MULTIVARIATE STATISTICAL TECHNIQUE FOR SAFETY ANALYSIS INVESTIGATION AND MAINTENANCE OF THERMAL POWER PLANT COMPONENTS

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Abstract: This paper deals with the creation of the Eskom Fossil Fired Generating Fleet structural Equation Modeling quantitative safety inspection programs. This study is the outcome of different variable that influence the production of electricity by Eskom in a stable, continuous to guarantee the reliability of the energy supply. Eskom launched on the safety strategy to maintenance to fulfil, as stipulated by the Department of Labor, the statutory and safety criteria as well as the possible reduction of outage costs. The Risk Based Management Method was developed using the European CWA15740 methodology.

Keywords. "Probability of failure (PoF), Consequence of Failure (CoF), Regulation of Pressure Equipment (PER), Energy Availability Factor (EAF), Unplanned Device Capacity Loss Factor (UCLF), Loss Factor for Expected Unit Capability (PCLF), Structural Equation Modelling (SEM) Quantitative" [22].

1. INTRODUCTION

Eskom is "currently facing the threat of meeting already toughening manufacturing, protection, financial and contractual stresses in such an atmosphere for which qualified professional abilities and expert knowledge are analytically restricted on a world basis. The current Eskom fleet always operates to and even beyond the full design cap to meet the current demand for electricity" [1]

"In recent years, Eskom's productivity has deteriorated via an EAF point of view" [2]. "Eskom's 90:7:3 philosophies (90 percent energy supply, 7 percent energy availability) Maintenance scheduled and 3% maintenance unplanned) cannot be achieved" [3].

"In 2012, after the end of the MYPD2 determination, Eskom began the third Multi Year Price Determination process with Eskom asking NERSA for a tariff increase of 16 percent over a 5-year period" [4]. "The request proved unsuccessful as only an 8 percent rise was given to Eskom. And with a funding deficit of R255 billion" [5], Eskom now finds itself.

"With up to 9000 MW (20 percent of the installed EAF) of unplanned maintenance (UCLF) being performed [2, 6], plant output has gradually decreased, and as much as 25 percent of EAF has been unavailable at some stages" [7]. "Costs have been greatly influenced by the use of gas turbines to bring more electricity into the grid [2, 8]. This lack of energy has led to the frequent shedding of loads, with the cost of shedding loads being six times greater than the cost of running gas turbines" [9].

"The implementation of the new Pressure Equipment Legislation governing the use of pressure equipment has further added complexity to the operating environment of Eskom. This proposed policy states that all equipment functioning at a pressure of 50 kPa shall be treated as pressure equipment and, as such, 1.25 times the design pressure at a frequency of 36 months shall be hydrostatically pressure checked at a test pressure. Presently, Eskom pressure checks at intervals of 72 months, The new regulation does not permit an interval of 72 months, however, as the functional philosophy of 80:10:10" [3], "cannot be done as PCLF will double, reverting to a 36 month philosophy will lead to more complexity" [3].

As "an alternative to the necessity for periodic 36 month pressure checks, as part of a plant life cycle management strategy, the PER provides an option to incorporate a certified risk-based inspection (RBI) program" [3].

"This article describes the implementation of a multi - dimensional risk assessment process that enables Eskom to conform to the statutory PER requirement while retaining supply protection and achieving potential savings to complement the 8 percent tariff rise with some cost savings. CWA15740 process for the European RIMAP (Risk Based Inspection and Maintenance Application Process)" [3].

The "risk-based approach to fossil fired power plants is the first of its kind, both nationally and globally, according to initial literary surveys. No utility has carried out the European methodology of CWA154740 in its entire existence; most hazard techniques have adopted the methodology of API580" [3].

2. POWER INDUSTRY RISK-BASED APPLICATION

Risk-based "methods have gained favor over conventional maintenance methods, primarily because of the ability of the risk mechanism to reliably determine the state of functionally critical components and then improve operational and maintenance planning” [10].

“Maintenance specialists in the nuclear industry are being active in carrying out risk-based evaluations” [11]. “Recent decades, there has been awareness of risk-based practices in the field of Probabilistic Safe Assessments (PSA), a field in which maintenance work is carried out. There is no significant role played by specialists. In order to rationalize legislation as well as to maximize the use of capital, the nuclear industry and regulators are now using risk approaches” [11]. “With few coal-fired power stations applying this theory, the usage of RBI in coal-fired power generation is minimal” [11].

The “third biggest power company in the world is the National Thermal Power Corporation in India. The company has successfully applied RBI to all of its 105 power units to ensure safe and efficient operation of the units” [12]. “RBI was introduced by Progress Power in the United States to 19 of its power generating units. The risk-based approach allowed the utility to substitute 140 of its For $70 million less than the convention strategy, which considers all risks equally” [12], “the main tube components.

In power delivery systems, maintenance and reinvestment assessments are the primary fields of asset management. Risk Based Inspection is a technology that helps prioritize the activities of maintenance” [13]. “Experience in power delivery systems has shown that a limited number of high-risk components lead to the majority of system failures. Risk-based inspection can be used for the detection and identification of Prioritize the preventive maintenance of such high-risk products, significantly lengthening the device's life span while maintaining the same risk level” [13]. “For Distribution System Operators (DSO), which require them by Swedish Law to reimburse consumers for times greater than 12 hours when they encounter outages, That is, Customer compensation” [14], “which can be up to 50 percent of the customer's annual tariff depending on the length of the outage, which was a significant portion of the DSO's costs. In order to minimize customer outages, DSOs are now switching to a risk dependent approach” [15].

3. APPROACH OF RIMAP

The “RIMAP process began as a European initiative with the goal of creating a coherent decision-making process based on risk within the inspection and maintenance arena. This approach would be applicable to the respective electricity, chemical, petrochemical and steel industries” [16]. “The European Commission has partially funded research into the creation of RIMAP. A holistic philosophy for managing asset integrity is risk-based preparation and execution of inspection and maintenance (RBIM). For an enterprise that is used for risk-based asset management, RIMAP provides guidelines for RBIM, quality assurance and follow-up of operations and work processes. The relation between engineering planning and the actual execution of the RBIM (RIMAP workbook) is important to maintain. The risk evaluation method is based on a combination of the likelihood of failure and its consequences. A bow tie model” [16] “is used to determine this combination of chance and result. The results of the review are then used to evaluate maintenance Interventions” [16].

3.1.0. The Method of RIMAP

3.1.1. General Requirement:

The “RIMAP method depends on sound engineering practices to be implemented as it is based primarily on expert feedback. It is important to ensure that the requirements for risk acceptance and the goals of the evaluation are clearly defined” [16].

The “evaluation team must consist of an interdisciplinary team with experience in inspection, repair, materials, corrosion, electrical, fixed and rotating equipment, safety, risk and risk knowledge and health plant knowledge and appraisal of reliability” [16].

3.1.2 Initial Scheduling:

“The goals of the analysis are established in this phase and the boundaries for the evaluation are identified. The evaluation team is organized and the data sources are established. The required software is defined” [16].

3.1.3. Collect and Verify Data:

“When the origins of data were established, the data is processed. Generally, this information is obtained from various sources. The probability that the data may be of low quality is strong, so it is important for the evaluation team to verify the data and afterwards store the information through a well-structured database” [16].

3.1.4. Risk Analysis Multi Level:

The “PoF, CoF and general risks are determined in this process. The multilevel risk analysis ranges from an initial screening process to a very rigorous quantitative evaluation. The analysis of screening is intended to be relatively fast, easy and cost-effective. Using parameters such as extreme, medium and low risk, the components are analyzed. For further review, components falling under the high and medium risk criteria should be considered, whereas low-risk components must adopt a minimum approach to surveillance maintenance, this is done to ensure that the assumptions made during the evaluation are accurate” [16].

“The thorough risk assessment meets, but in greater depth, the same concepts as the screening review.

Per part, damage mechanisms are established and deterioration rates are calculated. In optimizing the PoF, CoF and overall risk determination, additional parameters are used” [16].

3.1.5. Project of Decision Making and Action:

"The team develops the optimum inspection approach on the basis of the findings of the risk evaluation. Assets and cost optimization should be maintained by the plan" [16].

3.1.6. Reporting and Execution:

"The maintenance plan established by the risk assessment is carried out and the effects of the maintenance steps are reported, indicating the device's stability. For further risk refining, these results are then fed into the risk evaluation" [16].

3.1.7. Analysis of Performance:

The "aim of the risk-based decision-making process assessment is to determine the efficacy and impact of the risk-based decision-making process on the establishment of maintenance and inspection programs, thereby facilitating continuous improvement. The appraisal process includes internal and external assessments carried out by the operating agency and independent experts, respectively. A deviation from the process may cause internal evaluation, or a change of perception or the facility that needs a risk reassessment. The RIMAP technique is a guide; making it company distinct is not prescriptive. The procedure is focused on best practices and provides advice on what should be included in a robust RBI procedure. These variables make it an optimal method to be implemented by Eskom. However, this approach is restricted in that it is heavily dependent on high quality data, refers to equipment in the service process, and is applicable to the ancillary plant in a nuclear power station. Furthermore, the RIMAP method supporting documentation is of a huge amounts and all this documentation" [17] can be daunting for individuals to go through.

4. GATHERING OF DATA

For "an efficient RBI evaluation, the data collection component of the RBI process is vital" [18, 19]. "The risk evaluation data must be of high quality" [20], "as poor and inconsistent data may lead to optimistic risk evaluation results in that the costs involved with the materials being evaluated could be overestimated. To ensure that the data is reliable and applicable to the risk analysis, all information gathered must be checked and verified" [22].
"The information needed for an RBI evaluation is divided into two groups, namely design and operational data. Design data offers data on a device's engineering and building requirements. Operating data contains information on the parameters under which the device is in (ambient temperature, operating pressure, etc.).In operation, a standard or foundation data set is mandatory for the evaluation when conducting an RBI assessment. The appropriate data was obtained for the Eskom project" [22]:

4.1. Data from Design and Construction

In "order to determine aspects of structural integrity, design and construction data is needed. This data is commonly used as a benchmark to which it is possible to compare testing and inspection activities. Records of manufacturing inspections are also available to assess the consistency of the material used in the production of a product" [22]. "Usually, such inspections will reveal problems such as poor materials weld flaws, weld repairs and building compromises. In assessing areas of potential degradation, this knowledge is useful. During device implementation, NDT reports may provide an interpretation of the structure that was included throughout construction" [22].

4.2. Reports of Examination and Inspection

"Inspection reports could be used to monitor time cycle degradation rates. The RBI evaluation team will then use these patterns to assess a device's secure operating procedure. It is important to ensure that not only the latest report is examined in all inspection reports. To evaluate the effectiveness of the selected technique, it is also critical to evaluate the NDT techniques mentioned in the inspection reports" [22].

4.3. Repairs and Upgrades

"In order to ensure that it has been repaired in compliance with the required building standards, any repairs or improvements carried out on the equipment under assessment must be reviewed. The cause behind the repair or alteration must also be determined to decide whether this will have an effect on the likelihood of deciding failure" [22].

4.4. Records Management

"To determine the efficacy of the maintenance measures, maintenance documents are required. The documents also provide an indication of the conditions "as established". The RBI team must analyze these "as found" situations in order to decide if there are active risk mechanisms occurring and to evaluate whether the maintenance measures are sufficiently successful to avoid any active damage mechanisms" [22].

4.5. Devices of Security

"In order to assess their viability under the RBI regime, the form and performance of the protective devices should be checked. Protective devices, since they normally operate infrequently, may present unique problems and might never function whatsoever; they can be sensitive or influenced by the content of the device under changes in the external environment" [22]. In "four provinces (Mpumalanga, Limpopo, Free State and the Western Cape) and the headquarters, Megawatt Park in

Johannesburg, data storage within Eskom is distributed through fourteen power stations. This dissemination of data makes the processing of knowledge very complicated. Multiple teams were used with support from both the headquarters and the relevant power stations to ensure that the relevant and reliable data was gathered" [22].

"Data management was done using Microsoft Excel and Microsoft SharePoint was used to communicate with the data collection teams and the power stations" [22]. "This meant faster updates to data sets and created a record and paper trail of all changes to the data at the same time. All the final sets of data were then processed in the Eskom Document Management System, Hyper wave, for use by the RBI evaluation team. Validation of data is undertaken to ensure that the data is validated. The selection is precise and appropriate" [22]. "To ensure data integrity, there are diverse levels of validation. The data collectors carry out initial validation as the data collectors are, this is a temporary and this validation uses the Excel spreadsheet filter feature and a 100 percent search is conducted on all the captured data" [22]. "In accordance with the power station system engineer, the second check is conducted by the head office lead engineer. Once again, a 100 percent check is performed on the results. The third validation is carried out by the appropriate plant expert. This is a sample search, and the sample size increases based on the number of mistakes found" [22].

"Until all tests are done the data is signed off by the Power Station Engineering Manager and the appropriate plant Specialist. The data is then loaded into the record management system for use by the risk assessment team. The data collection component is an essential step in the process of risk-based inspection as the results of the evaluation would be influenced by errors and inaccuracies in data. In order to enhance data quality, validation measures are required, thus ensuring an efficient risk assessment" [22].

5. SEM-QUANTITATIVE SAFETY BASED MODEL

"The risk model is based on the methodology of the CWA15740 RIMAP.

To ensure that a robust process that meets international requirements has been established in accordance with the ISO31000 standard rules. The model consists of three evaluation levels" [22]:

- "A risk assessment of level one that is qualitative in nature
- A sem-quantitative level two risk evaluation in nature, and,
- A quantitative evaluation of level three in nature" [22]

5.1. Risk Evaluation for Level One

"The level one evaluation is a fully qualitative evaluation in which the most low risk components are evaluated for screening. The level one assessment assesses the possibility and effects of the failure of the component under analysis and measures the risk for the component on the basis of the PoF and CoF assessment performance" [22].

5.2. Determining the likelihood of failure at level one:

"A screening evaluation that is used to evaluate items that pose a low risk to the organization is the first stage of evaluation. By evaluating which of a number of particular parameters will affect the likelihood of a failure occurring, a simple PoF assessment is carried out. For example, if a component operates under conditions well above design specifications, it is more likely that this will malfunction than if it operates under conditions below the design specifications" [22]. "In this case, therefore, the input for the operating conditions parameter would be a high response, while if it is understood that the component operates below the design, the input would be low. The words high and low are similar to a high and a low ranking" [22]. "All the most likely active harm mechanisms must be considered in carrying out the level one screening evaluation and the worst-case scenario in terms of malfunction must

Criterion	high (weight =10.0)	Low (weighting =1)
Device length	"If the device is aged (above 150000 service hours) or new (less than 50,000hours service or replaced with less than 50000 service hours)" [22]	"If the component is between 50000 and 150000 service hours"[22].
Product	"If identified product occurred" [22]	"If no known material problems or defects exist" [22].
Year from last check-up	"If not recent i.e. >3years (25000 operating hours)" [22]	"If recent i.e.3 years or less (25,000 operating hours)" [22]
Existence of deterioration	"If there is a history or knowledge or indications of an active degradation mechanism" [22]	"Degradation mech-anisms identified,inspections carried out and no indications found" [22]
Rate of deterioration	"If conservative estimate of degradation indicates problem within 70,000 operating hours (9 years)" [22].	"If conservative estimate of degradation indicates no problem within 70,000 operating hours (9 years)" [22].
Functioning situation	"If operating is known or suspected to be at greater than design operating conditions" [22].	"If operating is known to be generally less than design operating conditions" [22].

be considered along with the likelihood that this collapse will occur.

For the level one screening assessment, the following rules are used" [22]:

- "The evaluation of risk must always be conservative" [22].
- "If there is any unfamiliarity with any factor or if no information is provided then the default state is indeed" [22] "high".

"A total of ten parameters are evaluated to determine the likelihood of failure" [22]

"The criteria for evaluating the likelihood of failure are listed in table 1, together with the weighting applied to each criterion" [22].

Table1: "Probability of failure criteria and the associated weighting" [22].

Table 2: "The evaluation criteria for determining whether the component actually ranked high or low" [22].

Possibility to mal-operate	"If mal-operation is known to occur or possible to occur e.g. large temperature excursions, passing valve, significant chemical excursions, large thermal transients, fast ramp rates, etc" [22].	"If mal-operation is unlikely or cannot/does not occur" [22].
Impacts about architecture	"If component is considered to have potential design issues e.g. is seam welded HT components, or large change in section at weld, etc" [22]	"If component is considered to have no design issues" [22].
Discover in companies	"If there is knowledge within the industry of the component failing" [22]	"If there is no knowledge of the component failing" [22].
Previous reparations or harm	"If it is known or suspected that repairs have been made or serious levels of damage found in the past" [22].	"If no repairs or serious damage have occurred or been found in the past" [22].

"Each selection criteria is weighted as per the level of impact it has on the probability of failure being caused. Each criterion is scored for each component evaluated; relative to a qualitative measure as to how likely it is to influence the component. As indicated previous section, this is a simple high or low for the level 1 evaluation, which equates to a numerical score in the evaluation. This gives the component Probability score" [22].

"However in order to produce an indicative probability of failure (PoF) the score needs to be modified by a Generic Failure Frequency (GFF). The Generic Failure Frequency (GFF) is a scientific method that is used based on experience to recognize failure frequencies of numerous ingredients" [22]. Typically, it is created using an expert Judgment and background of equipment breakdown" [22]. "For the level 1 evaluation, the GFF for the Eskom trial is based on the system of DNV" [21]. "The RBI evaluation team will determine the most appropriate GFF for the component for every component being evaluated" [21].

Criterion	Weight
Device length	0.07241
Product	0.05432
The Last year from check-up	0.14480
Existence of deterioration	0.14484
Deterioration Rate	0.14481
Functioning situation	0.16290
Possibility to mal-operate	0.07242
Impacts about architecture	0.05433
Discover in companies	0.12674
Previous reparations or harm	0.05431

"An indicator of the probability of failure in any given year is generated by using the GFF along with the ranking. Because most damage mechanisms depend on time, the likelihood of component failure may increase with time. In order to take this into account, the GFF uses a variable such that the longer the time needed between inspections, the greater the risk" [21]. "This multiplier is centered exponentially in such a way that in

The variable for Year 1 is 1,

The variable for Year 6 is 10, and

The variable is 100 for Year 12" [21]

"This makes it possible to measure and compare the risk of a component over time, e.g. if the risk of a component is 1x10-4 in year 1, it would be 1x10-3 after 6 years of further service and 1x10-2 after 12 years of further service. This helps to make decisions on the appropriate service period between inspections” [21].

Grade one Failure calculation result

“The three key categories for the Eskom RBI process are taken into consideration” [21]:

- “Safety and Health
- Business
- Environmental” [21]

“The classification of safety and health takes priority over the classification of business and environmental. Along with the hazard type (SANS 347 Pressure Classification) and the nature of failure (leak or explode), the above requirements are used. For each criterion, except for the hazard category that has 3 key classes (IV highest to Class II)” [21], the "Low classification is used, as in the case of the PoF determination, a High classification. Lower classifications do not involve an RBI mechanism to be used to control their credibility (Category I and Sound Engineering Practice (SEP). Table 3 indicates the parameters used. For the high criteria (10), a logarithmic numeric is used and for ranking, low criteria (0.1) are used. The RBI team will give a ranking that will be taken into account by the weighting for each variable to be evaluated. The category Hazard is based on the device's measurements and the material. This generates a CoF component” [21].

Table 3 “for CoF Criteria and Weighting”[22]

Criterion	Weight
Risk Categorization	6.671/10
Malfunction form	6.672/10
Safe	59.990/10
Healthy	0.673/10
Environments	0.674/10
Businesses (lost MW/H	2.671/10
Businesses (repairs cost)	0.672/10

Level one complete risk calculation:

“The risk of failure of a part is a function of the PoF and the CoF, i.e.

Risk = PoF x CoF

On the matrix below, the Level One risk plate is represented, (Illustration 1). If the risk of level 1 falls to the green area, the risk is then deemed very low by the matrix and the regular routine maintenance measures are followed” [21].

(Possibility category Vs Consequence category)

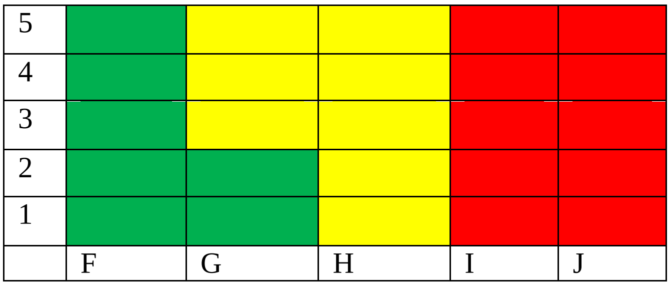

Fig. 1. Stage 1 Risk Matrix

“If the calculated risk lies within the Green area the risk is at an appropriately low level and no other evaluation is required. Now this current regular maintenance strategy is to be evaluated for potential application and upgraded where necessary. If the calculated risk lies in the Yellow, then the part must step forward to be evaluated under level two (medium risk) or Red (high risk)” [22].

5.2. Elaboration of testing and evaluation strategy

“A comprehensive component for the high or very high risk components needs inspection. In order to establish the required RBI IMT plan, an RBI Inspection, Repair and Test (IMT) plan development team will be convened” [22].

“To ensure that the plan is appropriate, applicable and will reduce the defined risks, the plan is reviewed by the experts and professionals for the portion under analysis” [22].

“During the next outage, all outage activities are scheduled by Engineer for the Plant Method. The Maintenance or Plant System Engineer will develop quality control plans and these QCP's have been approved by the AIA in advance. Finally, during the expected unit shutdown, all preparations will be executed” [22].

5.3. Post outage risk evaluation

“The inspection reports will be evaluated by the RBI team after ready for the revised risk evaluation, the outage and re-assessment of degradation rates, etc. The RBI team is then re-convened to the Level 2 repeat risk evaluation the latest inspection information is used to determine the existing level of risk. It will assess the level of risk after 6 years. Any high risk category components can require re-inspection earlier than 6 years. The results shall be collected and submitted to the Site RBI Steering Committee for approval in a formal RBI Report” [22]

6. CONCLUSION

"This model of the RBI, which was developed using the Standard European CWA 15740" [22]. "There are 4 separate stages in this established risk model, namely" [22]:

- "Process of data collection and validation in which the, as an input for the risk evaluation to be conducted, specific component data relating to design, function and test and repair information is collected. This information is checked and tested in order to ensure that" [22],
- "A category one diagnostic evaluation in which the qualitative criteria for evaluating component risk is used. If a variable is considered to be of high risk, a further level of evaluation is needed based on the qualitative criteria" [22].
- "Further evaluation in which a combination of qualitative and quantitative (sem-quantitative) criteria is used to assess the component risk" [22].
- "Finally, a completely objective level test is used to deal with unacceptably high risks based on the findings of level two evaluations" [22].

This "model was created in order to promote ease of use of assets distribution and availability (people, knowledge and technology) in mind" [22].

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