MAINTENANCE DECISION MAKING MODEL USING MULTIPLE CRITERIA ANALYSIS FOR SMALL AND MEDIUM INDUSTRIES

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Abstract: In small and medium industries (SMI), there are less number of machines use, which are always grouped together in serial lines. Well organized of these machines maintenance structure will ensure the effectiveness of the entire production lines. Their maintenance data should be stored to process and subsequently transform them into a useful knowledge for decision making. In order to increase the effectiveness of the machines in the production lines, we have studied some decision support models in maintenance area. Choosing the model and optimizing maintenance strategies is the formost importance in maintenance management. We have written a paper to identify the strategies for the machines based on 2 factors, *i.e.* downtime and frequency of machines failures with multiple criterions using decision making grid (DMG) model. In this paper, we use the results obtained from the maintenance strategies implementation in one of the SMI in Malaysia. We collected raw data for the whole period of 2004 and 2005 for analysis using DMG model. We gave few recommendations to the maintenance crew after analyzing the dataset. In 2006, we collected the data again and compare the result after the implementation of those strategies.

Keywords: Decision support model, computerized maintenance management system, maintenance strategy, multiple criteria analysis, repair performance measure.

1. INTRODUCTION

Throughout the years, the importance of the maintenance management system and their functions have grown rapidly. There are various papers discussed on the maintenance system, including performance measures, indicators and matrices to reduce failures in the production floors. We visited few food processing SMI in Malaysia. From our observation, only a few machine, ranged from 10 to 40, are used in their production floors. There has been a long journey of corrective maintenance techniques evolution since 1940 including operational research models to maintain those machines. In this paper, we would like to extend our findings after implementation of few maintenance strategies in the production floor, given by [1]. Once the strategies are redefined using Decision Making Grid model, then few rules-based system can be derived to provide good decisions for maintenance department.

2. LITERATURE REVIEW

Small-scale industry is defined as those with capital less than RM250,000.00 and having 5 to 49 workers [2]. Medium-scale industry employing 50 to 199 workers with capital RM250,000.00 to one million. Companies beyond that limits are considered as a large-scale industry. Since limited workers and capital used in SMI, there are only few machines installed in SMI environment [2]. The downtime can be defined as the total amount of time the machines would normally be out of service owing to the failure. It is the time from the moment it fails until the moment it is fully repaired and re-operate again. Some repairing activities will take place in between the unit's failure time and the time it is re-assembled. As mentioned, equipment may experience breakdown at any time during their lifespan. They may have multiple failures at a particular breakdown and which failures should be entertained first is a concern. We have discovered that studying the failure data and the downtime by itself is not enough to provide a decision for SMI. The machine may failed only once in two years time, while others may fail more frequently, even with a shorter downtime.

There are still insufficient studies made on the application of measurement in service processes as it always takes into consideration a verbal sense and are not to be dealt with mathematically [3]. Output oriented management concept is used to evaluate some maintenance performance indexes. By looking at the index, we can predict next failure and prepare maintenance procedures accordingly. Systematic mathematical measurements on covariates illustrated with the use of the semi-parametric, multistate hazards model for transition and reverse transition among more than one transient state emerged from follow-up studies [4][5]. The proportional-hazards model is used to analyze transitions in human contraceptive use over time and illustrate the score test on testing the equality of parameters for models on transitions and repeated transitions. Paper [6] employs the models proposed by [5] to estimate the risk factors that delay the machines downtime. [6] identify the relationship between repair time and various risk factors of interest including underlying characteristics of the technicians, *i.e.* their age, experiences, qualifications and estimate them respectively.

Paper [7] analyze failure data, especially downtime using general renewal process for repairable systems. [7] use Kijima Model II to model complex systems and calculate general likelihood function for single and multiple systems. Then they estimate the parameters with the time truncated and failure truncated data using Weibull ++7. However, they used only one parameter, failure data to be observed at a time.

Paper [8] use fuzzy logic to derive rule-based decision support analysis. Later, [9] extend the technique to assess and select most informative and efficient maintenance approach using fuzzy multiple criteria decision making evaluation methodology. [10] use a fuzzy linguistic approach to achieve subjective assessments of maintenance strategies and practices in an objective manner.

Paper [11] describe an application of analytic hierarchy process for selecting the best maintenance strategy for an oil refinery. Then [12] proposed an artificial neural network framework for repair time estimation after deploy the strategies. [13] reviews maintenance organization models such as advanced terotechnological model, Eindhoven University of technology model, total quality management, Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM) in their study. He concluded that maintenance can be a contributor to profits by using Information Technology (IT) and showed that the integrated IT as Computerized Maintenance Management System (CMMS) permits co-planning of production with maintenance.

CMMS provides good solution for data storage. However quantitative optimization modules should be embed into CMMS to provide Decision Support System (DSS) to optimize maintenance and close the gap between theory and practice. DMG considered as a preliminary screening process model to identify potential machines for RCM, TPM *etc*. The optimization strategy is not based only on the machines downtime, but also the frequency of downtime, experienced by the individual machine to identify those critical machines. Once the most problematic machine is identified, further reliability analysis will be conducted to improve their time-based maintenance. In particular, the maintenance management is able to:

i) Define better maintenance strategy dynamically based on two factors, *i.e.* downtime frequency and machine downtime simultaneously; and
ii) Identify certain maintenance work knowledge that can be transferred from technical experts to the operators in the production floor.

Paper [14] defined DMG as a control chart by itself in 2 dimensional matrix forms. The columns of the matrix show the 3 criterion of the downtime, while the rows of the matrix show 3 criterion of the frequencies of the failures. A better maintenance model for quality management can be formed by handling both the rows and columns of the matrix respectively. The matrix offers an opportunity to decide which maintenance strategies is needed for decision making such as to practice fixed-time maintenance, condition-based maintenance or design-out maintenance. The grid can be used to decide which maintenance concepts are useful for each defined cell of the matrix such as TPM or RCM approaches. The results will provide maintenance policies in the respective functional group in production lines to achieve their common goal to reduce downtime. We proposed some maintenance analysis in this paper with few main objectives:

i) To enhance machine reliability analysis proposed by [14] to identify most problematic machine in the production floor;

ii) To give few suggestion on the maintenance strategies for one of the food processing SMI in West Malaysia; and

iii) Report some improvement after the implementation of those strategies.

3. MACHINES EFFICIENCY MEASUREMENT

Most of the reliability, availability and failures of the machines are dependent on time. [15] represent the repetitive failure patterns as shown in Figure 1. Assume that N individual machines placed in operation are up and running. The times at which failures, f, occur are recorded during a test time interval, T. Let the downtime, T_{Dj} be the total time that elapses between the occurrence of the jth failure and the time the equipment back into normal operation. Let N_f be the number of failures of the N device during the T interval.

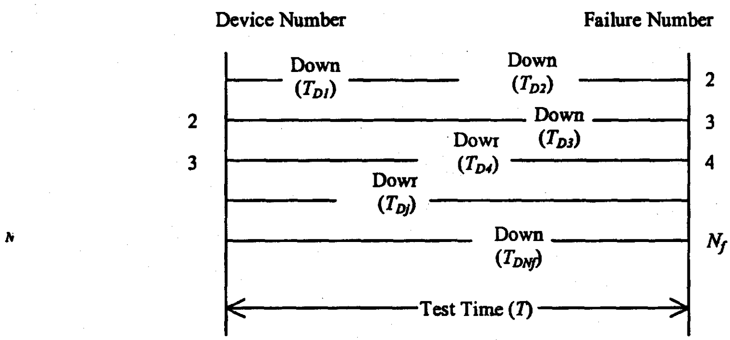

Figure 1: Repairable Items Failure Patterns [15]

Based on Figure 1, few measures and formulae are derived as follows [15]:

$$\text{Mean Downtime (MDT)} = \frac{1}{N_f}\sum_{j=1}^{j=N_f} T_{Dj}$$

$$\text{Total Up time} = NT - \sum_{j=1}^{j=N_f} T_{Dj}$$

$$\text{Mean Time Between Failures (MTBF)} = \frac{NT - N_f MDT}{N_f}$$

$$\text{Failure rate } (\lambda) = \frac{N_f}{NT - N_f MDT}$$

$$\text{Availability} = \frac{(N_f \times MTBF)}{(N_f \times MTBF) + (N_f \times MDT)}$$

$$\text{Unavailability} = \frac{(N_f \times MDT)}{(N_f \times MTBF) + (N_f \times MDT)}$$

The relationship between the concepts of reliability from MTBF, MDT, mean waiting time (MWT) and mean time to repair (MTTR) are given in Figure 2. The machine is reliable when their MTBF is higher. As contrast, the lower is better for MDT.

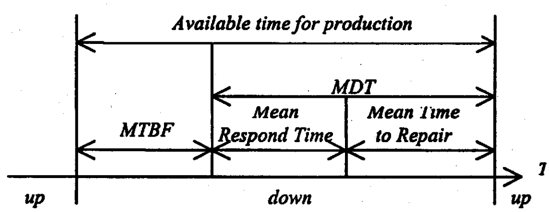

Figure 2: The relationship between MTBF, MDT, Mean Respond Time and MTTR

As of our case study in the food processing company, we observed few main characteristics, that machines must operate, given as follows:

i) Reliability: they must work for at least 10 hours per day, 6 days a week in a year. MTBF and MDT index is used as reliability measures;

ii) Every machine have different frequency of failures. Once failed, it has different downtime, which includes waiting and repairing time; and

iii) Machines operate in a serial line to manufacture seven types of products in different volumes.

In order to quantify both, time and costs of maintenance, various maintenance models were introduced. However, most of the mathematical methods, used to decide the inspection intervals are too complicated to be resolved as 'ready to use' numerical solutions. Moreover, in the practical applications, the machinery plants must satisfy the required conditions of these theoretical models; which are not the case usually. And yet, in this paper we proposed a DMG model to define maintenance strategy for the specific machine in the SMI production plants.

4. DECISION MAKING GRID

We have fitted our data into multiple criteria analysis, introduced by [16]. We consider two major factors of failures, *i.e.* downtime frequency and machine downtime, separated in different criterion: high, medium and low. We developed a query to select top ten machines having highest frequency of downtime. Subsequently, top ten machines have highest downtime chosen from a CMMS. The highest 3 is categorized as high. The next 3 is medium and the last 4 as low. There are 3 stages in multiple criteria analysis [14]:

i) Criteria Analysis: establish a Pareto analysis of the two factors, downtime frequency and machine downtime,
ii) Decision Mapping: those machines that meet both criteria and ranked in step 1, are mapped in the two dimensional matrix, and
iii) Once mapping is finalized, the decision is developed by comparing the two dimensional matrix developed in step 2 with Decision Making Grid (DMG) as shown in Figure 3.

Frequency	Downtime: Low	Downtime: Medium	Downtime: High
Low	OTF	FTM	CBM
Medium	FTM	FTM	FTM
High	SLU	FTM	DOM

Figure 3: Decision Making Grid (Labib(2004))

The objectives of this exercise is to implement appropriate strategies that will lead to the movement of machines towards an improved maintenance stages, complied with [14], respect to the multiple criterion as follows:

i) Operate to failure (OTF): Machine is very seldom failed. Once failed, the downtime is short;
ii) Fixed time maintenance (FTM): Failure frequency and downtime are almost at the moderate cases;
iii) Skill levels upgrade (SLU): Machine is always failed, but it can be fixed very fast;
iv) 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; and
v) Design out maintenance (DOM): Machine is always failed. Once failed, it takes a long time to bring it back to the normal operation.

TPM strategies is recommended for lower triangle of the DMG matrix as shown in Figure 4 [16]. TPM is applied widely in Japanese industries and one of the TPM concept is to empower the operators to maintain continuous productions on totally efficient lines [17]. Our approaches of TPM are the continuous knowledge transfer to operators and maintain the production machines together with the maintenance crew. Hence, slowly we can reduce a responding time 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 initial stage, before they become big ones.

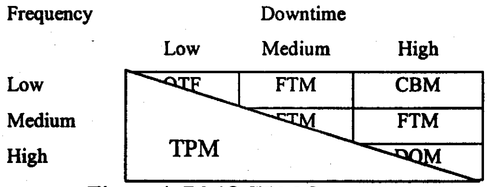

Figure 4: DMG-TPM Strategy

RCM approach should be applied for upper triangle of the matrix as shown in Figure 5 [16]. RCM involved a study and measurement 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, maintenance strategy is adjusted to ensure the longest survival of the machine to complete their production mission at specific time [18]. Strategies such as condition-based monitoring or design out maintenance is executed based on the measurement and estimates.

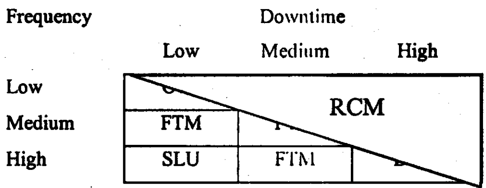

Figure 5: DMG-RCM Strategy

5. CASE STUDY

As a case study, we choose a SMI in Malaysia, a food processing company, which proven to have the capabilities to meet stringent customer requirement in terms of quality, price and delivery schedule. We collected a real dataset of the machines failures for the whole period of the year 2004 and 2005. Over the period, 109 breakdown were recorded. The operation time zone is set from 8:00am to 6:00pm, 6 days a week. Currently, all maintenance activities are recorded manually using forms. We proposed a CMMS, to be embedded with DMG for the company. We consider all types of failures for 21 machines, that utilized to produce *starfruit jam*, *rozel jam*, *pineapple jam*, *roselle cordial juice*, *seri kaya*, *kaya madu* and *ground fried coconut*. Out of 21 machines, only 14 experienced failures over the year of 2004 and 2005.

Total production operating times for these 2 years are expected at 6240 hours. Machine efficiency analysis is shown in Table 1. The fields are the machine name (ID), number of failures (Freq), breakdown time in hours (Downtime), mean downtime in hours (MDT), mean time between failure in hours (MTBF), failure rate, availability of the machine (Avail) and unavailability of the machine (Unavail). Machine H (Filling machine), is experienced highest number of failures (30 times) with longest downtime (737 hours), and followed by label machine, M (19 times). Machine H shows the lowest MTBF (183 hours) and machine B (coconut milk squeezer) shows the highest MDT (30 hours). This means that both machine H and B are the most unreliable machines in the production floor. Machine A (coconut grinder) is the most reliable machine as it has highest MTBF (6238 hours) and lowest MDT (2 hours).

Table 1: Efficiency Measures of the Machines

ID	Freq	Down time	MDT	MTBF	Failure Rate	Avail	Unavail
A	1	2	2	6238	0.0002	0.9997	0.0003
B	3	89	30	2050	0.0005	0.9857	0.0143
C	8	193	24	756	0.0013	0.9690	0.031
D	2	13	7	3113	0.0003	0.9979	0.0021
E	5	33	7	1241	0.0008	0.9947	0.0053
F	16	249	16	374	0.0027	0.9600	0.04
G	5	129	26	1222	0.0008	0.9792	0.0208
H	30	737	24	183	0.0055	0.8819	0.1181
J	5	73	15	1233	0.0008	0.9882	0.0118
K	3	54	18	2062	0.0005	0.9913	0.0087
L	1	8	8	6232	0.0002	0.9987	0.0013
M	19	188	10	318	0.0031	0.9698	0.0302
N	9	63	7	686	0.0015	0.9898	0.0102
P	2	33	17	3103	0.0003	0.9947	0.0053
Total	109	1864	211	28811			

Based on the criterion analysis proposed by Labib (2004), we have developed two dimensional matrix for the machines on both the frequency and downtime factors as shown in Figure 6.

Frequency	Downtime Low	Downtime Medium	Downtime High
Low	J, K	G, B	
Medium	N		C
High		M	H, F

Figure 6: Maintenance matrix based on 2004 and 2005 Dataset

The maintenance matrix is evaluated thoroughly with DMG models in Figure 3, 4 and 5 above. Based on 2004 and 2005 DMG analysis in Figure 6, we recommend few maintenance strategies or actions as follows:

i) Machine J (Bottle washer and cleaner) and Machine K (Capping machine) fall in matrix, $DMG_{1,1}$ at OTF's region. Since both frequency of breakdowns and downtime are low, we recommend that the current maintenance strategy should be maintained and strictly followed. However, TPM strategy can be considered on teaching the operators to tight up the connectors. So that, they can adjust the connectors once failures occurs at the initial stage.

ii) Machine N (Cuplid machine) falls in matrix, $DMG_{2,1}$ at FTM's region. Since it is near to the OTF's region, then who will perform the repair is the concern. The machine is always failed but it is easier to fix the problem where time taken to repair is not very long. If the maintenance crew can train the operators to adjust the belting, then the downtime especially on technicians responding time can be reduced tremendously.

iii) Machine G (Pump and piping for cookers) and Machine B (coconut milk squeezer) fall in matrix, $DMG_{1,2}$ at FTM's region. Since it is near to the OTF region, it requires re-addressing issues regarding when will the maintenance instruction to be implemented. This is true with our observation where Machine G has a lot of problem with the motor pump. Maintenance crew should re-evaluate their preventive maintenance strategy on changing the engine oil. As of Machine B, most of the problem occurs because of the coconut waste filter always torn. We suggest to keep the filter as the inventory control item in the store and change it at least once in every six months. Further analysis on delay time modeling introduced by [19] could help to provide better preventive maintenance estimation for the machines, G and B.

iv) Machine C (Coconut milk siever) fall in matrix, $DMG_{2,3}$ and subsequently, Machine M (Jetprinter and labels) falls in matrix, $DMG_{3,2}$. Both fall in FTM's region. The difficult issues in these two regions are the one related to the contents of the instruction itself. It might be the case that the wrong problem is being solved or the right one is not being solved adequately. From our observation on machine M failures, shows that most of the problem due to the usage of liquid type of ink to print the labels in the production floor. The ink is incompletely injected by the printer head and nozzel. We found that the problem is not being solved adequately, where technicians just service and adjust the head and nozzel for most of the time. We recommend that the maintenance crew should start looking at the type of ink is used. Laser jet ink may improve the print out quality as it dry faster and reduce the particles in the production lines.

v) Machines H (Filling machine) and F (Cooker) fall in matrix, $DMG_{3,3}$ at DOM's area. Both machines are identified as the worst performing machines based on both frequency and downtime criterion. Major design out projects need to be considered or purchase backup machines as a redundancy plan. Or install predictive-maintenance monitoring equipment, or form production emergency response team or trigger any emergency indicators immediately in the production floor, when these machines fail. Or embed these machines with self maintenance capability to reduce downtime as recommended by [20]. Consequently, we recommend that the maintenance engineers to conduct thorough analysis on machines, H and F, which includes maintenance cost analysis, RCM or analytic hierarchy process to count how much losses to the production floor.

After giving the recommendation, we collected another set of data for the whole period of 2006. The resulting DMG is shown in Figure 7.

Frequency	Downtime Low	Downtime Medium	Downtime High
Low	H, B, N	G	
Medium	J	A	E
High			M

Figure 7: Maintenance matrix based on 2006 Dataset

After implementation of those strategies based on Figure 6, there are some improvement, especially for machine H, B and N as shown in Figure 7. We have reduced time waiting for parts for machine B by keeping waste filter as an inventory control item, where B is removed from $DMG_{1,2}$ in Figure 6 to $DMG_{1,1}$ in Figure 7. We observed that the failure due to the machine N is reduced, where N is removed from $DMG_{2,1}$ in Figure 6 to $DMG_{1,1}$ in Figure 7. This is because of the technicians effort to provide proper training to operators on simple repairing task such as adjusting the Cuplid machine's belt. There are not much comments we can give on machine F as there is a backup cooker installed in the production plant and operate as a standby unit whenever failure occurs on machine F. Similarly, new filling machine is installed to replace worst performing machine, where H is improved from $DMG_{3,3}$ in Figure 6 to $DMG_{1,1}$ in Figure 7.

6. CONCLUSION

Small and medium industries in Malaysia startup with smaller capitals, hence they are not able to upgrade the entire production lines as a whole. They always operate with limited number of machines to produce a few types of products. The machines operate with their own specific functions and always contribute to a dedicated mission in the production serial lines. They operate with the minimum number of maintenance staff and sometime outsource the maintenance work. As far as maintenance is concerned, they will just follow maintenance guidelines provided by the machine's suppliers. They are still lack of good CMMS in place with decision making capabilities to measure the machines utilization based on their operation time. We believed that they may either under or over maintain certain machines in their production floors. As mentioned earlier, based on the SMI nature of business, DMG model is the most suitable to be embed with the CMMS to identify different strategies of the maintenance based on their utilization.

The failure records of 21 machines are considered in our study for the whole years of 2004 and 2005. We have conducted DMG analysis in Figure 6 and identified machine J, K, M and N for TPM approach. If the maintenance management can train the operators to handle basic troubleshooting of these machines, downtime of the machines can be reduced tremendously. RCM approach should be implemented for machines, B, C, F, G and H. After the implementation of the strategies, we observed that purchasing new machine H and cool standby unit of machine F are able to reduce their downtime. Figure 7 shows some evidence of the improvement after implementation of the strategies based on Figure 6 multiple criteria analysis.

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