Risk-Informed Profitability-Based Analysis Support
Of Nuclear Power Station Balance-Of-Plant Change Management

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In this paper, a three-phased method is proposed for the STP Nuclear Operating Company (STPNOC) Risk and Reliability Analysis Section (RRA) to perform analyses and decision-making support for the STPNOC Balance-of-Plant (BOP) Task Force in managing change to simultaneously optimize plant safety and maximize long-term return-on-asset (or profitability) for the South Texas Project Electric Generating Station (STPEGS).

1. Introduction and Summary

STPNOC has formed a BOP Task Force to identify and evaluate potential changes to BOP equipment, operation, and maintenance at the South Texas Project Electric Generating Station (STPEGS) to improve plant reliability and safety. The RRA is represented on the BOP Task Force. This document sets forth the objectives, philosophy, methodology, and broad procedural guidance for RRA support of the BOP Task Force in its efforts to improve STPEGS safety and reliability in an efficient and cost-effective manner. RRA probabilistic risk assessment (PRA) tools and techniques are employed to support the BOP Task Force evaluation and decision-making processes. It is important to note that these probabilistic tools and techniques are supplemental in nature, that is, they are designed to support and enhance (not replace) current deterministic BOP Task Force processes.

In general, the RRA support process involves the probabilistic quantification of decision support figures-of-merit (or "metrics") to aid the decision-makers in determining, not only which reliability improvement options should be implemented, but how to prioritize plant resources for their implementation. Key decision support metrics include, but are not limited to the following: predicted net benefit over the remainder of expected plant life, benefit-to-cost ratio, payback period, estimated gross change implementation and maintenance cost, estimated change in long-term plant profitability, and return-on-asset annual percentage rate. Note that these are economic or financial metrics. However, using the RRA approach, these metrics incorporate predicted "soft dollar" cost aversion issues as well as the more conventional "hard dollar" direct cost issues. In addition to primary economi c metrics, the RRA provides safety metrics, like core damage frequency and large early release frequency, that give the decision-makers high confidence that change implementation will not breech any pre-established safety criteria for the plant (i.e., core damage frequency or core damage probability limits). In this way, decisions can be made to implement changes with positive impact on long-term profitability and associated insignificant impact on plant safety. The RRA can also supply interim metrics, like projected plant trip frequency or projected generation loss (in MWH), to characterize the predicted impact of recommended changes on plant reliability. Experience has shown that a structured evaluation of these quantitative decision support metrics not only provides valuable relative prioritization information to the decision-makers, but also "injects" a more rigorous, systematic approach into the overall decision-making process than might be applied without their consideration. This paper provides guidance on the development and application of quantitative decision support metrics and the analysis of our uncertainty in them at various stages of the improvement option development and implementation process. This process has been applied to "real" decisions at STPEGS. Examples of these process applications will be summarized in the paper.

2. Objectives

The overall objective of this activity is to develop the methodology required to integrate RRA insight into the STPNOC BOP Task Force recommendation processes for BOP reliability improvement (BOP Task Force Phase II - based on INPO AP-913). The primary requirement of RRA support in the BOP reliability program is to provide quantitative, mathematically tractable (as opposed to heuristic) metrics that can aid in the decision-making processes for the development and prioritization of BOP equipment reliability improvements. Currently, the available processes utilize deterministic methods for decision-making that largely ignore integrated reliability impacts and their effects on other important plant metrics such as safety and cost performance. Also, to successfully make continuous cost-effective reliability improvements, the profitability of the station needs to be considered integrally with improvements and equipment ranking. The BOP Phase II project will provide quantitative, mathematically tractable, profitability-based indices for ranking and prioritization.

The detailed objectives of the Phase II BOP reliability improvement project (as given in INPO AP-913) program are:

A. Processes are simple and efficient, incorporate human factors considerations, and ensure effective performance during all phases of plant operations.

B. Uniform processes are used among all plants in the family.

C. Applicable in-house and industry lessons learned are uniformly incorporated into the processes to improve adequacy and efficiency.

D. Where appropriate, multiple plants use common services, maintenance, and logistical support.

E. Changes to standard processes are timely, responsive to user feedback, and implemented at all affected plants.

F. Critical equipment will be identified based on importance to safety function, safe shutdown capability, and power generation capability. Insight from probabilistic techniques will be considered in this determination.

G. Equipment and system performance criteria are established, performance is tracked, adverse trends are identified, and corrective actions are implemented in a timely manner.

H. Failures of concern are identified for critical equipment, and measures are established to prevent them.

I. **The need for in-depth analysis of equipment failure is commensurate with the importance to plant safety and performance and the likelihood of recurrence.**

J. When needed, in-depth analysis of equipment failures or adverse trends is conducted. Corrective actions are identified, implemented, and verified for effectiveness.

K. Predictive maintenance technology is implemented to detect equipment degradation at an incipient stage and optimize equipment performance.

L. Aging of equipment is managed using preventive and predictive maintenance techniques.

M. A documented technical justification exists for each preventive maintenance activity.

N. Equipment performance data and associated trend information are uniformly collected and accessible to all family and plant members to support the prompt identification of problems and their root causes.

O. Equipment unavailability caused by preventive maintenance activities is balanced by the resulting improved equipment reliability and availability from prevented failures.

P. Equipment reliability processes contribute to sound decisions by qualified personnel at the working level.

Q. Communication, coordination, data access, reviews, and approvals are facilitated by the use of information systems applications that include electronic approvals.

All these objectives can be supported, to some degree, via RRA tools and techniques. Objectives that are anticipated to require significant RRA support are printed in boldface type.

3. Background

By design, BOP systems and equipment have relatively little importance to core damage frequency (CDF). Because of this, classic probabilistic risk assessment (PRA) ranking metrics (i.e., Fussell-Vesely Importance, Risk Achievement Worth, etc.) based on CDF or large early radioactivity release frequency (LERF) will generally show that BOP components have relatively low safety importance. When used to prioritize equipment maintenance, CDF-only-based methods tend to ignore BOP equipment in favor of the equipment designed with high importance to CDF. It is clear that using CDF-based metrics exclusively for all plant equipment change decision support could ultimately result decisions leading to unreliable BOP performance. In this RRA support activity, profitability-based metrics are developed and applied to prioritize BOP equipment based upon balancing safety, reliability, and corporate profitability. Because BOP reliability is so important to plant profitability, the new set of metrics forces higher priority assignment to components important to reliability of generation. This philosophy is consistent with the STPNOC station goals for Nuclear Safety, Reliability, and Cost.

RRA tools and techniques are required for two important functions in the BOP Task Phase II project:

- Ranking of BOP equipment and/or associated operations and maintenance (O&M) issues via appropriate figures-of-merit (or metrics) to support the proper focus of plant resources on developing options for BOP improvement.

- Prioritization of proposed changes to BOP equipment and/or associated O&M issues to support recommendations for BOP change management.

Ranking is intended to give general direction on which components or O&M issues represent relatively high levels of risk of potential profitability loss. Change priority is intended to prioritize proposed modification recommendations. The scope of modifications includes design, operations, and maintenance changes. The basis for both ranking and change recommendation prioritization is primarily to maximize long-term predicted plant profitability, while maintaining prudent but reasonable safety, reliability, and other appropriate plant performance goals.

It can be shown that a generalized metric based on plant profitability will facilitate a reliable plant operation. The reason for this outcome is that only good business choices will allow for optimal plant operation. Bad business decisions will result in revenue loss and reduced capacity to effect positive change. This concept is reflected in the NRC emphasis on reliable production. In this RRA support specification, a method is described that appropriately weights core damage risk (CDF), generation reliability, and other station cost factors to prioritize BOP improvements based on their predicted impact on long-range profitability.

4. Requirements

1) Measures for ranking and modification decision-making must be traceable to plant profitability. Measures must, where possible, be quantitative and mathematically tractable, but should also incorporate subjective plant experience and engineering judgment.
2) Decision-making software and databases must meet 0PGP07-ZA-0014 "Software Quality Assurance" Level 2 criteria.
3) All input data must be traceable to STPNOC maintenance database(s) (i.e. Oracle) or other controlled verifiable information sources.
4) Plant-specific reliability data must be maintained by STPNOC Reliability Engineering.
5) All component data must be related (e.g., primary key, subdirectory structure) to the associated PlantForma basic event name(s).
6) Component aging effects must be accounted for in the change assessment process.
7) Data maintenance and transfers must be automated to the highest degree practical.
8) A component failure rate database for modeled STPNOC components (by PlantForma basic event ID) must be developed and maintained.
9) Baseline metrics for plant profitability and other key metrics identified in this specification will be developed, and appropriately updated by RRA.

5. Specification

A component database (tied to appropriate PlantForma basic event name(s)) is developed. The database is required for high-ranking components. Note that this requirement will change as modifications are made.

Critical equipment is identified based on importance to safety function, safe shutdown capability, power generation capability, and contribution to plant profitability. Insight from probabilistic risk assessment techniques is considered in this determination. Failures of concern are identified for critical equipment, and measures are established to prevent them.

When required to support change management, in-depth analysis of equipment failures or adverse trends is conducted. Corrective actions are identified, implemented, and verified for effectiveness.

A documented technical justification exists for each preventive maintenance activity. Equipment unavailability caused by preventive maintenance activities is balanced by the resulting improved equipment reliability and availability from prevented failures.

6. Methodology

The methodology incorporates the relationship of reliability, safety, efficiency, and other station cost element measures to a plant profitability measure. In this project, the reliability measure is based, in part, on the PlantForma "Unplanned Production Loss" metric. PlantForma ranks each basic event in the reliability model using the well-known fractional importance measure. The STPEGS PlantForma model encompasses all major production loss scenarios (plant trips, controlled shutdowns, reduced power operation, etc.) as contributors to production loss. The PlantForma model is based on a combination of generic and station-specific data that has an historical baseline. The PlantForma model will be periodically updated to reflect new historical data and generic data updates, but, it is important to note that, even without these updates, the relative metrics (i.e., percentage contributions) associated with specific components or operations issues are not expected to change dramatically from update to update, unless there are real changes implemented at the plant. BOP relative performance is probably more important than absolute performance parameters in the process of component prioritization and improvement option assessment. In the case of ranking, the model is normalized to actual performance at the component level. For prioritizing modifications, the differential Unplanned Production Loss (Base Case to Simulation Case) can be used as an initial indicator to identify potential areas for BOP improvement.

The plant profitability measure uses the STPEGS Operations and Maintenance Cost-Benefit-Risk Analysis (OMCBRA), which is a comprehensive profitability model benchmarked for STPNOC. The OMCBRA model includes unplanned production loss as well as plant modification, maintenance and engineering costs. It also includes a translation of changes in plant safety performance to cost. For any proposed change, the reliability metrics, safety metrics, and associated input cost impacts can be entered into the OMCBRA model to simulate the new profitability metrics for the station. The projected change in profitability is then applied in decision-making associated with BOP improvement option evaluations. The product of the fractional importance and unplanned production loss is the basis for the ranking measure. That is, the change in profitability due to the change in fractional importance of a specific component unreliability change associated with a BOP improvement option. Effects of equipment aging can be applied within the plant safety and reliability models by modifying component failure rate equations appropriately for age-related failure rate acceleration.

6.1 Profitability Model

Within the scope of the original OMCBRA project work at STPEGS, the Risk & Reliability Analysis Section (RRA) of the STPNOC Risk Management and Industry Relations Department performed the following tasks:

- **TASK 1** – KEY COST VARIABLE DETERMINATION AND FAMILIARIZATION: RRA worked with STPNOC outage management and cost estimation experts to identify and define quantitatively the key variables impacting operating plant versus plant outage costs under the current outage schedule being implemented at STPEGS (i.e., the 21 day outage schedule profile performed at currently planned time intervals). This task required access to key STPEGS staff. The product of this task is a list of key cost and cost-determining variables for the project analysis. This list is contained in both key product files for this project, the Microsoft Access file named OMCBRA97.mdb and the Microsoft Excel file named OMCBRA2000.xls, both presented to STPNOC with this final report.

- **TASK 2** – COST VARIABLE COMPARISON DATABASE DEVELOPMENT: In this task, RRA developed a relational database defining and relating key cost variables in a format applicable to this baseline study and useful to STPEGS as a product which can be continuously updated to support their future analyses of improvement options. The product of this task is a relational database encoded in readily available software (i.e., Microsoft Access) defining, both qualitatively and quantitatively, the key cost and cost-determining variables in this analysis.

- **TASK 3** – COST-BENEFIT-RISK ANALYSIS QUANTIFICATION: In this task, RRA developed a cost-benefit-risk analysis spreadsheet workbook using commercially available software (i.e., Microsoft Excel) which is designed to perform the quantitative analysis of the baseline case and two alternative option or "delta" cases, one in which the outage schedule duration is increased to 30 days and another in which the outage schedule duration is decreased to 14 days. The primary figure of merit or "metric" for this analysis is average expected total cost of power generation in dollars per megawatt-hour generated, where "total cost" includes all key operation and maintenance costs during both plant operation and refueling outages. Also, in this task, an uncertainty analysis of the results was constructed using a format consistent with commercially available software (i.e., Crystal Ball) compatible with the baseline point estimate spreadsheet. The methodology in this task followed, in general terms, but was not limited by, the processes outlined in NUREG/CR-6349, "Cost-Benefit Considerations in Regulatory Analysis," NUREG/BR-0058, "Regulatory Analysis

Guidelines of the U.S. Nuclear Regulatory Commission," NUREG/CR-3568, "Handbook for Value-Impact Assessment," NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook – Draft Report," and other industry documents on cost-benefit analysis. The product of this task is an integrated Excel/Crystal Ball spreadsheet including tables of quantitative results and associated cost comparison charts and graphs.

- **TASK 4** – OMCBRA PROJECT FINAL REPORT AND PRESENTATION: In this task, RRA developed a brief project final report (this report) presenting the results of all task work. The sections of the report are: Introduction, Technical Approach and Methodology, Results, Conclusions, and References. Also, appendices including key project databases, results tables, and graphics are included. Also in this task, RRA developed and presented a brief viewgraph presentation of the project results. This presentation is designed to be approximately one hour in duration and is presented as an appendix to the final report (Reference 6). The products of this task are one hard copy of the project final report, copies of computer files developed as product files in all tasks of this project including the final presentation, and one hard copy of the final project results presentation viewgraphs, presented as a final report appendix (see Reference 6).

The original OMCBRA model focused on the analysis of alternative refueling outage durations. Since the original development and application of OMCBRA, described in Reference 6, the tool has been expanded to include all operations and maintenance (O&M) cost elements used at STPEGS, representing approximately 11,000 model variables.

The OMCBRA2000.xls spreadsheet was originally used to perform project point estimate calculations for cost-benefit-risk parameters. This spreadsheet contains several worksheets, including one for key data input, one for key parameter estimation/calculation, one for total O&M direct cost calculation, one for outage-related O&M cost calculation, and one results summary worksheet containing bottom-line generation cost results.

Direct cost fractional importance for each direct cost variable is calculated in the direct cost worksheets of the OMCBRA2000.xls spreadsheet. This spreadsheet is linked with the project relational database file, OMCBRA97.mdb. In this way, the cost variable fractional importance can be used to automatically develop ranked lists of cost variables by importance to total cost of generation, even when input variables are changed in future case studies. "Fractional importance" is simply the contribution of one cost variable (or element) divided by the total absolute value of the variable category for the station (i.e., the sum of the individual element contributions here).

The following references and information sources were used in support of the original OMCBRA project:

1. 1999-2003 STPNOC Business Plan (20/20 Vision).
2. STPEGS Long-Range Strategic Outage Plan.

3. STPEGS Probabilistic Risk Assessment (PRA).
4. STP Business Planning Guideline (particularly the Economic Analysis Section)
5. NUREG/CR-6349, "Cost-Benefit Considerations in Regulatory Analysis," October 1995.
6. Cost and Plant Performance Data from STPEGS Planning and Controls Group.
7. Net Power Generation Estimates from STPEGS Thermal Performance Group.
8. Electric Power Research Institute (EPRI), Outage Risk Assessment and Management (ORAM) Studies (Diablo Canyon Nuclear Power Plant and others).
9. NUREG/BR-0058, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," 1995.
10. NUREG/CR-3568, "Handbook for Value-Impact Assessment," December 1983.
11. NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook – Draft Report," Unpublished draft circulated for review and comment.
12. "STPEGS 10 CFR 50 Appendix J Local Leakage Rate Test Improvement Analysis," January 1996.
13. TVA, "Watts Bar Severe Accident Mitigation Design Alternative (SAMDA) Potential Enhancement Value-Impact Case Study Analysis," May 1994.
14. Electric Reliability Council of Texas (ERCOT) Data from Financial Times Megawatt Daily, 1998.

As time progresses, the associated input data in the OMCBRA spreadsheet is periodically updated to ensure accurate profitability predictions.

6.2 Reliability Model

Component ranking and prioritization of proposed changes to BOP design, operation, and/or maintenance activities can be determined by studying the effect on BOP component reliability and using the change as input to plant safety, reliability (or availability), and efficiency models, which, in turn, provide input to the OMCBRA model. The PlantForma BOP model can be used to simulate the effect of planned changes on overall plant reliability by modifying component failure probability appropriately. Plant changes at the component level can be evaluated directly in PlantForma. In general, significant plant changes may be made at the component level. The effect of changes at the component level needs to be accurately reflected in the metric.

The effect of changes to BOP equipment at the component level can be estimated by developing a component fault tree that is normalized to the current component failure rate. SAPHIRE can be used for detailed fault tree development. For simple models (where the only important failures are single point failures for instance) a spreadsheet could be used. SAPHIRE would require as input the fault tree structure as well as component failure rate data. A change to the component design and/or maintenance program can then be simulated in the component fault tree, producing a new component failure rate. The new failure rate can then used at the component level in the BOP PlantForma model to assess the new plant performance. The new plant performance is then entered into the OMCBRA model along with associated costs to evaluate profitability. This profitability measure then becomes the basis for prioritizing a change.

The key information provided by the PlantForma model includes the following general unit-level metrics: availability (A), capacity factor (CF), forced outage rate (FOR), unplanned capability loss factor (UCLF), frequency of reduced production operations, frequency of elective controlled shutdowns, frequency of required controlled shutdowns, frequency of uncontrolled shutdowns, frequency of all production loss scenarios, unplanned down time, unplanned production loss, and the value of unplanned production loss. In addition to these unit-level metrics, PlantForma can be used to produce several summary reports and importance measure reports that can aid in the development of economic data for use in the evaluation of plant performance and potential reliability improvement options. For example, key importance reports can be generated at the system, component type, and basic event levels of indenture in PlantForma. Among other parameters, these importance reports provide the following key parameters: expected frequency of events (F), expected down time (DT), expected production loss (EPL), and expected production loss cost (EPLC). In practice, the results of these reports are exported to MS Excel files, and the results are "post-processed" to be compatible with OMCBRA profitability measures. Three key parameters are calculated at all available levels of indenture in the PlantForma importance reports. These three parameters are: expected production loss cost for the station (EPLCS) in dollars per calendar year, expected recoverable production loss "if perfect" for the station (ERPLCS) in dollars per calendar year, and profitability achievement worth (PAW). As previously stated, the values of F, DT, EPL, and EPLC are provided via the BOP PlantForma model quantification. The values of the three post-processed parameters are calculated as follows:

EPLCS = 2*EPLC (Note: an adjustment for actual production loss value can also be made here if a difference between PlantForma and OMCBRA exists.)

ERPLCS = EPLCS*UF*PF

PAW = (CP+ERPLCS)/CP

where

UF = Unshadowing Factor = CF+(EPL/8766)

PF = Profitability Factor = (SP-FC)/SP

CP = Current Baseline Projected Profitability Value for the Station ($/CYR)

SP = Average Projected Sales Price of Electricity for STPEGS ($/MWH)

and

FC = Average Projected Cost of Fuel ($/MWH).

The resultant ERPLCS and PAW metrics can be useful in helping to direct station resources for the effective and efficient development of proposed reliability improvements options.

6.3 Safety Model

The effect of changes on plant safety (measured primarily in terms of associated change in reactor core damage frequency (CDF), from both operating plant and shutdown plant models) are analyzed via the plant PRA (or RISKMAN® model) and PSSA (or ORAM model). The results are applied directly within the decision-making process to ensure that no safety limits are challenged. The results are also incorporated within the OMCBRA model to aid in calculating predicted long-term profitability impacts.

6.4 Plant Efficiency Model

The effect of changes on plant efficiency (measured primarily in terms of associated change in heat rate) is analyzed via the plant efficiency model (e.g. PEPSE model). The results are then incorporated within the OMCBRA model to aid in calculating predicted long-term profitability impacts.

6.5 Data

Sufficient data are required to support all program requirements. These data include equipment unavailability due to preventive and corrective maintenance. Data are required in some cases at the component or component level of indenture. Cost data are required for the OMCBRA model. Much of this data is developed at the individual cost element level of indenture defined by a "triplet" of the associated STPNOC cost center (CC), program element (PE), and element of expense (EE) applied within the STPEGS accounting system. Reliability data need to be compatible with the current PlantForma model description of the BOP.

To apply the BOP change management support, the RRA needs periodically (ideally continuously) updated data on BOP equipment. The scope of this data ideally includes BOP equipment failure, success, and maintenance data for all key BOP components modeled in the PlantForma model. This data should be developed and updated using Bayesian updating techniques outlined in Reference 9. The processes and work effort involved with this activity should be integrated with similar data collection and analysis activity associated with Maintenance Rule application at STPEGS.

Equipment aging can be accounted for in out years using appropriately modified basic event probabilities. The typical way that aging is accounted for in reliability calculations is to apply a failure rate "acceleration factor" which takes effect after the equipment of interest exceeds its normal design life (usually assumed to be 30 years for most equipment). If we assume that a certain component of interest has a baseline constant failure rate of F_0 that is effective during design life and an age-related failure rate acceleration of X% per year past design life, then we can calculate (and apply in risk calculations) an updated failure rate, F, as follows:

$$F = F_0 (1+(X/100))^{(n-d)}$$

where n represents the current total age of the component in years and d represents design life in years. Assumptions on age acceleration rates and design life values can, of course, be varied as desired for different components by applying appropriate corresponding variations of this equation. For example, if we are interested in a component with a baseline failure rate of 1.00E-04 failures per operating hour, a design age of 30 years, a current age of 37 years, and an age-related failure rate acceleration rate of 25% per year past design life, then the current failure rate of the component, using the above equation would be calculated as follows:

$$F = (1.00E\text{-}04)(1+(25/100))^{(37-30)}$$

yielding a current failure rate of 4.77E-04 failures per operating hour for the component of interest.

6.6 Fundamental Integrated Profitability Evaluation Process Description

The basic data flow for a single evaluation is shown schematically in Figure 1. As shown, basic data at the component level are made available to the reliability model from the appropriate databases. In the case of ranking, data are required at the component level. These data are already in PlantForma Where component data only are required (for ranking, for example) the SAPHIRE process is not required since the model has the necessary information already. Currently, the model input data are static (OMCBRA, PlantForma, and SAPHIRE.) PlantForma data at the component level will be updated commensurate with implementation of the BOP on- line maintenance and Trip Avoidance project. A new process is required to update OMCBRA and component databases.

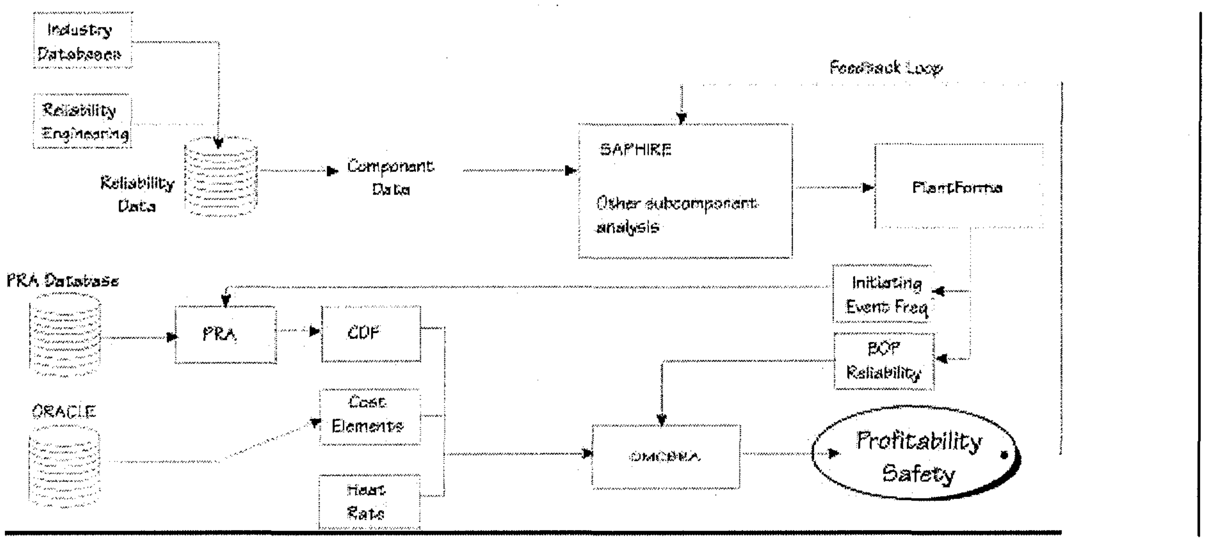

Figure 1. Schematic Diagram of Data Flow

The process needs to be duplicated for simulation of a change(s). The indices so produced are then tied to the associated plant change, allowing prioritization of reliability improvements (based on maximizing profitability.) Proposed changes can be analyzed individually or in groups (i.e., change "packages"). The process is combined with the STPEGS change cost-benefit analysis spreadsheet, which predicts change cost recovery times (or payback periods) and net benefit of changes.

6.7 Recommended Plant Change Analysis Application Process

For most applications of RRA support of recommended BOP changes, a three-tiered or three-phase analysis case study approach is recommended. BOP change recommendations can be originated by the BOP Task Force or be submitted to the task force from other STPEGS groups or outside organizations. These "change package" recommendations can, of course involve hardware design modifications, operations or maintenance procedure changes, management policy changes, or combinations of these change sources. The first two phases of RRA analysis are screening analyses of potential results of change implementation on predicted plant long-term profitability. The third phase is a more detailed "best estimate" analysis of the predicted impact of the change on STPNOC corporate long-term profitability, including a presentation of uncertainty.

6.7.1 Level 1 Screening Analysis

In the first level of analysis for proposed BOP changes, the RRA will, with assistance from other BOP Task Force members and other STPEGS staff assistance as necessary, identify which basic events in the BOP PlantForma Reliability Model and could be affected by the proposed change, and make rough optimistic bounding estimates of the implementation costs associated with the change. Then the RRA will determine how to modify the reliability model data and/or model logic to estimate the maximum potential positive impact of the change on predicted plant reliability. The RRA will then execute a reliability model case study incorporating these data and/or model changes. The RRA may also, at its option, execute a limiting case study of the expected change on the PRA results, but most frequently will just estimate the limiting positive effect on (i.e., maximum reduction in) predicted core/fuel damage frequency (CDF) metrics. Similarly, the RRA will consult plant staff members to obtain a rough bounding estimate of the potential limiting positive impact on other plant cost impacts, such as reduction in operations and/or corrective or preventive maintenance costs. The results of the reliability model case study and estimates for change in CDF and/or other cost-benefit factors will then be incorporated into an optimistic "delta" profitability calculation that will normally be accomplished using standard Microsoft Excel spreadsheets and may employ uncertainty analysis via supplementary software such as Crystal Ball or @Risk, but generally will be a point estimate calculation only. The result of this screening analysis is an "upper bound" estimate on the potential net benefit of the change on plant long-term profitability. The key resultant metrics provided by the RRA in this bounding analysis will include predicted net benefit over the remainder of expected plant life, benefit-to-cost ratio, payback period, estimated gross change implementation and maintenance cost, estimated change in long-term plant profitability, and return-on-asset annual percentage rate. The RRA will provide the BOP Task Force with projections of these "optimistic" level 1 screening decision support metrics to help determine if the recommended change package should be discontinued or developed further and analyzed in greater detail.

6.7.2 Level 2 Screening Analysis

The Level 2 screening analysis is very similar to the Level 1 analysis. The difference is that, in Level 2, the RRA, with additional support from other BOP Task Force members and other STPEGS staff assistance as necessary, will expend additional effort in the development of initial "best estimate" parameters for reliability model failure rate and/or model changes, and for implementation and other cost impact factors expected to be associated with the proposed plant change package. The RRA will then execute a reliability model case study incorporating these data and/or model changes. The RRA may also, at its option, execute a refined case study of the expected change on the PRA results, but most frequently will just estimate the "best estimate" effect on predicted core/fuel damage frequency (CDF) metrics. Similarly, the RRA will consult plant staff members to obtain a rough best estimate of the potential impact on other plant cost impacts, such as change in operations and/or corrective or preventive maintenance costs. The results of the reliability model case study and estimates for change in CDF and/or other cost-benefit factors will then be incorporated into a rough best estimate "delta" profitability calculation that will normally be accomplished using standard Microsoft Excel spreadsheets and will generally employ uncertainty analysis via supplementary software such as Crystal Ball or @Risk. The result of this screening analysis is a rough best estimate on the potential net benefit of the change on plant long-term profitability. The key resultant metrics provided by the RRA in this analysis will, as in Level 1, include predicted net benefit over the remainder of expected plant life, benefit-to-cost ratio, payback period, estimated gross change implementation and maintenance cost, estimated change in long-term plant profitability, and return-on-asset annual percentage rate. The RRA will provide the BOP Task Force with projections of these "more realistic" level 2 screening decision support metrics to help determine if the recommended change package should be discontinued or developed further and analyzed in greater detail.

6.7.3 Level 3 Detailed Analysis

The Level 3 detailed analysis is a full scope profitability model analysis. In Level 3, the RRA, with additional support from other BOP Task Force members and other STPEGS staff assistance as necessary, will expend additional effort in the development of final "best estimate" parameters for reliability model failure rate and/or model changes, and for implementation and other cost impact factors expected to be associated with the proposed plant change package. The RRA will then execute a refined reliability model case study incorporating these data and/or model changes. The RRA will also execute a refined case study of the expected change on the PRA results to develop a refined "best estimate" effect on (i.e., change in) predicted core/fuel damage frequency (CDF) metrics. Similarly, the RRA will consult plant staff members to obtain a refined best estimate of the potential impact on other plant cost impacts, such as reduction in operations and/or corrective or preventive maintenance costs. The results of the reliability model case study and estimates for change in CDF and/or other plant cost factors will then be incorporated into a refined best estimate profitability calculation that will normally be accomplished using the STPEGS OMCBRA model. The result of this detailed analysis is a refined best estimate on the potential net benefit of the proposed change package on plant long-term profitability. The key resultant metrics provided by the RRA in this bounding analysis will, as in Levels 1 and 2, include predicted net benefit over the remainder of expected plant life, benefit-to-cost ratio, payback period, estimated gross change implementation and maintenance cost, estimated change in long-term plant profitability, and return-on-asset annual percentage rate. The RRA will provide the BOP Task Force with projections of these "realistic" level 3 decision support metrics to help determine if the recommended change package should be discontinued or implemented at the plant.

6.7.4 Analysis of Multiple Recommended Change Packages

As outlined in Sections 6.7.1 through 6.7.3, quantitative figures-of-merit or decision support metrics can provide valuable information to decision makers in evaluating individual recommended changes to BOP equipment, operation, and/or maintenance practices. These quantitative measures can, when applied correctly, provide even greater support in prioritizing two or more "competing" recommended change packages. The RRA can provide ranked lists of the competing change packages based on each of the metrics used in the decision-making process (i.e., predicted net benefit over the remainder of expected plant life, benefit-to-cost ratio, payback period, estimated gross change implementation and maintenance cost, estimated change in long-term plant profitability, and return-on-asset annual percentage rate). The RRA can also provide safety and reliability metrics associated with the changes, such as predicted core damage frequency, large early release frequency, plant reactor trip frequency, and, in most cases, projected generation losses (in MWH). The BOP Task Force may, at its discretion, develop a methodology for consistently prioritizing BOP change recommendations based, at least in part, on the ranked lists of change packages by selected projected quantitative metrics. For example, the task force may choose to use return-on-asset annual percentage rate (ROA APR) as its primary figure-of-merit for ranking, with total implementation/maintenance cost as a secondary metric. Simultaneously, the task force can use core damage frequency (CDF) as its "safety limitation" metric. In this type of decision support scheme, only change packages that meet the safety limitation requirements would be considered for implementation. Then, implementation would be prioritized based on descending values of projected ROA APR by change package. Only those change packages with total implementation/maintenance cost estimates within the bounds of the site predetermined budget for such changes would be recommended for implementation, unless special consideration was given to solicit and obtain additional funds for highly desirable (i.e., cost-beneficial) change packages.

7. Applications of the Method

Several pilot applications of the phased analysis method described herein have been performed at STPEGS. First, the Level 1 and 2 screening processes were applied to a proposed design modification for three sets of key valves at STPEGS. The proposed modification involves changing the control circuitry for the main feedwater system regulating valves (FWRVs), the main feedwater system isolation valves (FWIVs), and the main steam system isolation valves (MSIVs) from a "de-energize-to-actuate" control scheme to an "energize-to-actuate" control scheme. The BOP change screening evaluation was applied to each target valve set change individually, and to all three target valve sets grouped. The analysis showed that the grouping of all three sets was the most attractive from a cost-benefit standpoint. This evaluation also showed that there was an effective "win-win" or double benefit in the implementation of these design modifications, because they not only were shown to improve the profitability of the station, but also to improve reactor safety (i.e., decreased predicted reactor trip frequency and resultant core damage frequency). An example of the summary-level results of the phased level analysis is presented in Tables 1 and 2. These example results have been "sanitized" so as not to reveal any STPEGS proprietary or business-sensitive information.

BOP CHANGE CASE NO.	BOP CHANGE CASE DESCRIPTION	TOTAL COST ($)	PROJECTED NET BENEFIT OVER PLANT LIFE ($)	PROJECTED CHANGE IN PROFIT ($/YR)	PROJECTED BENEFIT-TO-COST RATIO OVER PLANT LIFE	PROJECTED PAYBACK PERIOD (YRS)	PROJECTED EQUIVALENT RETURN ON EQUITY APR (%/YR)	REMARKS
0	BASE CASE (NO CHANGES)	$0	$0	$0	0.00	0.00	0.00	BASE CASE
1	REDUCED FWRV SPURIOUS CLOSURE	$180,300	$5,800,500	$241,600	33.17	0.72	15.56	PASS
2	REDUCED FWIV SPURIOUS CLOSURE	$380,900	$4,850,000	$202,100	13.80	1.74	11.21	PASS
3	REDUCED MSIV SPURIOUS CLOSURE	$375,000	$8,392,700	$349,700	23.38	1.03	13.83	PASS
4	REDUCED FWRV SPURIOUS CLOSURE, REDUCED FWIV SPURIOUS CLOSURE, AND REDUCED MSIV SPURIOUS CLOSURE	$934,200	$19,100,300	$795,000	21.42	1.12	13.39	PASS

Table 1. Example Return-on-Asset Analysis Results

BOP CHANGE CASE NO.	BOP CHANGE CASE DESCRIPTION	UNCONTROLLED SHUTDOWN FREQUENCY (Events/YR/Unit)	PROJECTED CDF (Events/YR/Unit)	CHANGE IN CDF (Events /YR/Unit)	RELATIVE CHANGE IN CDF (%)
0	BASE CASE (NO CHANGES)	1.72	1.64E-05	0.00E+00	0.00%
1	REDUCED FWRV SPURIOUS CLOSURE	1.67	1.62E-05	-1.70E-07	-1.04%
2	REDUCED FWIV SPURIOUS CLOSURE	1.68	1.63E-05	-1.36E-07	-0.83%
3	REDUCED MSIV SPURIOUS CLOSURE	1.65	1.62E-05	-2.38E-07	-1.45%
4	REDUCED FWRV SPURIOUS CLOSURE, REDUCED FWIV SPURIOUS CLOSURE, AND REDUCED MSIV SPURIOUS CLOSURE	1.58	1.59E-05	-4.76E-07	-2.90%

Table 2. Example Nuclear Safety Impact Results

A second application of the method involved the evaluation of a set of major equipment capital spares that were proposed to be procured for the station. The list of proposed capital spares included the following 12 items: turbine 1R blade, condensate pump motors, circulating water 96" valve, moisture separator drip tank pump, circulating water pump motor, open loop auxiliary cooling water pump, essential chiller 300-ton compressor, circulating water pump internals, condensate pump internals, feedwater regulating valve, feedwater regulating valve actuator, and an auxiliary feedwater pump motor. Again, using levels 1 and 2 screening analysis methods, the RRA showed that, based on available failure prediction and economic data, only five of these twelve items were recommended for procurement. The five recommended items were the moisture separator drip tank pump, essential chiller 300-ton compressor, feedwater regulating valve, feedwater regulating valve actuator, and the auxiliary feedwater pump motor. This analysis provided prudent decision support resulting in a station procurement cost savings of well over one million dollars.

A third application of the method involved the analysis of proposed main generator rotor replacement strategies and five associated implementation options. These options included consideration of both new rotor procurement and rotor refurbishment, and also considered the timing and sequencing of the rotor replacement/refurbishment activities and associated impacts on outage scheduling. The most cost-beneficial option, based on the analysis methods described herein and predicted return-on-asset results, was chosen for implementation. This application is an important one, not only because it involved high-cost activities, but also because it supported key decision analysis presentations made to both senior STPNOC management and to the station owners.

A fourth application involved the analysis of changes to improve station feedwater heaters. This application is important because it exercised the plant efficiency (or heat rate) change analysis portion of the method. A level 1 analysis showed that the proposed changes were not predicted to be cost-beneficial, and were not recommended for further development or implementation, as proposed.

In addition to these pilot applications of the method, others have been proposed including analysis of proposed major maintenance activities at the station and prioritization of procurement quality assurance auditing and checking activities. These applications are currently under development at STPEGS.

8. Conclusions

Application of the method described herein provides rigorous, systematic, prudent decision-making support for proposed changes to BOP equipment and associated operation and maintenance practices and policies at STPEGS. The phased approach helps keep the scope of the supporting analyses at a level that supports and promotes reasonable change development efforts and costs. Consistent, continuous application and improvement of the methods described herein will significantly aid plant decision-makers in optimizing resources to maximize return-on-asset for the generating station.

9. References

1. INPO AP-913, "Equipment Reliability Process Description," (Preliminary Document), December 1996.
2. STP Nuclear Operating Company (STPNOC), South Texas Project Electric Generating Station (STPEGS) Probabilistic Risk Assessment (PRA), Current Verified Version.
3. STPEGS RRA, "Risk and Reliability Impacts of Balance of Plant Systems," Final Report, October 1999 (Note: includes PlantForma and SAPHIRE reliability models).
4. Electric Power Research Institute (EPRI), "Guideline for System Monitoring by System Engineers," EPRI TR-107668, March 1997.
5. Electric Power Research Institute (EPRI), "System Monitoring by System Engineers – 37 System Monitoring Plans," EPRI TR-107434, March 1998.
6. STPNOC, STPEGS Outage Schedule Cost-Benefit-Risk Analysis," Final Report, Revision 9, and November 18, 1999 (Note: includes current OMCBRA cost-benefit analysis model).
7. STPNOC, STP Nuclear Operating Company Business Plan, Current Version.
8. STPNOC, STP Nuclear Operating Company Business Planning Guideline, Current Version.
9. PLG-0500, "Database for Probabilistic Risk Assessment of Light Water Nuclear Power Plants," 1989.
10. STP Nuclear Operating Company (STPNOC), South Texas Project Electric Generating Station (STPEGS) Probabilistic Shutdown Safety Assessment (PSSA), Current Verified Version.
11. STP Nuclear Operating Company (STPNOC), South Texas Project Electric Generating Station (STPEGS) Configuration Risk Management Program (CRMP), Current Verified Version.