Development of plant condition measurement – The Jimah Model

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Abstract. The Jimah Model is an information management model. The model has been designed to facilitate analysis of machine condition by integrating diagnostic data with quantitative and qualitative information. The model treats data as a single strand of information - metaphorically a 'genome' of data. The 'Genome' is structured to be representative of plant function and identifies the condition of selected components (or genes) in each machine. To date in industry, computer aided work processes used with traditional industrial practices, have been unable to consistently deliver a standard of information suitable for holistic evaluation of machine condition and change. Significantly the reengineered site strategies necessary for implementation of this “data genome concept” have resulted in enhanced knowledge and management of plant condition. In large plant with high initial equipment cost and subsequent high maintenance costs, accurate measurement of major component condition becomes central to whole of life management and replacement decisions. A case study following implementation of the model at a major power station site in Malaysia (Jimah) shows that modeling of plant condition and wear (in real time) can be made a practical reality.

Key words: Data management, maintenance management

1. Introduction

In power plants and similar industries, it is common to find data and information gathered from various departments and work processes not being fully utilized and analysed. Introna (1997, 78) makes the point that pioneers of information management systems may have failed to notice that managers, if they are involved in a process, already understand the problems. In contrast non-involved managers often need to engage in dialogue with others in order to make sense of available information. In plant there exist both involved and non-involved managers each with differing information needs. Consequently there exists potential for managerial insecurity about how much is enough information, Managers that want to remain in control by micro management can, in plant that is aging, seek increasing information and risk: “…. drowning in ever increasing irrelevant data and starving for relevant information” (Introna 1997).

Adopting the human body as an analogy, Jimah believes that it has been able to develop an improved model for managing information. A human body is made up of a lot of systems such as respiratory and digestive systems - all interconnected to the brain which forms the central control for function and behaviour. Each biological system consists of several organs in which genes on the DNA are important in determining the overall condition, behaviour and expected life of the whole biological...
system. Similarly, an industrial plant can be broken down into specific technical systems. Evans (2008) has previously described the concept of sub-assemblies interconnected to form machines and machines interconnected to form technical systems.

Within each technical system there is major equipment sub-assemblies (organs) comprised of a lot of small parts and components that can be likened to cell, DNA and genes. These components directly influence the health of the equipment of an industrial technical system and, consequently, the health and condition of the overall plant.

Operational researchers such as Sherwin (1994, 2002) have repeatedly pointed out that, practically, it is components that fail and not the whole system or machines. It is components that cause loss of system functionality; therefore it may be argued, the perspective for understanding machine wear and its statistical modeling may be related to measuring simple component condition and relating its influence to overall machine condition and functionality.

Currently, there are several available KPI metrics that have been developed and are being used to measure plant parameters - metrics such as Overall Equipment Effectiveness OEE (Nakajima, 1988), Overall Production Effectiveness OPE (Muchiri and Pintelon, 2008), Risk Based Inspection (RBI) and some customized Maintenance Measurement metrics. The objective of these metrics has been to ensure that key maintenance processes have been carried out and evaluated (P. Muchiri et al., 2010).

In contrast to these existing metrics the Jimah information model describes a method of combining all significant plant data into an objectives matrix in order to report on “real time” plant condition. The advantage of the Jimah model is that it provides not only a generalized overview of plant condition but also contains data that can be drilled and mined for detailed analysis.

2. Objective

The main objective of this work is to develop a new approach in plant condition measurement, an approach that is easily understood and accepted by all members across the organisation. The proposed approach encompasses full utilisation and integration of data and information gathered from multi disciplines and sources across the plant.

3. Concept and literature

3.1 Introduction

As a fledgling power company, Jimah was presented with a bewildering array of literature relative to industrial plant management: Life Cycle Costing (LCC) Blanchard (1981), Reliability Centered Maintenance (RCM) Moubray (1991) and Smith (1993), Total Production Maintenance (TPM) Nakajima (1988) together with many variants of Statistical Quality Management (SQM) methodologies. Jimah opted for a model simple in structure; a model able to provide both practical and objective ways to manage and report on short and long term condition of plant.

The philosophical approach adopted by Jimah was that “plant reliability was inherent in the designed and delivered configuration of plant”. Inherent in the Jimah philosophy was the belief that the organisation sought and needed predictable and dependable performance to optimise commercial outcomes.

3.2 Lead and lagging metrics

When Jimah was developing its strategies for managing and reporting on plant condition, a conclusion was reached where the traditional method of reporting reliability and availability was considered to be a “lag” metric; lag in the sense that the metric was forcing plant to be managed using static historical records.

Jimah sought a “lead” metric where data was to be current and able to be presented in a context able to provide prediction of remaining plant life. At Jimah, the concept of an objectives matrix has been developed as a “lead” indicator.
3.3 The data Genome – an objective matrix; a “lead” metric

An advantage of an objectives matrix is that it is able to accept and normalise different units and present a summation of different readings in percentage form. The conceptual challenge in developing an objectives matrix as a “lead” indicator was to develop a model of cryptic data that would be representative of plant condition.

Central to the concept was the acceptance that within each sub-assembly each component would exhibit a recognisable statistical failure pattern. The component exhibiting the shortest statistical life would determine $\gamma$ - the threshold time to failure for that particular sub-assembly (Weibull analysis). Such components were to be identified as “Dominant Components”. Live data taken from “Dominant Components” would then provide an indicator of expected remaining statistical life of each sub-assembly.

In order to be able to implement the single component analysis concept Jimah separated its plant into thirty one (31) defined functional areas. Each functional area contained technical systems (Gits, 1988) where each technical system is an interconnected collection of sub-assemblies, e.g. a condensate functional area consisted of interconnected sub-assemblies of motor, pump, valves, control modules and electrical cables.

3.4 The metaphor of the data genome

In the Jimah model the Data Genome schema is used to provide, for participants in the Jimah “Data to information process”, a conceptual reference of a structured database. By selecting and monitoring dominant components in each sub-assembly of its technical systems, Jimah has been able to develop a cryptic representation of each technical system’s “real time” condition.

In the Jimah model, information is considered to be: “A message containing structured data”. In order to develop a report or message about plant condition both subjective information from logs and measured objective data from the Data Genome are combined to develop a context (the objective matrix) from which knowledge about changing plant condition can be evaluated.

4. Plant Structure and implementation

Jimah Power Plant has been subdivided into 31 defined technical systems. Sub-assemblies have been interconnected to form machines and machines interconnected to form each technical system – technical systems interconnected to form major assets as described in figure 1, Evans (2008).

![Figure 1. Concept of interconnecting sub-assemblies and machines to form a technical system.](image)

Firstly, in order to develop a cryptic model and scorecard of condition, sub-assemblies are identified for each technical system, and then, dominant components are determined for each sub-assembly. The conceptual condition framework proposed in this paper is illustrated in figure 2. Under each technical system, there are listed machines and equipment that are important to each system’s...
functional configuration. Listed in the next level are the dominant components that play a big role in ensuring each machine’s health. These components may be serviced by several engineering disciplines such as mechanical, electrical, control and instrumentation.

![Diagram of technical system](image)

**Figure 2.** Jimah Power Plant General Equipment structure.

5. **Data Management**

The crucial part of the measurement exercise is data collection and collation. Some data such as vibration and oil analysis, motor current and temperature are only available while plant is in-service. However, other data such as bearing clearance, impeller tip clearance, boiler tube thickness, etc. can only be measured during plant shutdown. Additionally there are two types of data – quantitative and qualitative. Quantitative data is able to be presented objectively, for example, measured tolerances or allowable limits of a bearing clearance. On the other hand, qualitative data is more difficult to define because consensus of opinion for interpretation must be sought (Evans, 2008). Figure 3 illustrates the data management structure applied in the Jimah development.

The challenge has been to combine both data types (quantitative and qualitative) from the various sources and work processes. To address this challenge, quality check sheets are designed and based upon the structure shown in figure 3. The check sheet system provides understanding of what to inspect quantitatively and so differentiates quantitative data from qualitative opinion. The methodology effectively improves data gathering from the various engineering disciplines.

The other challenge was to combine ‘in-service’ and ‘out-of-service’ data as their collection periods differed. In-service data is collected just prior to and after plant maintenance. Out-of-service inspection, recording and measuring is performed during actual shutdown. This established practice enables better evaluation of the changes in plant condition and performance before and after production (in-service) and restorative (condition based out-of-service) maintenance.
5.1 Plant Condition Measurement – Rating Guideline

After the identification of dominant components (refer figure 2), a rating guideline for each component is developed. In this exercise, pre-defined scores ranging from 1 to 10 are developed for each individual dominant component. A score of 10 is defined as the best achievable target condition and is generally based on the actual original condition, desired values recommended by OEM or data taken during initial equipment commissioning. On the other hand, the lower score will indicate deterioration or degradation of the component sustained while fulfilling its intended function, desired performance and life. In the rating guideline development, to ensure the rating is reliable and meaningful in representing the actual condition of each dominant component, it is crucial to acquire the advice and opinion from the component or machine expert, e.g. Original Equipment Manufacturer (OEM) or equipment/component specialists. Table 1 below is an example of a rating guideline developed for a dominant component of the Induced Draft Fan (IDF). The score of 10 represents the best achievable vibration limit and is based on the actual recorded vibration level during initial plant commissioning in 2008.

5.2 Plant Condition Measurement – Data Matrix

The next stage is to develop a comprehensive data matrix for each of the machines and dominant components. In considering the objective of this initial project, the concept of a lead matrix is introduced so that a score or rating can be given to both quantitative and qualitative sets of data. Data is defined as being divided into two sub-categories i.e. in-service (plant condition) reports and off-service (overhaul or maintenance) reports. Plant condition data is usually taken periodically during plant in-service, e.g. monthly, and used for plant monitoring purposes e.g. oil condition and drive
motor vibration level. On the other hand, off-service data are overhaul or maintenance service reports
that can only be obtained during plant shutdown e.g. heating element thickness in RAPH, bearing
clearances, visual inspection to internal part of fan impeller, etc. A descriptive content and guideline of
a typical data matrix is shown in figure 4.

| Vibration Limit (mm/s) | Rating |
|-----------------------|--------|
| 0.50 to 0.70          | 10     |
| 0.71 to 1.00          | 9      |
| 1.10 to 1.40          | 8      |
| 1.41 to 1.60          | 7      |
| 1.61 to 2.00          | 6      |
| 2.01 to 2.30          | 5      |
| 2.31 to 2.5           | 4      |
| 2.51 to 2.8           | 3      |
| 2.81 to 3.10          | 2      |
| 3.10 and above        | 1      |

5.3 Plant Condition Measurement – Score Card
The sum of all component ratings, in percentage values (%), will represent the level of equipment
health for each technical system. By combining the rating (%) for all defined technical systems, a final
and single rating (%) can be produced to represent the overall plant condition. A plant score card
format is then developed to combine results of all the listed components and equipment under a
technical system. The format provides simple and structured yet informative representation of the
overall system condition and health, promoting better understanding and acceptance across the entire
organisation.

As each component, machine and system is deemed to have different criticality to one another, a
weightage factor is considered. Using standardised and agreed criteria the weightage factor needs to be
pre-defined through a criticality assessment of each component, machine and system.
| Data Type | Measures / Indicators | Units | Description | Recommended Target |
|-----------|-----------------------|-------|-------------|--------------------|
| In-Service | Vibration | mm/s (velocity) | Vibration usually measured for rotating equipment such as fan, pump etc. Usually higher vibration indicates worsening machine condition. | Each type of equipment has specific limit. ISO is a good reference to build a rating. Generally best practice is to keep machine vibration below 2mm/s |
| | Oil Analysis | ppm | Oil analysis of machine component will reflect the condition of machine | Minimum amount of wear such as iron, chromium, copper in PPM, the best practice is below 50ppm |
| | Temperature | Celsius | Temperature of component such as bearing, equipment such as motor or operating condition such as boiler exit temperature | The best is to follow the OEM recommendations |
| | Current | Ampere | Motor current | To ensure the current well below rated current |
| | Functional Test | Function / Not function | This applies for standby and safety devices to ensure its function when needed. | Full function during routine test |
| | Plant Cleanliness | Rating | To ensure plant in a clean condition. No oil spillage, waste, etc near equipment and in each technical system | Rating approach could be used - 10 for excellent clean condition down to 1 for very dirty. |
| Off-Service | Corrosion | % | Visually inspected and estimate the affected area, or some specific measurement such as thickness or depth of crack. | Rating approach could be used - 10 for no affected area down to 1 for large affected area |
| | Crack | % | | |
| | Erosion | % | | |
| | Deformation | % | | |
| | Wear | % | | |
| | Alignment | micron | Coupling alignment for rotating equipment should be checked and recorded for trending purpose and adjustment need to be done if necessary. | Refer to OEM recommended allowable and acceptable limits |
| | Clearance | mm or micron | Clearance, such bearing clearance and impeller tip clearance | |

Figure 4. A summary of condition indicator of a typical fan used for a Data Matrix

6. Case study
Jimah Power Plant is an Independent Power Producer (IPP) and consists of two coal-fired generating units with independent net output capacity of 700 MW each. Located in the western coast of Malaysia, the plant was fully commissioned in 2009.

The plant has been divided into 31 technical systems. Each of the 31 systems plays an interdependent and important role. To meet and satisfy the demand for electricity by the nation, each technical system must be operated continuously and be maintained in excellent condition. The draught system has been selected to be evaluated in this pioneer project of the JIMAH plant information management model. The draught system is one of the most important technical systems in the plant. Its
key function is to provide combustion air to the boiler to control furnace pressure and temperature. In order to achieve a complete combustion process a balanced draft system that combines both Force Draft Fans and Induced Draft fans is employed.

To determine the condition and maintain efficiency, effectiveness and performance of the draught system, four pieces of equipment are selected, by the expert, to act as cryptic model - Force Draft Fan (FDF), Induced Draft Fan (IDF), Primary Air Fan (PAF) and Regenerative Air Pre-Heater (RAPH). As stated by Sherwin (1994, 2002), it is components that fail and cause loss of the system functionality not whole systems or machines. Thus, to verify the condition of the draft system holistically, a dominant component for each major piece of equipment must first be determined. A weightage factor can only be given to each dominant component when single component reliability is understood. Understanding of criticality of components becomes central to building a cryptic or interpreted model for this particular study.

In the case study of Jimah Plant Unit 1 Draught System, rating guideline, data matrix and system score card have been developed using the actual current plant condition (in-service) data and the most recent plant shutdown (off-service) inspection and overhaul record taken in November 2011. Expert opinion is gathered mainly through discussion with the maintenance team members specializing in draft fans and RAPH. Other inputs include the Operations and Condition Monitoring team.

The full data and result of the study are attached in Appendix A. Figure 5 presents the summary of overall evaluated condition results for the Draught System as analysed in the case study. In order to develop comprehension of total plant condition, complete evaluation of equipment and components in all 31 available technical systems must also be completed.

![Figure 5. Jimah Power Plant Unit 1 Draught System overall condition after 2011 Minor Overhaul](image)

7. Conclusion and Further Work
At present, several methods and techniques have been developed to measure and indicate plant performance, equipment efficiency, maintenance performance, etc. However there is no known complete tool or technique able to measure plant condition by using a holistic and integrated data approach. Through the development work done and conceptual framework demonstrated in this paper, plant condition measurement can be readily presented and easily understood by all levels within the organisation. The case study on Jimah Power Plant Unit 1 Draught system indicates an overall condition of 96.91% healthy soon after a minor overhaul exercise. This implies that the system has deteriorated 3.09% from its baseline or initial commissioning condition. The simple information format presented will allow better understanding of the actual plant condition and provide ability to identify the deficiency contributors for further improvement. Nonetheless, the current attempt on the
development of this new approach is far from complete. Further work needs to be done in improving the identification of a complete data matrix together with development of an accurate algorithm that will produce a more reliable representation of actual plant condition measurement. Additionally, using the same concept, approach and framework it is considered that, artificial intelligent programming can be developed to predict equipment, system and plant behaviour. Jimah envisages that the work using this new approach for the development of improved plant condition measurement will continue. The expectation is that this new methodology will take the industry to the next level of plant predictability and reliability. A level necessary to be able to confidently participate in and deliver within current global competition and increasing demands from stakeholders.

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### Appendix A

**PLANT CONDITION MEASUREMENT (PCM) FINAL SCORECARD**

**PLANT**: UNIT 1 JEV POWER PLANT  
**TECHNICAL SYSTEM**: DRAUGHT

| NO | EQUIPMENT | COMPONENT | IN-SERVICE | OFF-SERVICE | OVERALL EQUIPMENT | OVERALL SYSTEM |
|----|-----------|-----------|------------|-------------|-------------------|----------------|
|    |           |           | SCORE      | TOTAL SCORE | SCORE             | TOTAL SCORE    |
| 1  | Raph A    | RDU       | 96.00      | 92.30       | 94.35             |
|    |           | Rotor     | 100        | 99.61       |
|    |           | Main Bearing | 100     | 95.08       |
|    |           | Heating Element | 100    | 95.08       |
| 2  | Raph B    | RDU       | 96.60      | 93.55       | 95.08             |
|    |           | Rotor     | 100        | 99.61       |
|    |           | Main Bearing | 100     | 95.08       |
|    |           | Heating Element | 90     | 90.00       |
|    |           | Impeller  | 90         | 90          |
|    |           | Shaft     | 100        | 99.61       |
|    |           | Casing    | 100        | 99.61       |
|    |           | Inlet box | 100        | 99.61       |
| 3  | Paf A     | Inlet cone | 100     | 99.61       |
|    |           | Radial inlet vanes | 100 | 99.61 |
|    |           | Bearing   | 84         | 92.30       |
|    |           | Coupling  | 100        | 92.30       |
|    |           | Drive motor | 96.67   | 94.35       |
|    |           | Actuator  | 6          | 6           |
|    |           | Linkages  | 100        | 90          |
| 4  | Paf B     | Impeller  | 100        | 96.60       |
|    |           | Shaft     | 100        | 99.61       |
|    |           | Casing    | 100        | 99.61       |
|    |           | Inlet box | 100        | 99.61       |
|    |           | Inlet cone | 100    | 99.61       |
|    |           | Radial inlet vanes | 100 | 99.61 |
|    |           | Bearing   | 90         | 95.08       |
|    |           | Coupling  | 100        | 95.08       |
|    |           | Drive motor | 85      | 85          |
|    |           | Actuator  | 100        | 100         |
|    |           | Linkages  | 100        | 100         |
| 5  | Fdf A     | Impeller  | 100        | 96.67       |
|    |           | Shaft     | 100        | 99.61       |
|    |           | Casing    | 100        | 99.61       |
|    |           | Inlet box | 100        | 99.61       |
|    |           | Inlet cone | 100    | 99.61       |
|    |           | Radial inlet vanes | 100 | 99.61 |
|    |           | Bearing   | 88         | 96.91       |
|    |           | Coupling  | 100        | 96.91       |
|    |           | Drive motor | 98.33   | 98.33       |
|    |           | Actuator  | 100        | 100         |
|    |           | Linkages  | 100        | 100         |
| 6  | Fdf B     | Impeller  | 100        | 96.67       |
|    |           | Shaft     | 100        | 99.61       |
|    |           | Casing    | 100        | 99.61       |
|    |           | Inlet box | 100        | 99.61       |
|    |           | Inlet cone | 100    | 99.61       |
|    |           | Radial inlet vanes | 100 | 99.61 |
|    |           | Bearing   | 68         | 72          |
|    |           | Coupling  | 100        | 72          |
|    |           | Drive motor | 98.33   | 98.33       |
|    |           | Actuator  | 100        | 100         |
|    |           | Linkages  | 100        | 100         |
| 7  | Idf A     | Impeller  | 100        | 96.67       |
|    |           | Shaft     | 100        | 99.61       |
|    |           | Casing    | 100        | 99.61       |
|    |           | Inlet box | 100        | 99.61       |
|    |           | Inlet cone | 100    | 99.61       |
|    |           | Radial inlet vanes | 100 | 99.61 |
|    |           | Bearing   | 84         | 84          |
|    |           | Coupling  | 100        | 84          |
|    |           | Drive motor | 98.33   | 98.33       |
|    |           | Actuator  | 100        | 100         |
|    |           | Linkages  | 100        | 100         |
|    |           | Lubricant System | 100 | 100     |
| 8  | Idf B     | Impeller  | 100        | 96.67       |
|    |           | Shaft     | 100        | 99.61       |
|    |           | Casing    | 100        | 99.61       |
|    |           | Inlet box | 100        | 99.61       |
|    |           | Inlet cone | 100    | 99.61       |
|    |           | Radial inlet vanes | 100 | 99.61 |
|    |           | Bearing   | 88         | 88          |
|    |           | Coupling  | 100        | 88          |
|    |           | Drive motor | 98.33   | 98.33       |
|    |           | Actuator  | 100        | 100         |
|    |           | Linkages  | 100        | 100         |
|    |           | Lubricant System | 100 | 100     |
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