An Improvement of the Decision Making Grid Model in Failure-Based Maintenance on RSG-Gas System/Components

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Abstract. Maintenance is an important part of asset management, to control the risk of system or component failure in reactor operation. Preventive maintenance strategies involve maintenance before failure occurs so that unforeseen costs due to failure, such as delays in operations can be minimized. This paper discusses the integration of established maintenance planning, their limits and maps them in the decision matrix using the Decision Making Grid (DMG) model for the RSAS-GAS system/component. Optimization of decision-making system on maintenance is done as a consideration of safety management to be able to focus on maintenance so that the reliability of the system/component can be maintained. The methodology is limited by the concept of maintenance planning that integrates maintenance and decision-making techniques with the DMG concept. Then extend the theoretical and formulation in DMG using tri-quadrant approach to cluster and categorize the variables. The research object is only performed on the main system/component of the operating system and the criticality level affects the operation of the reactor. Data obtained from RSG-GAS maintenance data (2010-2015), ie frequency and time range of damage to test compare the result. The results obtained that the approach using tri-quadrant shows better results in the DMG model.

1. Introduction

Maintenance and reinvestments are an important part of asset management, to control the risk of system/component failure in an operation process. Preventive Maintenance (PM) strategies involve maintenance before failure occurs, resulting in unforeseen costs due to failure, such as delayed operations can be avoided or at least minimized. Implementation of the PM strategy is based on a scientific approach involving specific processes and principles that employ various analytical techniques, such as statistics, mathematical programming, and Artificial Intelligence. The main advantage of Preventive Maintenance is a fact-based decision through real data analysis. Time-based maintenance (TBM) and Condition-based maintenance (CBM) are the two most accepted approaches to PM decision making.

The initial prerequisite for Total Productive Maintenance Implementation in the company is Development of Computerized Maintenance Management System (CMMS). CMMS is used to save and retrieve maintenance data. This system can handle data related to frequency and duration of maintenance damage as well as component cost.

Studies and research on maintenance management have been widely implemented. Developing Decision Making Grid (DMG) to provide a relatively comprehensive perspective on policy making including overall equipment effectiveness (OEE) [1]. Conducting a literature review for decision-making
on condition-based maintenance (CBM) [2]. Defines the Effectiveness for Maintenance approach of High Reliability Organizations (HROs) [3]. Perform reliability analysis of RSG-GAS primary cooling system to support aging management program [4]. Presents an application of risk-based and reliability methods for OM (operation and maintenance) planning [5]. Development an integrated decision-making policy for scheduling maintenance and production sequencing [6]. Presents a fuzzy logic hybridization, and local genetic algorithm to solve preventive maintenance optimization problems in parallel-series multi-state systems [7]. Tested Improved system performance without sacrificing environmental or safety issues [8]. Presents an association rule in the form of Bayesian Networks mined from different databases of IPS2 (Industrial Product-Service Systems), further establishing a framework based on Bayesian inference, which is used to support associated decision-making in maintenance [9]. Selective maintenance for multi-state systems with structural dependence. A selective maintenance optimization model was developed to maximize system reliability. An algorithm is used to define a sequence for selective maintenance scenarios [10]. Proposed a new strategy for maintenance planning in a timely multi-component system. In this way, maintenance decisions can be tailored to a particular situation [11]. Conducted an overview on maintenance optimization models based on conditions for a stochastic declining system. Condition-based maintenance (CBM) is a maintenance strategy that collects and assesses real-time information, and recommends maintenance decisions based on the current state of the system [12]. Perform implementation of missing values handling method for evaluating the system/component maintenance historical data [13]. Perform Determination of Maintenance Priority Index (MPI) For Component on RSG-GAS Safety System [14]. Perform clustering Analysis to Improve the Reliability and Maintainability with Self-Organizing Map Neural Network [15].

The purpose of this study is to perform optimization model of computational maintenance using decision making grid (DMG) model for systems/components of RSG-GAS in decision-making system. Then an improvement of the theoretical and formulation in DMG. This research was conducted so that maintenance management can evaluate the maintenance that has been done.

The methodology used to determine the maintenance model of system/component based on the frequency of damage and downtime using decision making grid analysis. The improve of the DMG method uses a tri-quadrant approach to clustering and categorize variables ie Euclidean and Canberra Distance.

This research is done with the following problem limits: Only for done on the main system/component of the reactor and the criticality level is based on the influence of the reactor operation from the design and technical data and the data of the interruption or maintenance. Conduct system maintenance optimization model or RSG GAS component computing using DMG for decision-making system. Data of frequency of damage and time to of damage are collected from system maintenance data.

2. Theory
2.1 Maintenance Structure of the System/Component
Maintenance pattern is one of the important factors in supporting reactor operation. Therefore reactor operation must be supported by a working and reliable component. To achieve that system/component of supporting operation of reactor must be carried out regular maintenance and planned. In general, the structure of the system/component maintenance is divided into two namely planning and not planning. Maintenance can be planned in advance based on the history of maintenance in the previous period to take follow-up maintenance subsequent.

The above maintenance is classified based on time (time base maintenance or preventive maintenance) and maintenance on condition basis (on Condition base maintenance or predictive maintenance). Predictive maintenance (PdM) is a process that requires the technology and expertise of people who combine all existing diagnostic and performance data, historical maintenance, operating and design data to make decisions when to take major maintenance actions. Maintenance can also be done as not planned in advance due to unexpected or emergency interruption (breakdown maintenance).
2.2 Corrective maintenance and reactive maintenance.
   a. Corrective Maintenance (CM) is a care done to restore (repair and adjust) a system that is not working properly, it can be done while the system is operating, stand-by or equipment is not operating. Overall the reactor remains in operation. This maintenance activity is just waiting until the damage occurs first it will be fixed.
   b. Reactive maintenance (Emergency maintenance) is based on a sudden machine failure, performed when the component is completely damaged or failed to use. This maintenance model requires a large cost because the component must be completely out of the system and shut down.

The main objectives of maintenance can be identified as follows:
   a. Extend the life of the component or facilities;
   b. Ensure availability of component for the reactor operation to be optimally utilized;
   c. Ensure operational readiness of the entire component to be used in emergencies, such as units used as reserves,
   d. Ensure the safety of the operator using the component.

The category of maintenance model is presented in Figure 1.

2.3 Decision Making Grid (DMG)
The DMG model is recommended as a decision-making model with performance placement of problematic equipment based on multiple criteria. Furthermore, the definition of DMG in the form of two-dimensional diagram. The first dimension is machine downtime with low, medium and high criteria, and second is the frequency of equipment damage, also with low, medium, and high criteria. This methodology is implemented as follows:
   a. Criteria analysis: Create an analysis for each criterion.
   b. Defining decisions: criteria on the matrix
   c. Decision-making: by identifying the treatment to be performed.

Retrieving data maintenance results calculation from previous research that is from data treatment system or component of RSG-GAS 2010-2015. The data is divided into 3 columns ie system or component code, frequency (number of interference and criteria: low, medium and high) and downtime (broken time in hours and criteria)

2.4 Model Development
The data are first categorized by taking data system/components that have the greatest damage frequency and break time of the data, using the formula below:
If h is the largest number in the data and l is the smallest number in the data, then
\begin{align*}
\text{High Limit} &= h \\
\text{Medium to high Limit} &= h - 1/3h \\
\text{Low to medium Limit} &= h - 2/3h \\
\text{Low Limit} &= l
\end{align*}

Write down the two variable data frequency and downtime into the two-dimensional matrix shown in Table 1 with two step processes as follows:

a. Both criteria of each machine are categorized using the above formula and then inserted into a two-dimensional matrix, and

b. Once the data has been incorporated into the matrix, the maintenance decision is made by considering the two-dimensional matrix with the maintenance strategy for each criterion.

| Criteria | Downtime |
|----------|----------|
|          | Low      | Medium | High    |
| Low      | OTF      | FTM    | CBM     |
| Frequency| Medium   | FTM    | FTM     |
| High     | SLU      | FTM    | DOM     |

Mapping data is performed to implement the appropriate maintenance strategy on each system/component to increase the effectiveness of the system/component on a regular basis. Description of Table 1 as follows:

a. Operate to Failure (OTF): the system or component will be functioned until damaged. This strategy is implemented when the system/component is rarely damaged and the timing of damage is low;

b. Fixed Time Maintenance (FTM): This strategy uses a maintenance schedule (preventive maintenance), implemented when the frequency of damage and break time are between the mean values in the data;

c. Skills Level Upgrade (SLU): This strategy is implemented by improving the skills of the operator because the system or component includes components that are often damaged, but can easily be fixed;

d. Condition-Based Maintenance (CBM): Used by analyzing damage data and knowing the signs of the system/components will be damaged, including the type of component that is rarely damaged but when damaged requires a long time to repair;

e. Design Out Maintenance (DOM): DOM is the most effective maintenance strategy. This strategy is different from other strategies. DOM aims to redesign or replacing some components on the system that have the most maintenance costs high or which has frequency and downtime the highest damage.

In the use of this DMG model, there are two cases found and must be fixed. First is when the equipment is located close to the boundary between each criteria group within the matrix, and the second is when the two devices are in the same group but have a much different data variable value so it looks unsuitable for entering into a group of maintenance strategies. For both of these cases, a new DMG model with development using machine learning can be used to smooth each strategy group's boundaries and gradually give rules by paying attention to the weighting of each variable value.

2.5 Propose Model

The present study concentrates on developing DMG models to observe downtime and frequency system/component failure. Data mining techniques are used to classify variables before charting to DMG. Clustering analysis is used to show the distance between low, medium and high intervals. The most
commonly used in distance analysis is Euclidean. Let \( x_{ij} \) be the observed value of the variable to \( j \) for the \( i-th \) individual; \( i = 1..., n \) and \( j = 1 ..., m \). The Euclidean distance between these two points in the dimension of space is:

\[
d(s,t) = \sqrt{\sum_{j=1}^{m} (x_{ij} - x_{tj})^2}
\]  

(5)

Canberra used to find the size of the inequality between variable. Let \( x_{ij} \) be the observed value of variable \( j-th \) for individual \( i-th \); \( i = 1 ..., n \) and \( j = 1 ..., m \). The Canberra distinction between these two points is in dimension space is:

\[
\delta_{(i,j)} = \sum_{j=1}^{m} \left| \frac{x_{ij} - x_{tj}}{x_{ij} + x_{tj}} \right|
\]  

(6)

System component on three categories using tri-quadrant approach. Let \( k=(x_{\text{max}}-x_{\text{min}})/3 \) then the intervals are obtained as:

- **High** = \([x_{\text{max}}, x_{\text{max}}-k]\)
- **Medium** = \([x_{\text{max}}-k, x_{\text{max}}-2k]\)
- **Low** = \([x_{\text{max}}-2k, x_{\text{min}}]\)

(7) \quad (8) \quad (9)

3. **Methodology**

a. **Criteria Analysis**: Create a pareto analysis of two important criteria:

b. **Downtime**, which is the main activity undertaken by maintenance management; and frequency of damage. The purpose of this phase is to assess the performance of the system or component over a period of time. The components, relating to each criterion of the upper, medium, and low limits, are divided into three categories using a tri-quadrant approach.

c. **Creates a plot of the criteria of frequency failure and downtime**

d. **Decision Mapping**: which meets both criteria and is ranked in criteria analysis, then mapped on the grid, with maintenance criteria: OTF, SLU, CBM, FTM and DOM

e. **Compared DMG to extend the theoretical and formulation in DMG using tri-quadrant approach to cluster and categorize the variables**

4. **Results and Discussion**

Maintenance data of system/component RSG GAS during the year of 2010-2015 shown in Table 2. Maintenance on the RSG-GAS system/component is performed on components for the primary cooling system, secondary cooling system, primary purification system, purification system and warm water layer, and Sewer heat dissipation system. The data evaluated are failure frequency and downtime. Data obtained from RSG GAS system/component maintenance data for 2010-2015. The highest failure frequency data is 13 and the lowest is 1, while the highest downtime data is 4176 hours and the lowest is 144 hours.

Based on Table 2, using equation 1-4, then the data categories for frequency and downtime are obtained. Data maintenance criteria from systems/component are presented in Table 3. Category of frequency data with high criteria for 3 components, criteria of medium 3 components and the remaining 13 components is low criteria. Category data downtime with high criteria for 2 components, medium criteria for 3 components and the remaining 14 components is low criteria.
### Table 2. Maintenance Data of System/Component RSG-GAS (2010-2015)

| Subsystem                  | Component                          | Component Code       | Frequency | Downtime (hour) |
|----------------------------|------------------------------------|----------------------|-----------|-----------------|
| Primary Cooling System     | Primary pump                       | JE-01(AP01-02)       | 9         | 2688            |
|                            | Instrumentation of the primary system (The ultrasonic censor water level indicator) | JAA01 (CL001)       | 2         | 432             |
|                            | Automatic trip reactor             | SPR (JE-01 CT811/821/831) | 1         | 144             |
| Secondary Cooling System   | Backup pump                        | PA-03 AP-01          | 2         | 192             |
|                            | Valves in press pipes and back flow pipes. | PA01-02/AA-14 dan PA01-02/AA 16 | 5         | 1104            |
|                            | Suction insulation valves          | PA-01-02/03/AA-03    | 1         | 264             |
|                            | Conductivity gauge (located inside the main suction pipe) | PA-01 CQ001          | 1         | 336             |
|                            | Secondary System Instrumentation Flow | PA01-02/CF002       | 3         | 984             |
|                            | Instrumentation measurement of activity γ continuously | PA01-02/CR001       | 13        | 4176            |
| Primary Purification System| Primary purification pump          | KBE01 AP-01-02       | 11        | 4152            |
|                            | Activity monitor                   | KBE01 CR001          | 2         | 480             |
|                            | Isolation valve                    | KBE01 AA-67/ AA-68   | 5         | 600             |
| Purification system and warm water layer | Warm Layer Heater   | KBE02 AH-01          | 1         | 360             |
|                            | Insolation valve                   | KBE02 AA-01/AA-02    | 3         | 2520            |
|                            | Detector γ (purification water)    | KBE02 CR002          | 2         | 528             |
| Sewer heat dissipation system | Circulating and piping pumps in pool cooling systems | JNA10/20/30 AP001, JNA10/20/30 BR00 | 1         | 360             |
|                            | Expansionary tubes                 | JNA10/20/30 BB001    | 2         | 264             |
|                            | Valves                             | JNA10/20/30 AA001    | 1         | 672             |
|                            | Heat exchanger                     | JNA10/20/30 BC001    | 6         | 1416            |

### Table 3. Maintenance Data Criteria of System/Component RSG-GAS

| No | Component Code       | Frequency Number | Criteria | Downtime (hour) | Criteria |
|----|----------------------|------------------|----------|-----------------|----------|
| A  | JE-01(AP01-02)       | 9                | High     | 2688            | Medium   |
| B  | JAA01 (CL001)        | 2                | Low      | 432             | Low      |
| C  | SPR (JE-01 CT811/821/831) | 1        | Low      | 144             | Low      |
| D  | PA-03 AP-01          | 2                | Low      | 192             | Low      |
| E  | PA01-02/AA-14 and    | 5                | Medium   | 1104            | Low      |
### Table 1: Component Maintenance Data

| Component     | Criteria | Frequency |
|---------------|----------|-----------|
| PA01-02/ AA 16| F        | 264 Low   |
| PA01-02-03/AA-03 | G     | 336 Low   |
| PA01-02/CF002 | H        | 984 Low   |
| PA01-02/CR001 | I        | 4176 High |
| KBE01 AP-01-02| J        | 4152 High |
| KBE01 CR001   | K        | 480 Low   |
| KBE01 AA-67/ AA-68 | L    | 600 Low   |
| KBE02 AH-01   | M        | 360 Low   |
| KBE02 AA-01/AA-02 | N   | 2520 Medium |
| KBE02 CR002   | O        | 528 Low   |
| JNA10/20/30 AP001, JNA10/20/30 BR00 | P | 360 Low |
| JNA10/20/30 BB001 | Q  | 264 Low   |
| JNA10/20/30 AA001 | R | 672 Low   |
| JNA10/20/30 BC001 | S | 1416 Medium |

### Figure 2. Criteria Frequency of failure

Criteria based on the component maintenance data for the failure frequency are shown in Figure 2, and the downtime criteria is shown in Figure 3. Based on Figure 2, the high failure frequency criteria for the component: I(PA01-02/CR001), J (KBE01 AP-01-02). Medium criteria for components: S (JNA10/20/30 BC001), E (PA01-02/ AA-14, PA01-02/ AA 16) and L (KBE01 AA-67/ AA-68). The other components not mentioned above are low criteria.

### Figure 3. Downtime Criteria
Based on Figure 3 the highest downtime criteria for components: I (PA01-02/CR001), J (KBE01 AP-01-02) and A (JE-01(AP01-02)). Medium downtime criteria for components: N (KBE02 AA-01/AA-02), S (JNA10/20/30 BC001), E (PA01-02/ AA-14, PA01-02/ AA 16) and H (PA01-02/CF002). The other components mentioned above one low criteria.

Tables 4 and 5 show the categorical results of the frequency of failure decision analysis based on tri-quadrant analysis. This gives better results to equate frequency of failure and downtime compared to Table 3.

| Component | Frequency | Level  | Euclidean | Canberra |
|-----------|-----------|--------|-----------|----------|
| I         | 13        | High   |           |          |
| J         | 11        | High   | 2         | 0.083333 |
| A         | 9         | High   | 2.828427  | 0.183333 |
| S         | 6         | Medium | 4.123106  | 0.383333 |
| E         | 5         | Medium | 4.242641  | 0.474242 |
| L         | 5         | Medium | 4.242641  | 0.474242 |
| H         | 3         | Low    | 4.690416  | 0.724242 |
| N         | 3         | Low    | 4.690416  | 0.724242 |
| B         | 2         | Low    | 4.795832  | 0.924242 |
| D         | 2         | Low    | 4.795832  | 0.924242 |
| K         | 2         | Low    | 4.795832  | 0.924242 |
| O         | 2         | Low    | 4.795832  | 0.924242 |
| Q         | 2         | Low    | 4.795832  | 0.924242 |
| C         | 1         | Low    | 4.898979  | 1.257576 |
| F         | 1         | Low    | 4.898979  | 1.257576 |
| G         | 1         | Low    | 4.898979  | 1.257576 |
| M         | 1         | Low    | 4.898979  | 1.257576 |
| P         | 1         | Low    | 4.898979  | 1.257576 |
| K         | 1         | Low    | 4.898979  | 1.257576 |

The result of tri-quadrant analysis in Table 4 shows that for the failure frequency criterion is same. The procurement occurs in Table 5 on the downtime criterion for the S code component (JNA10/20/30 BC001). The result of the frequency of failure decision analysis shown in Figure 4 and downtime is shown in Figure 5.
Table 5. Downtime Decision Analysis

| Component | Frequency | Level  | Euclidean | Canberra |
|-----------|-----------|--------|-----------|----------|
| I         | 4176      | High   | 24        | 0.002882 |
| J         | 4152      | High   | 0.216917  |
| A         | 2688      | Medium | 1841.443  |
| N         | 2520      | Medium | 1871.538  |
| S         | 1416      | Low    | 1867.687  |
| H         | 984       | Low    | 1871.538  |
| R         | 672       | Low    | 1897.367  |
| L         | 620       | Low    | 1898.732  |
| O         | 528       | Low    | 1900.097  |
| K         | 480       | Low    | 1901.309  |
| B         | 432       | Low    | 1902.672  |
| M         | 360       | Low    | 1902.672  |
| P         | 360       | Low    | 1902.672  |
| G         | 336       | Low    | 1902.823  |
| F         | 264       | Low    | 1904.185  |
| Q         | 264       | Low    | 1904.185  |
| D         | 192       | Low    | 1905.546  |
| C         | 144       | Low    | 1906.15   |

Figure 5. Downtime Decision Analysis

The result of component maintenance criteria according to DMG matrix is shown in Table 6.

Table 6. Decision Mapping

| Criteria | Low | Medium | High |
|----------|-----|--------|------|
| Frequency| OTF (B,C,D,F,G,H,K,M,O,P,Q,R) | FTM (N) | CBM |
|          | FTM (E,L,S) | FTM |      |
|          | SLU | DOM (L,J) |      |
From the results of the DMG matrix decisions above, the component maintenance criteria are shown in Table 7.

| Maintenance Criteria          | Component Code                      |
|-------------------------------|-------------------------------------|
| Operate to Failure (OTF)      | JAA01 (CL001)                       |
|                               | SPR (JE-01)                         |
|                               | CT811/821/831)                      |
|                               | PA-03 AP-01                         |
|                               | PA-01-02-03/AA-03                   |
|                               | PA-01 CQ001                         |
|                               | PA01-02/CF002                       |
|                               | KBE01 CR001                         |
|                               | KBE02 AH-01                         |
|                               | KBE02 CR002                         |
|                               | JNA10/20/30 AP001,                 |
|                               | JNA10/20/30 BR00                    |
|                               | JNA10/20/30 BB001                   |
| Fixed Time Maintenance (FTM)  | JE-01(AP01-02)                      |
|                               | PA01-02/ AA-14                      |
|                               | PA01-02/ AA 16                      |
|                               | KBE01 AA-67/ AA-68                  |
|                               | KBE02 AA-01/AA-02                   |
|                               | JNA10/20/30 BC001                   |
| Design Out Maintenance (DOM)  | PA01-02/CR001                       |
|                               | KBE01 AP-01-02                      |

Based on Table 7, then: from the 19 components evaluated there are 12 OTF criteria, 5 of FTM criteria and 2 of DOM criteria. The preventive maintenance system that has been done is very good. Components that still need attention are 5 components on FTM. The above strategies are arranged in ascending order with respect to perceived benefits. The benefits of the maintenance strategy are as follows: OTF < FTM < SLU < CBM < DOM. Components that have high damage and downtime frequency (including critical components) ie DOM criteria should get more optimal treatment handling by shortening preventive maintenance time.

5. Conclusion
The DMG concept previously used in the maintenance strategies is a flexible and adaptable decision model with many conditions. Tri-quadrat model with clustering concept and variable category can optimize DMG. Evaluations can be made easier because the limits of the maintenance system are well identified. Based on the system/component of RSG-GAS analyzed, the components that have high frequency of damage and downtime are components with DOM criteria should get optimal maintenance (PA01-02/ CR001 and KBE01 AP-01-02).

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