \leq$ Medium $> h-(2/3h)$
- Low Boundary = $h-(2/3h) \leq$ low $\geq l$

In this DMG model analysis, the author proposes to use mean time to repair (MTTR) and mean time between failures (MTBF) data instead of the downtime and number of failures data. The reason is because the differences number of failures for the Containers (A3) in comparison with other production equipment is just too wide. It could lead to the difficulty in determining the interval of boundary. Since the downtime is proportional to MTTR value and the number of failures is inversely to MTBF value, the criteria evaluation will be as shown in table 3.

Downtime			Frequency		
Machinery/ Equipment	MTTR (hours)	Criteria	Machinery/ Equipment	MTBF (hours)	Criteria
Boiler (H1)	52	High	Container (A3)	41.4	High
Settling Tank (E2)	26	Medium	Loading Ramp (A2)	140.1	
Thresher (C2)	26		Digester (D1)	170.1	
Steriliser/ Autoclave (B)	18.04		Water Piping (H6)	213.8	
Screw Press (D2)	17	Low	Sludge Centrifuge (E5)	244.1	
Digester (D1)	15		Screw Press (D2)	263.7	
CPO Storage Tank (F)	10		Crane/ Hoist (C1)	283.6	
Vacuum Dryer (E6)	9		Steriliser/ Autoclave (B)	322	
Steam Piping (H4)	4.3		Steam Piping (H4)	339.7	
Water Treatment (H3)	4.1		Thresher (C2)	398	
Transfer Carriage (A4)	4		Vacuum Dryer (E6)	418	
Nuts and Fibres Sep (G1)	3.2		Water Treatment (H3)	425.9	
Crane/ Hoist (C1)	3.10		Water Centrifuge (E4)	428.6	
Conveyor (C3)	3		Conveyor (C3)	570.3	
Loading Ramp (A2)	2.77		Boiler (H1)	804	Medium
Vibrating Screen (E1)	2.1		CPO Storage Tank (F)	842	
Sludge Centrifuge (E5)	1.6		Transfer Carriage (A4)	855.8	
Water Centrifuge (E4)	1.4		Vibrating Screen (E1)	857.9	
Oil Centrifuge (E3)	1.3		Oil Centrifuge (E3)	858.7	
Water Piping (H6)	1.2		Settling Tank (E2)	1686	Low
Container (A3)	0.55		Nuts and Fibres Sep (G1)	1716.8	

Table 3 Criteria Evaluation

- Decision Mapping

Based on the criteria analysis proposed by Labib (1996), the aim of this step is to address both downtime and frequency criteria into two dimensional matrix as shown in table 4.

Decision-Making Grid (in index)		Downtime Low	Downtime Medium	Downtime High
Frequency	Low	OTF (G1)	FTM (E2)	CBM
	Medium	FTM (F,A4,E1,E3)	FTM	FTM (H1)
	High	SLU (D2,D1,E6,H4,H3,C1,C3 A2,E5,E4,H6,A3)	FTM (C2,B)	DOM

Table 4 Decision Making Grid Mapping

- DMG Model Suggestion

The objective of the DMG model analysis is to implement appropriate maintenance policies that will lead the movement of machinery and equipment toward an improvement. In general, the decision making grid (DMG) mapping indicates that most of machinery or major equipment is located in the lower triangle of the DMG matrix except for Boiler (H1) and Settling Tank (E2). As mentioned earlier in

Figure 12, it means by implementing an adequate Total Productive Maintenance (TPM) concept in these machineries and equipment could lead to an availability improvement. Otherwise, in case of Boiler (H1) and Settling Tank (E2), Reliability Centred Maintenance (RCM) concept will be more appropriate.

The following numbers are few maintenance strategies or actions recommended to be taken based on the DMG model analysis:

1. Operate to Failure (OTF): this strategy is implemented to machine G1 (Nuts and Fibres Separator). Since the downtime and frequency of failures of this equipment are low, the author recommends that the current maintenance strategy should be maintained and strictly followed.
2. Fixed Time Maintenance (FTM): this strategy is implemented to machinery and equipment which have the downtime and frequency of failures is almost at moderate cases. Preventive maintenance schedules should be applied. Fixed Time Maintenance, as mentioned earlier in Figure 7, is divided into easy tasks FTM and difficult tasks TPM. The recommendations proposed for every machinery and equipment which fall to FTM region in the DMG mapping as follow:
   - CPO Storage Tank (F), Transfer Carriage (A4), Vibrating Screen (E1) and Oil Centrifuge (E3) are located in the region between OTF and SLU. In this region, the question is about who will performed the maintenance tasks is the main concern. However, since it is near to SLU region, an upgrading the operator skill could be considered to be implemented.
   - The Settling Tank (E2) is fall into the FTM region between OTF and SLU. Since it is categorised as easy task FTM and near to CBM region, the adequate schedules of preventive maintenance should be established.
   - Thresher (C2) and Steriliser (B) are located in the region between SLU and DOM. In this case, the contents of the preventive maintenance instructions need to be investigated and an expert advice is needed.
   - Boiler (H1) is mapped in the FTM region between CBM and DOM. In this case, the appropriate actions should be taken to analyse the breakdown events. The part of machinery that usually becomes failure should be observed and the adequate preventive maintenance activities need to be scheduled. Furthermore, since it is near to CBM region and presents the highest MTTR, Condition Based Monitoring (CBM) policy could be considered to be implemented.
3. Skill levels upgrade (SLU): this strategy is implemented to machinery and equipment which indicates high frequency of failures for limited periods (low downtime). The machinery and equipment which is located in the SLU region are D2 (Screw Press), D1 (Digester), E6 (Vacuum Dryer), H4 (Steam Piping Installation, H3 (Water Treatment), C1 (Crane/ Hoist), C3 (Conveyor), A2 (Loading Ramp), E5 (Sludge Centrifuge), E4 (Water Centrifuge), H6 (Water Piping Installation) and A3 (Container). Since the downtime is low, it can be assumed that the maintenance tasks relatively are easy. It can be passed to operators after upgrading their skills level.

Multiple Criteria Decision Making

Once the performance of machineries and equipment are identified and the appropriate actions are recommended, the next step is to determine a focused action to be implemented. In other word, the analysis needs to move from the strategic level to the tactical level of maintenance management.

Labib (2004), and Tahir et al (2008) used fuzzy logic to render the DMG model analysis. Furthermore, Labib and Juniarto (2009) designed fuzzy logic controller that able to determine when and what type of maintenance policy should be implemented to the system in any given condition.

Although the fuzzy logic provides DMG analysis with enhanced maintenance strategy decisions, its implementation should handle a mixture backlogged which might happen during maintenance activities. Since the cost function of the DMG analysis implementation, was mentioned by Fernandez et al 2003 and Labib 2004, is linear and follows the relationship: DOM > CBM > SLU > FTM > OTF, it also should be taken into consideration before maintenance strategy decisions applied.

In term of implementation of recommendations suggested by DMG analysis, the Decision Maker (DM) should determine which machinery or equipment to be prioritised and treated first. Prioritising can be determined by using NUCREC (Need Urgency, Customer Rank and Equipment Criticality) analysis or by using Failure Modes, Effect and Critical Analysis (FMECA).

In this research, NUCREC analysis is proposed to determine the maintenance decision priority instead of FMECA. Whilst FMECA uses each potential failure modes as variable to be ranked, NUCREC analysis uses the equipment ratings as the main variable.

NUCREC analysis has three crucial factors: Need Urgency, Customer Rank and Equipment

Criticality. The rating systems for each crucial factor can be determined as following points below and the total multiplication will reflect the ranking of equipment priority as shown in table 5.

- Need urgency ratings:
  1. Emergency; safety hazard with potential further damage
  2. Breakdown; facility or equipment is not producing revenue
  3. Productivity losses
  4. Routine and preventive maintenance
- Customer rank is rated in the following order:
  1. Top management
  2. Production line with direct revenue implication
  3. Production line with indirect revenue implication
  4. Middle management, research and development of facilities
- The equipment criticality ratings:
  1. Utilities and safety system with large area effect
  2. Key equipment with no backup, high disruption to productivity
  3. Key equipment with backup, moderate disruption to productivity
  4. Little effect on output

Code	Machineries and Equipment	Crucial Factors			Total	Priority
		Need Urgency	Customer Rank	Equipment Criticality		
A1	Weighing Bridge	4	3	2	24	VI
A2	Loading Ramp	3	3	3	27	VII
A3	Container	3	3	3	27	VII
A4	Transfer Carriage	2	3	2	12	IV
B	Steriliser/ Autoclave	1	2	3	6	II
C1	Crane/ Hoist	2	2	2	8	III
C2	Thresher	3	2	3	18	V
C3	Conveyor	2	2	2	8	III
D1	Digester	3	2	3	18	V
D2	Screw Press	3	2	3	18	V
D3	Cake Break Conveyor	2	2	2	8	III
E1	Vibrating Screen	2	3	2	12	IV
E2	Settling Tank	2	2	2	8	III
E3	Oil Centrifuge	3	2	3	18	V
E4	Water Centrifuge	3	2	3	18	V
E5	Sludge Centrifuge/ Decanter	3	2	3	18	V
E6	Vacuum Dryer	2	2	2	8	III
F	CPO Storage Tank	3	3	3	27	VII
G1	Nuts and Fibres Separator	3	3	2	18	V
G2	Core and Shells Separator	3	3	2	18	V
H1	Boiler	1	3	1	3	I
H2	Turbine Generator	1	3	1	3	I
H3	Water Treatment	2	3	1	6	II
H4	Steam Piping Installation	1	3	2	6	II
H5	CPO Piping Installation	3	2	2	12	IV
H6	Water Piping Installation	2	3	2	12	IV

Table 5 Equipment Priority

Table 5 shows the priority in a roman numerical. The inferior number of the roman numeric has the higher priority. The roman numeric can be determined by multiplying the NUCREC crucial factors. It means that the lower of total multiplication has higher priority. To implement suggested policy by DMG model in this palm oil mill, the author suggests that the priority order should be followed.

5 CONCLUSION

6 This research proposes the Decision Making Grid (DMG) model analysis to determine the appropriate maintenance policy to be implemented for all individual machinery and major equipment in production line. Started by availability analysis to determine performance of the production equipment, the equipment which has unplanned breakdown records will be analysed then using the DMG model. The DMG analysis recommends TPM approach to be implemented for most of machinery and equipment in the system excluding Boiler (H1) and Settling Tank (E2). In case of Boiler (H1) and Settling Tank (E2), Reliability Centred Maintenance (RCM) concept will be more appropriate.

7 Furthermore, the DMG analysis also suggests an upgrading operator skills level for the equipment which is located in SLU region of DMG mapping. Meanwhile, the Boiler (H1) is located in the FTM region between CBM and DOM. Since it is near to the CBM region and has high downtime, Condition Based Monitoring (CBM) policy could be considered to be implemented. Other equipment which is also located in FTM area is recommended to establish an adequate preventive maintenance including the content, schedules, and who will perform the maintenance tasks.

8 Finally, this research suggests that applying the recommendations suggested by DMG analysis should follow the equipment priority order that can be determined by using NUCREC analysis. The equipment with the lower total value in this analysis should be more prioritised to apply DMG recommendation first.

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