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DATA MODELING TO QUANTIFY RELATIONSHIPS BETWEEN CHANGES IN MAINTENANCE AND OPERATING REGIME ON POWER PLANT RELIABILITY

Jennifer Santos / Consultancy Project Leader, Sciemus Ltd.,
Angelo Nicotra / Data Analyst – Power, Sciemus Ltd.

5th Floor, 52 Cornhill, London EC3V 3PD United Kingdom
Phone No: +44 (0) 20 7220 6298
Email: jsantos@sciemus.com, anicotra@sciemus.com

ABSTRACT

The thermal-fired power generation sector has been challenged by a number of factors - growing share of renewable energy, declining demand for electricity, low thermal coal prices while gas prices remain high. These pressures are affecting the duty cycle on gas turbine units, changing the operating regimes away from baseload towards two-shifting or peaking. As a result, power plant operators are reviewing their current business models and seeking ways to optimise their costs while maintaining high reliability and availability.

Utilising a data-driven modeling approach, this paper presents the work that Sciemus has completed for a power plant operator to quantify the impact of changes in maintenance levels and operating regimes on their power plant's reliability. Sciemus has defined a methodology that started with accessing the client's plant-specific historical operational and maintenance data, which was subsequently combined with Sciemus' database of thermal-fired power station reliability and maintenance history. Statistical analyses and modeling were employed to simulate the expected future performance of the power plant for a variety of maintenance and operating regime scenarios. Armed with this analysis, the power plant operator understood the relationship between maintenance, operating regime and performance, enabling it to maximise its profits through its operations and maintenance.

INTRODUCTION

Power generating companies are faced with significant pressures to remain competitive in the midst of very challenging market conditions. The rise of renewable energy, coupled with stagnating electricity demand, underscore the criticality for thermal power plant operators to maintain their plants' availability and flexibility and to optimise their plants' operations and maintenance. This is particularly important for those operators with several power plants operating under the same market and operating conditions but with different power plant configurations and maintenance strategies, and who desire to find ways to optimise their expenditures. Sciemus' analysis has aimed at helping power generating companies optimise their plant's operating regime and maintenance expenditures to maximise financial benefits.

Main Part of the Paper

PROFIT MAXIMISING MAINTENANCE EFFORT

The level of maintenance performed on a power plant has an impact on its performance. Sullivan et al (2010) have defined four types of maintenance philosophies applied on equipment or machineries. These are:

1. *Reactive Maintenance* involves a fix on failure, where no maintenance actions are undertaken to ensure that the equipment's design life is maximised. This maintenance mode is the

preferred option where the costs of failure are minimal.

2. *Preventive Maintenance* involves maintenance actions that detect, preclude or mitigate the equipment's degradation. Routine maintenance activities are performed on pre-set schedules irrespective of the equipment's current condition, which may arise from a manufacturer's recommendation to extend the equipment's useful life.
3. *Predictive Maintenance* uses information from the equipment's actual condition to estimate its likelihood of failure. Measurements are taken to detect the onset of equipment degradation, and maintenance is done to prevent equipment failure.
4. *Reliability-Centred Maintenance* combines the principles of equipment reliability and cost-effectiveness in structuring the most appropriate maintenance programme. This approach is predicated on predictive maintenance for equipment that is of higher importance to a power plant, whilst at the same time recognises that inexpensive or less important equipment may be more suited for a reactive maintenance approach.

Quantifying the relationship between maintenance effort and power plant performance has been one of the key objectives of this analysis. The principal maintenance philosophy on which this analysis has focussed is on preventive maintenance. Compared to other types of maintenance approaches, preventive maintenance has the highest potential for unnecessary expenditures as, at the point of implementing a preventive maintenance effort, the current and actual condition of the equipment is effectively unknown. Since any changes in maintenance effort will not have an immediate impact on the equipment's performance, focusing on a time-based maintenance approach can allow for the effects of delaying maintenance to be better understood.

Figure 1 is a conceptual illustration of how preventive maintenance costs, a power plant's profits and performance (i.e. measured availability, reliability and efficiency) changes with variations in preventive maintenance effort. This concept precludes any other types of maintenance philosophies.

There is clearly a threshold at which maintenance costs are at a minimum. If no preventive maintenance is performed on a power plant, the operator will be faced with high costs, all of which are unplanned, resulting from broken machinery. Running the plant at the minimum maintenance effort is likely to increase the risk of plant or equipment failure and reduce availability. However, any increase in preventive maintenance effort will result in higher expenditures, thereby adversely impacting a power plant's costs.

Equally, operating at maximum performance may not always be cost-effective. Performing too much maintenance leads to frequent equipment shutdowns and maintenance-induced failures, which negatively affects a power plant's performance. At the centre is a profit maximising region, where the additional costs of more maintenance are delicately balanced with the highest possible profits generated by better plant performance.

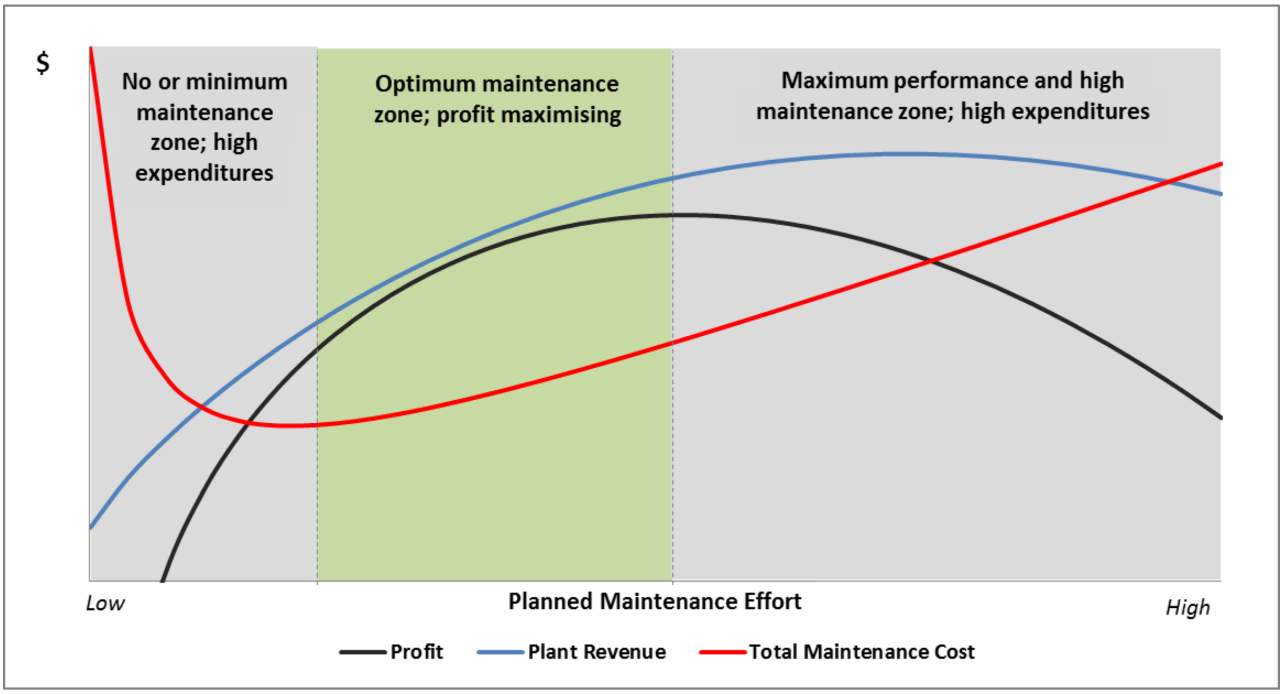

Figure 1. Profit Maximising Concept
Source: Sciemus

CASE STUDY

Sciemus has been approached by a leading power plant operator (hereinafter referred to as “the Operator”) who currently owns and operates a fleet of thermal power stations as well as a number of hydropower plants. Conditions in the thermal power generation market have proven to be quite challenging to yield sustainable profit margins for the Operator, which has now turned its attention on understanding operational savings opportunities that represent low-hanging fruits. Immediate gains are expected in two key areas – maintenance spend and the operating regime in which their plants are being run.

One of the Operator’s coal-fired power plants (hereinafter referred to as “the Plant”) has been the main point of analysis in this report. Commissioned in the 1980s, the plant has four units with a combined capacity of nearly 3GW. Due to its extensive redundancy, the Plant has not suffered from extensive failures and is predominantly run on a planned outage basis. Whilst the Operator has preconceived opinions based on experience on how to optimise their maintenance spend for this power plant, it has very little data on which to base their assessment on. Utilising a data-driven modeling approach, Sciemus has delivered an analysis to the Operator that quantifies the impact of changes in maintenance levels and operating regimes on the Plant’s reliability.

PROJECT APPROACH

Sciemus’ methodology is built around three distinct stages:

1. Data Collection and Normalisation

For each critical component comprising the Plant, maintenance and operational history, combined with the Operator’s expected operational hours and planned maintenance outages, have been collected. The data collection process involved extensive interaction with the plant’s engineers.

These plant and component-specific data have been combined with Sciemus’ database of power plant losses that details the reliability (i.e. component and sub-component failure) and maintenance history of a large number of thermal-fired power plants worldwide at a component and unit level, thus creating a sufficiently large data pool.

Sciemus’ data is sourced from insurance underwriting information obtained from approximately 4,000 engineering survey reports, and include historical planned outages, forced outages as well as a power plant’s starts and service hours. Sciemus’ data is anonymised and analysed, and statistic behaviours of components are derived to provide a statistical relevant basis for further evaluations. The data pool is cleansed, converted into a common format and normalised to ensure that one is able to compare and draw conclusions from the data.

2. Risk Profiling

In conducting its analysis, Sciemus has treated the power plant component as a starting point. The second stage involves analysing how each of the components' performance changes in time with variations in maintenance levels and operating regimes that are unique to the Plant. For each and every component in the Plant, three independent profiles of risk failures are generated:

- Probability of failure with time
- Outage Duration versus probability. The outage duration involves the time that the component is not in use given that it has first failed
- Repair Cost versus probability. The repair cost is expenditure used to repair the failed component given that it has first failed

Through these risk profiles, the Operator's management team can already determine the impact of variations on maintenance spend on two identical units. However, the impact of variations in maintenance spend on the Plant as whole cannot be immediately determined, as this is very much depends on equipment redundancy and the stochastic relationships between synchronised outages on different power plant machinery.

3. Power Plant Modeling

Once the risk profiles have been generated, a detailed plant configuration of the Plant was implemented. Figure 2 demonstrates a very basic configuration of the Plant. The outer boundaries of the plant are comprised of coal and water inputs, as well as electricity, ash and flue gas outputs.

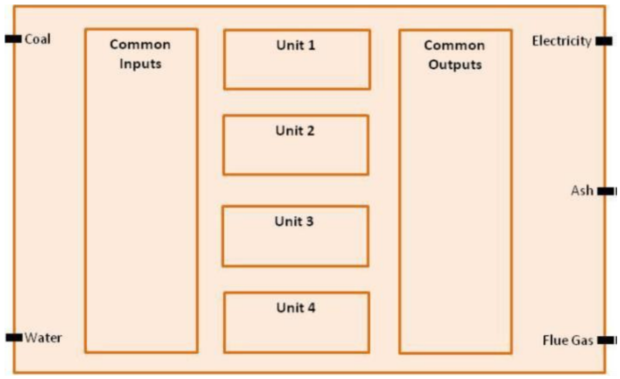

Figure 2: Simplest Level of the Plant

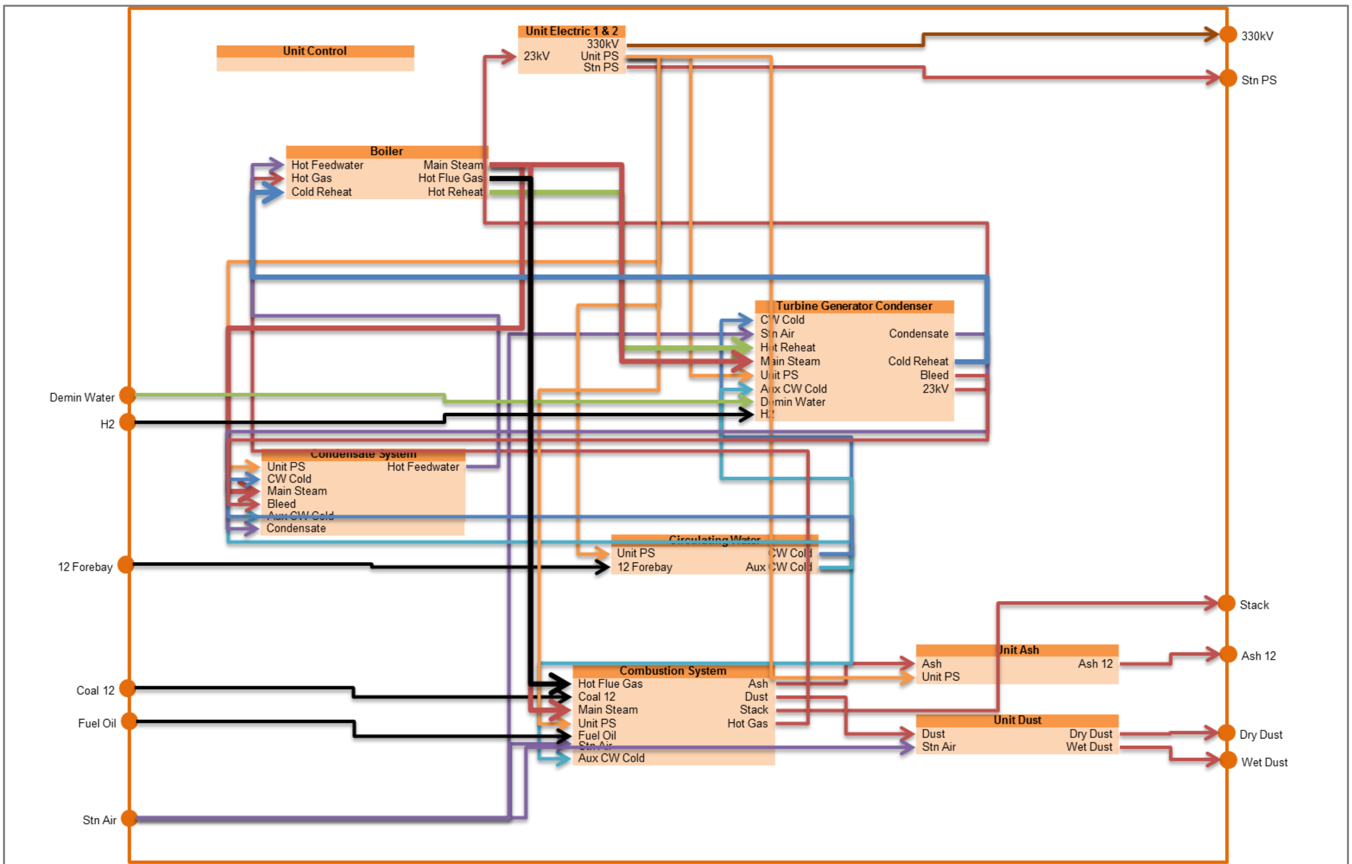

Figure 3: Configuration of Unit 1 the Plant

The configuration's structure also allows for an analysis through nested levels of plant performance, unit performance, component performance and finally sub-component performance.

To illustrate this concept, Figure 3 shows a more complex configuration of one of the units in the Plant, which include the different components and sub-components in the unit.

Once the detailed plant configurations were finalised, a power plant model has been developed to show the interdependencies between the sub-components, components and units in the Plant. Component risk profiles (specifically Mean Time to Failure and Mean Time to Repair) have been built into the plant model to assess the effect of component failure on the power plant's output. Additionally, specific component inputs relating to the maintenance and operating regime (as specified in Table 1) have also been loaded into the model.

Maintenance Inputs	Operating Regime Inputs
Maintenance Hours Number of hours (resulting in any availability loss) the plant/unit/component is expected to be maintained in the next 12 months	**Equivalent Fired Hours** Number of fired hours that the plant/unit is expected to operate in the next 12 months
Maintenance Events Number of events (resulting in any availability loss) the plant/unit/component is expected to be maintained in the next 12 months	**Number of Starts** Number of starts that the plant/unit is expected to operate in the next 12 months
Number of Failures Number of Forced Outage Events (resulting in any availability loss) the plant/unit/component has experienced in the last 12 months	
Outage Duration Number of forced outage hours (resulting in any availability loss) the plant/unit/component is expected to be maintained in the next 12 months	

Table 1: Inputs for Power Plant Modelling

CALCULATION MODEL

At the core of the calculation engine is a Monte Carlo simulation involving repeated analyses of simulated periods of operations to determine a distribution of possible outcomes of the Plant's reliability and availability. Given the complexity of the power plant model, 100 million simulated periods have been employed as basis for the Monte Carlo simulation, allowing to manage a Monte Carlo error to below 1% of the mean outcome.

Once the simulation was complete, the results have been interrogated based on several performance metrics of interest and at various levels of detail (i.e. plant level, unit level, system level and sub-system level). These metrics include the following:

- Plant or unit availability given the maintenance and operating regime inputs
- Plant, unit or component forced outage factor given the maintenance and operating regime inputs
- Probability of failure frequencies
- Probability of outage duration

Powered by the calculation engine, the model supported the Operator's management team in determining the impact of adjusting a number of maintenance and operating regime inputs on their power plant's reliability and availability through time as the plant ages. The outputs can be demonstrated in terms of both its magnitude and probability. Sample outputs of these metrics are demonstrated in the next section.

SAMPLE RESULTS OF THE ANALYSIS

The section below discusses four performance metrics for the Plant as an output of the Monte Carlo simulation, given variations in preventive maintenance effort and operating regime inputs.

1. Effect of Maintenance Effort on Forced Outages Frequencies

Figure 4 shows the impact of different preventive maintenance hours on the number of forced outage events to rectify faults on a unit of the Plant in the next 12 months. In Scenario 1, preventive maintenance hours for the entire unit were expected to be significantly lower at 200 hours in the next 12 months compared to 1,760 hours in Scenario 2 for the same unit and duration.

In Scenario 1, the probability that the unit will experience greater number of failures is higher than if it were to undergo preventive maintenance hours in the next 12 months as defined in Scenario 2. By the same token, in Scenario 1, it will experience a maximum of ~17 failures in the next 12 months compared to ~13 failures if it were to undergo preventive maintenance hours in Scenario 2.

2. Effect of Maintenance Effort on Outage Duration

Using the same number of preventive maintenance hours comprising Scenario 1 and Scenario 2, Figure 5 demonstrates that higher preventive maintenance hours performed on a unit of the Plant significantly reduce its outage duration per failure event.

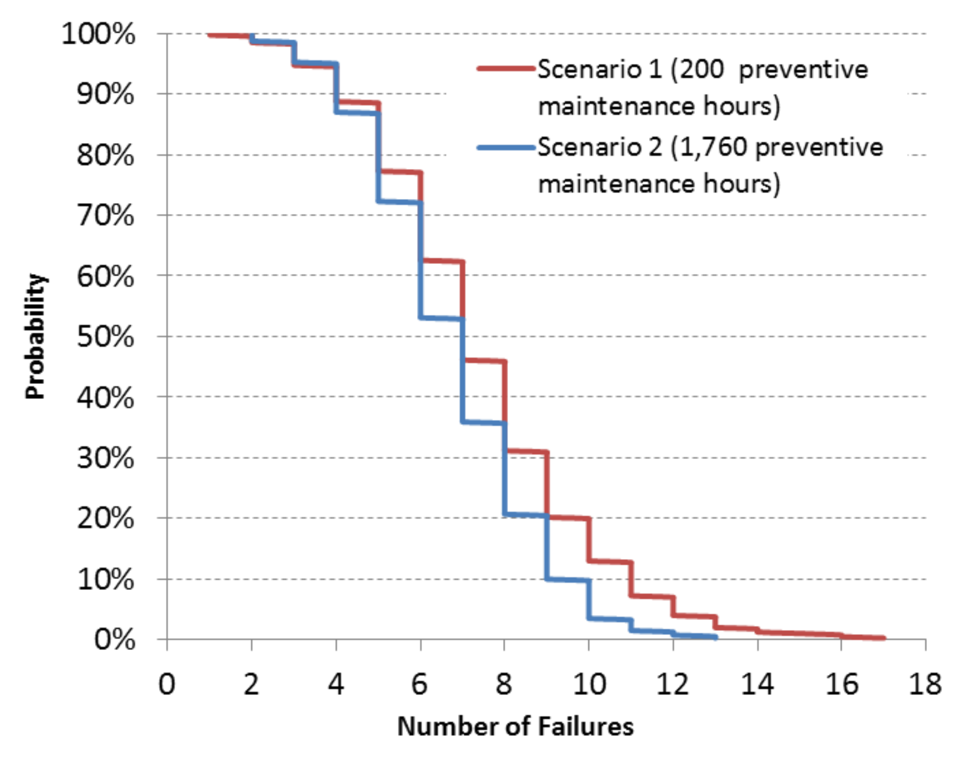

Figure 4: Preventive Maintenance Hours vs Number of Unit Failures

In the first scenario, the probability that a unit in the Plant will have an outage of 500 hours is higher at 5% compared, to 2.4% probability in the second scenario. Similarly, the maximum expected outage duration for a single event is 990.808 hours in Scenario 2. This is in stark contrast to Scenario 1, where the maximum expected outage duration per failure is 3,325.840 hours.

3. Effect of Operating Regimes on Outage Duration

In addition to preventive maintenance, the impact of changes in operating regimes was also assessed. Currently, the Plant is running in baseload mode.

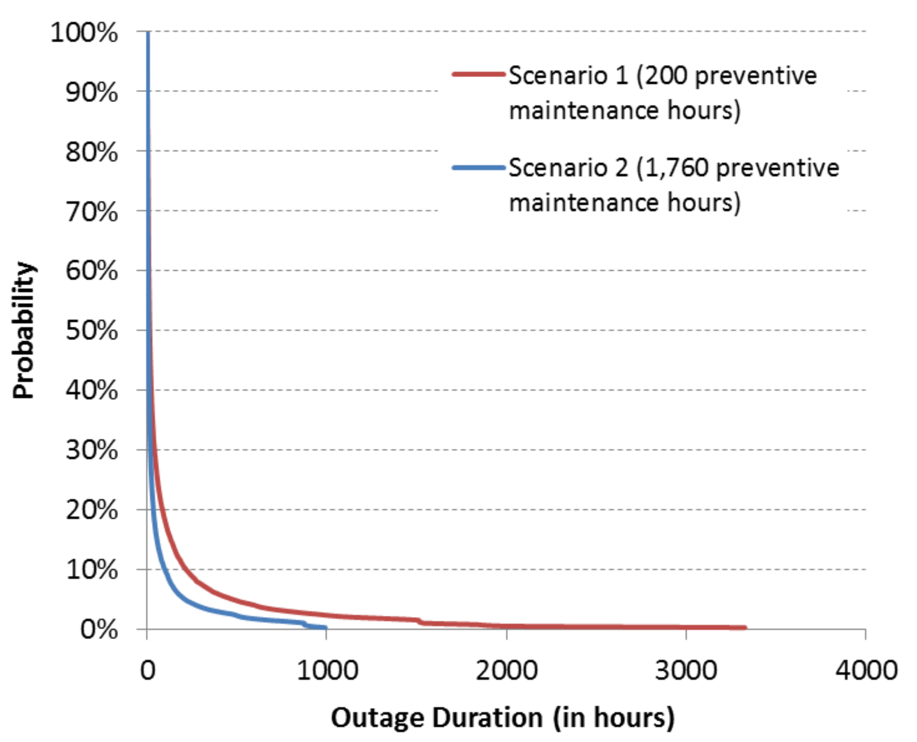

Figure 5: Preventive Maintenance Hours versus Outage Duration per Failure regime.

Sciemus has defined operating regimes based on the number of a unit's starts and fired hours in a month, as defined in Table 2. Both conditions stipulated in the number of fired hours and starts per month must be satisfied in order for a unit to qualify under a specific operating regime.

Operating Regime	Fired Hours / Month	Number of Starts / Month
Base load	More than 500	Less than 4
Two – Shifting	More than 200, but less than 500	At least 20
Load-Following	More than 200, but less than 500	Between 4 and 20
Peak load	Less than 200	More than 20

Table 2: Classification of a Unit's Operating Regimes

The quantified relationship among the Plant's fired hours, number of starts and its outage duration are illustrated in Figure 6. From this graph, one can see that if the Plant is operated on baseload mode, it is expected to have shorter outage durations than if it were to run under a two-shifting or peak load regime. This quantification enabled the Operator to forecast their unit's outage duration based on precise changes in the number of starts and fired hours. Similarly, the Operator was able to devise a scheduled maintenance strategy designed directly around the plant's operating

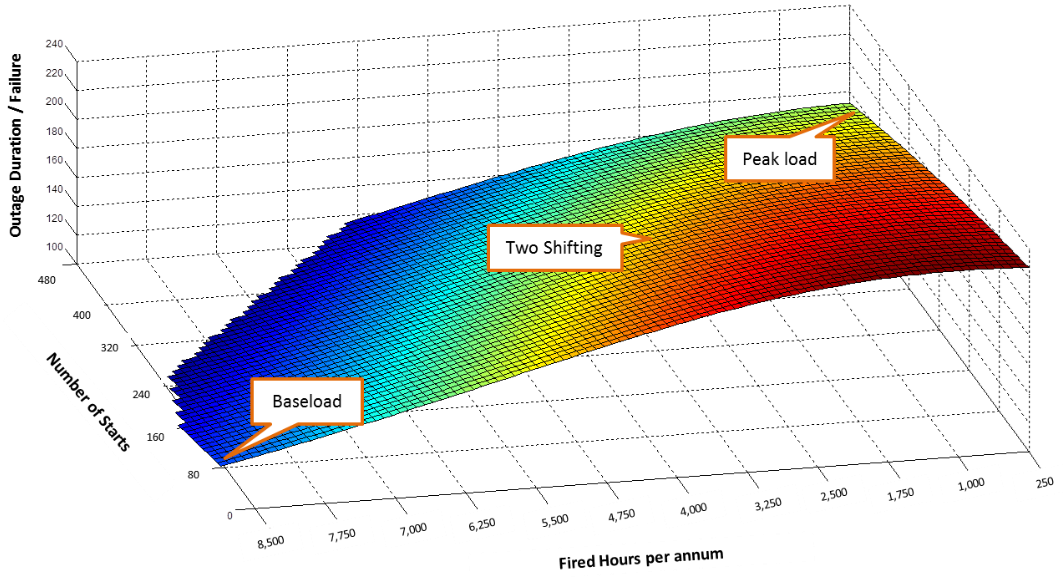

Figure 6: Relationship between Outage Duration and Operating Regimes

4. Effect of Operating Regimes on Forced Outage Frequencies

The quantified relationship among the Plant's fired hours, number of starts and frequency of failure are illustrated in Figure 7. When the plant is operated on peak load mode, it is expected to encounter a higher number of failures consistent with the increased number of starts. Consequently, the analysis provided the Operator with the ability to select the most profitable operating regime under market constraints and at cost levels in which it is comfortable to bear.

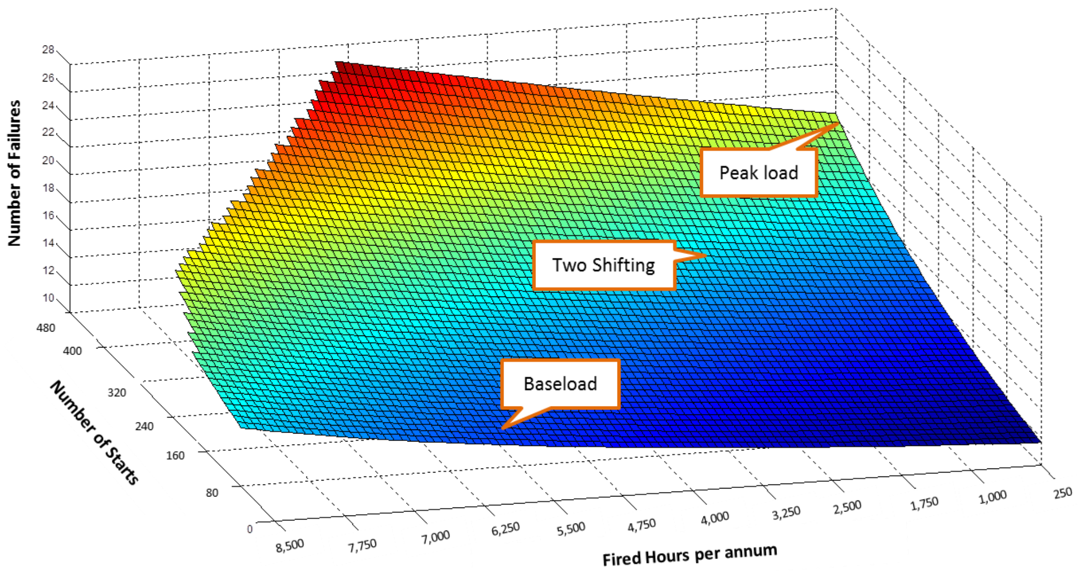

Figure 7: Relationship between Failure Frequencies and Operating Regimes

CONCLUSION

Whilst this report has focussed on an analysis of a coal-fired power station, the analysis and methodology employed also apply to other types of power plants including gas turbines. When the impact of changes in maintenance levels and operating regimes on a power plant's reliability is quantified and well-understood, power generating companies are able to make informed operational decisions that maximised profits while maintaining availability and reliability of their assets. These include creating a maintenance strategy designed directly around their power plant's operating regimes, optimising plant availability whilst minimising breakdowns and justifying maintenance spend.

By implementing the results of the analysis, power plant operators are empowered to justify decisions based on factual data whilst financial managers can make more informed decisions on where investments and savings can be realised.

ACKNOWLEDGEMENT

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