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RAM-based Data Analytics for Power Plant Case Study: Steam Power Plant in Thailand

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Abstract. This research project aims to improve a power plant maintenance program by using the theory of RAM (Reliability Availability and Maintainability). A North Bangkok Combined Cycle Power Plant, especially a steam turbines power plant, is selected to conduct research from 2021 to 2022. The steps of this research can be separated into 2 phases as follows; the first phase involves root cause analysis from failure notifications stored in the CMMS-KKS code database and risk prioritization. Unit C10 and the compressed air unit system in steam turbines operation are the critical systems subsequently, the RAM approach is applied to improve a preventive maintenance program of unit C10 by estimating an operation time before failure, system availability, and the ability to repair. RAM information is brought to reschedule a PM program, for example, *MTTF*, *MTTR*, failure rate, and repair rate, etc. It is found that the percentage of unit C10 system reliability, *R(t)*, and availability, *A(t)*, are higher than 90%. Furthermore, the trade-off between the cost of maintenance and failure for unit C10 is decided by running unit C10 at a percentage of reliability of 88% which can schedule a maintenance interval every 300 hours

Keywords. Reliability, Availability, Maintainability, Steam Power Plant, KKS code

1. Background

Presently, demand for electric power is highly increasing as a result of rising modern household, electrical vehicle transportation and digital twin industry, so power plant has mainly function to supply electrical energy as stable as possible, optimized life cycle cost and less environment impact. Combined cycle power plant, gas and steam turbine, is best alternative and suitable because there are more advantages about generating capacity, high operational flexibility, by-product recycling and low emission than other power plants [1,2]. North Bangkok Power Plant Block 1 operates both gas and steam turbines to generate electricity. Steam turbine power plant is a complex system comprising various systems, from combustion chamber, heat recovery steam generator (HRSG), steam turbine and generator operating simultaneously and continuously 24 hours to be available on demand [3,4] therefore there is a vast volume of operation and maintenance data recorded every day. By this reason, optimal maintenance planning is then important tool to achieve its reliability, availability and maintainability [5]. Preventive maintenance is basically performed in power plant maintenance due to fewer interruptions to critical operations and fixed schedule maintenance tasks because PM is a deterministic time-based maintenance activity [6,7,8]. The PM program at this power plant is classified as 1) inspection schedule (daily, monthly, yearly) and 2) maintenance & repair supply. Maintenance activities are stored in computerized maintenance management system (CMMS). During power plant operation, if failure is detected, all details related to failure, such as system, equipment or damage type damage, failure description, malfunction date, etc., will be input into CMMS. Specifically, **NBK** (North Bangkok) steam power plant system is classified into four levels according to its operational hierarchy from **unit** (e.g. cooling tower system, condensing system), **system** (e.g. pump, compressed air), **equipment** (e.g. filter, adjusting equipment) and **component** (e.g. valve, gearbox) as shown in Fig 1.

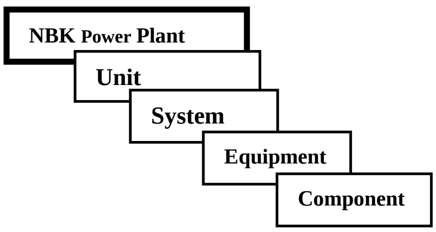

Fig. 1. Hierarchy of Steam Power Plant Database

The hierarchy for power plant is based on international standard identification system for power plant as called KKS code [9]. KKS is abbreviated as Kraftwerk - Kennzeichen-System and the used to identify process-related code, point of installation code and functional location code such as mechanical parts, electrical parts and instruments. For example, NBK-C10PGJ50AC001 means "NBK (North Bangkok steam power plant) – C10 (unit 10) – PGJ (cooling water system no.

50), AC001 (heat exchanger part no. 001). NBK-C13LCB10AP001 means "NBK (North Bangkok Steam Power Plant) – C13 (unit 13) – LCB (main condensate system no. 10) – AP 001 (pump unit no. 001). When failure functional location is reported so that all maintenance units know exactly where and when system or equipment need to be investigated and can prepare resources (spared parts and manpower) for repairing, as showed in Table 1.

Table 1. Functional Location Description of Each Failure Notification Based on KKS Code

Notification	Functional Loc.	Funct Loc Descrip.	Coding code txt	Malfunct. Start	Damage Code	Start Malfn	Completn date	Completion time
1791943	NBK-C10SCG10AN001	STATION AIR COMPRESSOR 1A	Leakage	07-01-2017	MC01	19:50:35	24-01-2017	17:35:27
1792922	NBK-C10PGJ50AC001	HEAT EXCHANGER	Flow blocked	10-01-2017	EX01	09:59:33	31-01-2017	10:56:25
1807218	NBK-C10PAD06AN001	COOLING TOWER FAN CELL 6	High output	30-01-2017	IS03	21:23:46	21-02-2017	14:41:49
1815622	NBK-C13MAJ10AP002	CONDENSER VACUUM PUMP NO. A	Leakage	14-02-2017	MC01	02:58:24	21-02-2017	14:35:24
1838789	NBK-C13UMA16	STEAM TURBINE BUILDING 2ND FL.	Deteriorate	24-03-2017	MC04	02:54:45	27-03-2017	10:55:24
1819733	NBK-C10QUD03CQ001	CONDENSATE AFT CHEMICAL FEED	Fail to function	21-02-2017	MT05	11:46:05	28-03-2017	17:10:18
1816111	NBK-C13PAS10BB001	CT MAKE UP PUMP (A) SUMP PIT	Flow blocked	15-02-2017	EX01	09:51:20	29-03-2017	11:26:19
1816112	NBK-C13PAS20BB001	CT MAKE UP PUMP (B) SUMP PIT	Flow blocked	15-02-2017	EX01	09:54:02	24-09-2018	23:11:51
1824697	NBK-C13PAR20AA102	CMP (B) OUTLET FLOAT VALVE	Leakage	02-03-2017	MC01	14:35:46	22-05-2017	15:10:29
1838345	NBK-C10PA	CIRCULATING WATER SYSTEM	Fail to function	22-03-2017	MT05	13:17:46	23-05-2017	10:36:30
1868339	NBK-C13MAY11AP001	HYDRAULIC FLUID PUMP (A)	High output	14-05-2017	IS04	13:55:16	23-05-2017	10:29:37
1868343	NBK-C13PAS20AP001	COOLING TOWER MAKE UP PUMP	Leakage	14-05-2017	MC01	16:23:27	23-05-2017	10:23:52
1829891	NBK-C10GCN29	HCI ACID SYSTEM	Leakage	09-03-2017	MC01	08:00:09	12-06-2017	13:59:56
1829892	NBK-C13LCB10AP001	CONDENSATE SYSTEM PUMP UNIT	Leakage	09-03-2017	MC01	08:11:56	12-06-2017	14:03:47

2 Problem Statement

However, there are two skepticisms about power plant maintenance that have various systems and big failure data 1) if the maintenance schedule is determined too broadly and some equipment/components are prematurely replaced in spite of good conditions resulting unnecessary maintenance tasks or over maintenance and 2) on the other hand, in some case, equipment/components might fail randomly before scheduled maintenance causing serious problems such as emergency plant shutdown or unprepared spared parts or manpower [10,11,12,13]. In order to change from fixed time-based preventive maintenance to probabilistic maintenance model, Reliability-Availability-Maintainability (RAM) estimation, the well-known model, is best applied to optimize maintenance planning and predict the possible failure occurrence [14]. However, with the limitation of literature research about reliability-based big data analytics, most applications are only familiar with *Mean Time to Failure (MTTF)* and *Mean Time to Repair (MTTR)* for assessing the system performance from past to present [15,16,17]. The advanced predictive maintenance parameters are yet known to improve maintenance scheduling such as failure rate, repair rate or hazard rate so this research aims to apply RAM concept with the huge maintenance data and complicated hierarchy levels.

3 RAM Model

3.1 Data Collection

This research is to propose a generic methodology for applying corrective maintenance data of power plants with RAM theory to improve and optimize maintenance interval. Data from each system unit are based on KKS code as follows;

- A failure start-time and failure end-time
- B functional location
- C downtime
- D damage code
- E money loss from outage

This is the necessary information to be collected for RAM analysis.

3.2 RAM Theory

RAM theory is a statistical function and defined as 1) reliability, *R(t)*, the probability that an item can perform a required function under given conditions for a given time interval, 2) availability, *A(t)*, the ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, and 3) maintainability, *M(t)*, the probability that a given active maintenance action under given conditions can be carried out within a stated time interval [18,19]
The formulas for RAM estimation are as follows.

$$R(t) = e^{-\lambda Tf} \tag{1}$$

$$\text{Time to failure } (Tf_i) = Mulfunction\_Start_i - Mulfunction\_End_{i-1} \tag{2}$$

$$\text{Mean Time to Failure (MTTF)} = \frac{\sum_{i=1}^{n} Tf_i}{Nf_i} \tag{3}$$

Nf_i = *numbers of corrective maintenance*

$$\text{Failure rate } (\lambda) = \frac{1}{MTTF} \tag{4}$$

$$A(t) = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu}\, e^{-(\lambda+\mu)Tf} \quad (5)$$

$$\text{Time to repair } (Tr_i) = Mulfunction\_End_i - Mulfunction\_Start_i \quad (6)$$

$$\text{Mean Time to Repair (MTTR)} = \frac{\sum_{i=1}^{n} Tr_i}{Nf_i} \quad (7)$$

$$Nf_i = \text{numbers of corrective maintenance}$$

$$\text{Repair rate } (m) = \frac{1}{MTTR} \quad (8)$$

$$M(t) = 1 - e^{-\mu Tr} \quad (9)$$

4 Data Analysis and Results

The flowchart of RAM-based data analytics which starts from root cause analysis of failure mechanism to statistical analysis is shown in Fig. 2. Failure criticality is evaluated by using severity and occurrence criteria. Once the root cause is found, then operational and maintenance data are calculated to be *Time to Failure (TTF)* and *Repair (TTR)* to build up the statistical exponential distribution and, finally, calculate RAM parameters as followed in equation (1) – (9)

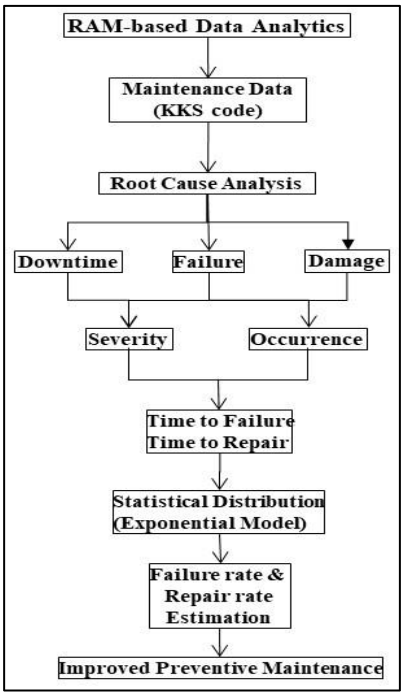

Fig. 2. RAM-based Data Analytics Methodology

According to the root cause analysis, both failure found and mean downtime are taken into consideration because these factors directly affect to RAM performance of steam power plant as "the higher failure found, the better for eliminating root cause failures". Fig. 3 shows that, from year 2017 – 2021, the unit C10 has the most failure occurrence by 153 notifications that it is of interest to analyze root cause and next hierarchy is to filter that SCG system (stationary compressed air unit) is the highest system failure by 42 notifications as depicted in Fig. 4.

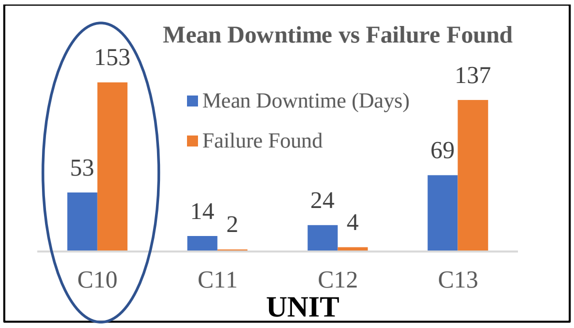

Fig. 3. Failure Occurrences for Each Block Unit

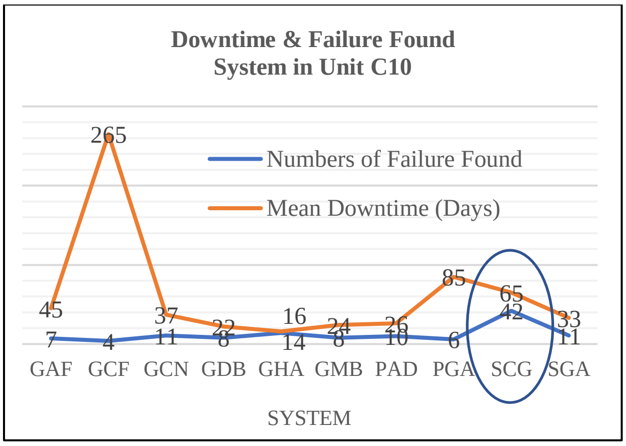

Fig 4. Failure Occurrence for Each System in C10

In Fig. 5, the pareto chart carefully reveals that 80% of significant damage consists of MC01 (leakage) 31%, MI00 (general) 20.7%, IS04 (out of spec) 17.2%, EX01 (blocked) 10.3% and MT06 (fatigue) 6.9% respectively. The root cause analysis has been significant step before RAM calculation (see Fig. 2).

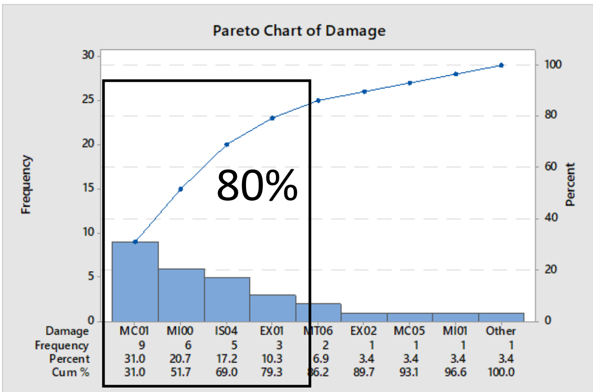

Fig. 5. Pareto Chart for Damages Problems

Next analysis is to evaluate the reliability and availability of compressed air unit in C10, statistical exponential function is applied by *using time to failure (TTF)* and *time to repair (TTR)*. *TTF* is calculated by $Start\ time_i - End\ time_{i-1}$ and *TTR* is calculated by $End\ time_i - Start\ time_{i-1}$. Summarized *R(t)*, *A(t)* and RAM estimation of unit C10 from 2017 to 2021 are displayed in Table 2.

Table 2. RAM Parameters for C10

Parameters	Calculation
Failure rate (λ)	0.000027 failures / hour
MTTR	187.69 hours
Repair rate (μ)	0.005327 repairs /hour
Failure Found	39
MTTF	37,032 hours

As the improvement phases, the maintenance planning department uses this information (from Table 2) to control a preventive maintenance program for unit C10 and compressed air unit. In addition, corrective maintenance (CM) has done simultaneously with preventive maintenance program such as setting standard repair time not over 187 hours, eliminating chronic damage problems and extending mean time to failure at least 37,032 hours. From Table 3 and Fig. 6,.*R(t)* and *A(t)* of compressed air unit from 2017 – 2021 are calculated and they are quite acceptable because all system reliability in unit C10 is between 93% to 99% and the availability is nearly 100% meaning that the operating conditions of unit C10 are running stable, under control and dependable.

Table 3. *R(t)* and *A(t)* for Every System in Unit C10

Functional Code	*R(t)*	*A(t)*
NBK-C10SCG30AN001	0.9915	0.9958
NBK-C10SCG	0.9954	0.9970
NBK-C10SCG20AA101	0.9856	0.9952
NBK-C10SCG10AN001	0.9857	0.9952
NBK-C10SCG30AN001	0.9955	0.9970
NBK-C10SCG10AN001	0.9948	0.9967
NBK-C10SCG01AN001	0.9831	0.9951
NBK-C10SCG02AN001	0.9999	0.9999
NBK-C10SCG02AN001	0.9985	0.9987
NBK-C10SCG10AN001	0.9619	0.9949
NBK-C10SCG20AN001	0.9824	0.9951
NBK-C10SCG30AN001	0.9494	0.9949
NBK-C10SCG10	0.9994	0.9994
NBK-C10SCG10	0.9999	0.9999
NBK-C10SCG03	0.9356	0.9949
NBK-C10SCG10AN001	0.9927	0.9961
NBK-C10SCG20CY002-B01	0.9859	0.9952
NBK-C10SCG10AN001	0.9446	0.9949
NBK-C10SCG20AN001	0.9999	0.9999
NBK-C10SCG30	0.9929	0.9962
NBK-C10SCG20AN001	0.9854	0.9952
NBK-C10SCG10AN001	0.9955	0.9970
NBK-C10SCG10AN001	0.9240	0.9949
NBK-C10SCG20AN001	0.9985	0.9987
NBK-C10SCG10AN001	0.9983	0.9985
NBK-C10SCG02AN001	0.9887	0.9954
NBK-C10SCG01	0.9890	0.9955
NBK-C10SCG01AN001	0.9994	0.9994

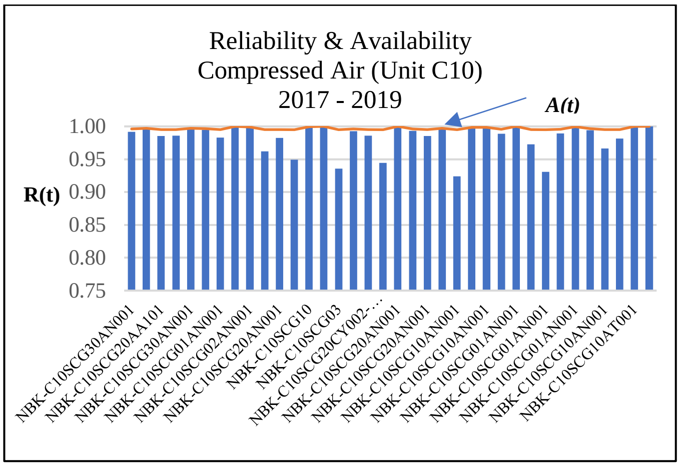

Fig. 6. Graph of *R(t)* and *A(t)* for Every System in Unit C10

Most importantly, the expected reliability varies with the numbers of operational hours, for example, if a SCG system (compressed air unit) needs to be well maintained at 99% reliability (very high reliability), it needs to inspect every 25 hours or every day. Therefore, cost of maintenance per year is a really large budget (70,000,000 Baht or 2,000,000 USD/year), but the failure chance is almost impossible and very less money loss. On the other hand, if this system is fairly maintained about 80% reliability, it needs to schedule every 558 hours (every 23 days or e weeks). Even cost of maintenance approximately reduces to 3,000,000 Baht / year (or 100,000 USD / year), seeming to be satisfaction, but cost of failure is a bit high about 26,000,000 Baht or 866,666 USD per year. It can be seen in Fig. 7.

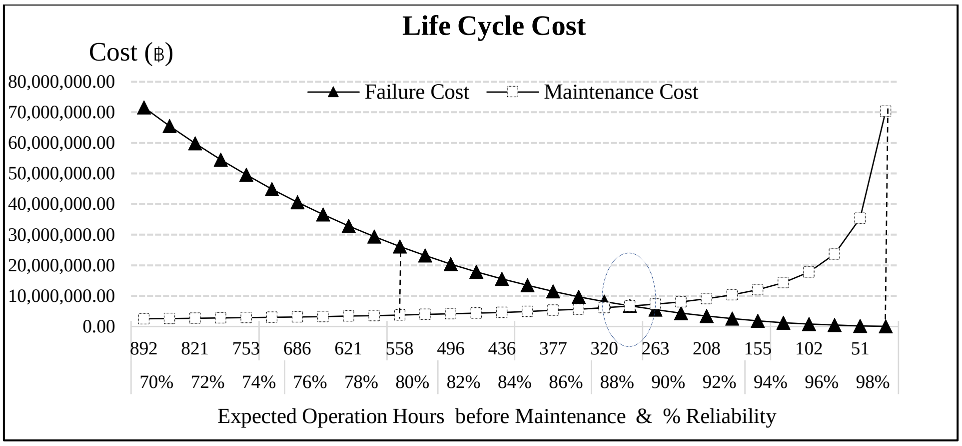

Fig. 7: Cost Optimization Between Failure and Maintenance Expense for Unit C10

5 Conclusion

From the problem statement in the problem statement, this research strongly proposes a new methodology for improving power plant maintenance by using RAM theory plus operational and maintenance data. To prove a conceptual idea, North Bangkok combined cycle power plant, especially steam turbine power plant, has been selected to conduct the research during 2021 – 2022 from big data collection, failures classification, risk prioritization, root causes of failure, and critical equipment lifetime prediction. Although, performing this research process is somehow similar to a failure reporting, analysis, and corrective action system (FRACAS), same output is to assist in identifying and implementing corrective actions [20]. However, this developed methodology emphasizes on RAM calculation with big maintenance and operation conditions which can predict equipment lifetime, plant availability and optimized repair time, that has never mentioned before in previous research. Especially, the RAM approach is able to estimate optimized operation time by *R(t)* and *MTTF* function which can also estimate numbers of possible failures in the future and optimized time to repair. This can avoid the over or under maintenance of the conventional preventive program as mentioned in the problem statement and prepare all necessary resources in advance, such as spared parts and manpower.

Finally, it is still a never-ending process for further study by concentrating on real time power plant operating conditions and RAM approach. The benefit and cost ratio are of interest to trade-off between maintenance cost and failure effect.

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