ADVANCED MODELS FOR POOLING MAINTENANCE IN POWER PLANTS: SIMULATION AS DSS FOR OPTIMISATION

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ABSTRACT

This paper presents a model for supporting decisions in managing power plants service, using simulation to test possible solutions that emerge from an intelligent optimization tool using genetic algorithms.

INTRODUCTION

Service and maintenance of power plants is a critical and strategic field, able to provide high profit to constructors if well managed. Nowadays it is a common strategy to use the same inventory of maintenance kits for different users in order to divide costs, so there is the need of well-planning the turnover of strategic kits and inspections in order to minimize costs for spare part acquisition.

In this work the authors propose a new approach based on simulation to find the best solutions. The need for simulation is due to the fact that the problem is very complex: inventory and planning are strictly related in a mutual relationship: critical items are involved in revamping/refurbishment/recoating with a percentage of scrapping and non-operative time to be taken in account. The choice on how to rotate kits or blades and van layers could affect or improve overall result.

Usually maintenance contracts for power plants are based on deadlines set on a number of equivalent operating hours (EOH) for the units to be maintained.

In this situation it is convenient to close the contract trying to optimize life cycle of high-cost items, that typically need refurbishment.

An element adding more complexity to this situation is the intervention of many stochastic factors: utilization profile for the power units is function both of the market demand both of the other power providers, so the EOH variance is high and affects the requirements for the scheduling of inspections, that is instead subject to severe bonds and constraints regarding the life cycle.

In addition it is to be considered the maintenance due to unexpected failures: it is a small factor, but the stops that it produces are very costly.

Stochastic factors affect also the refurbishment and supply of items: some of them have very high cost (i.e. blades and vanes or single big entities such as the rotor) and so this is another complexity factor.

In consequence of such considerations, stochastic simulation is the best approach to analyze the problem, and this paper is centered on the simulation model used for this purpose.

POWER PLANT POOLING

The concept of pooling in power plants service is to reuse maintenance kits sharing them among a number of power units: in this case, if the planning of maintenance inspections is well-structured, a kit that has been dismounted from a unit and refurbished can be used on another. In this case it is evident how spare parts number and inspection scheduling are strictly linked. A common pool has effects on inventory level and other costs connected: to share parts among different plants reduces the stock, the costs of maintenance teams and mobile warehouses. The complexity of relations among factors lead to a complex simulation architecture.

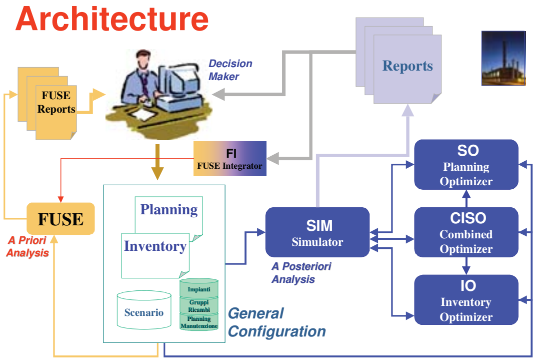

Figure 1 General Architecture

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GENERAL ARCHITECTURE

The simulation model proposed in this paper allows to support decision making in power plant service both for inventory both for maintenance planning, basing on boundary conditions set up by the key user, such as the possibility of making expediting orders, the weight of plant availability etc.

This model is the result of combination of simulation and AI (Artificial Intelligence) techniques used to test different scenarios and identify optimal solution. This statement is to be clarified: due to the complex constraints and highly stochastic behavior of the system, it is impossible to find an optimum in the mathematical sense of the term: but the fundamental result is to find a "robust" solution that statistically can provide good results in terms of costs and quality of service.

To develop a good planning in fact there are three factors to be considered:

- Inventory Optimization
- Scheduling Optimization
- Combined Inventory/Scheduling Optimization

The overall scheme of this innovative architecture is summarized in figure 1

SIMULATION MODEL DESCRIPTION

The model used is a stochastic, combined, event driven simulator. Events that drive simulation are all the critical time points as failures, maintenance inspections, start-up/shutdown contract milestone, deliveries etc.

The power demand and EOH are computed integrating expected profiles between two consecutive events.

In each timeframe and for every simulation run the model extracts values from distribution probabilities of stochastic variables based on Montecarlo Technique.

To define properly the statistical distribution to be used, the available historical data have been analyzed with subject matter experts (SME) and submitted to statistical tests such as Chi-square.

Usually historical data available are very few, this due to a short history of the system, errors in records, confidential nature of the information, and initially the authors assumed to use extensively beta distributions, that optimizes the combination of historical data with expert estimations.

The simulation model has been subjected to a VV&A (Verification, Validation and Accreditation) process in a specific scenario, because this is a fundamental step for every simulator. For the validation the authors used a dynamic validation based on Analysis of Variance (ANOVA), Mean Square pure Error (MSpE), Confidence Band, Statistical Comparison, Sensitivity Analysis. This approach allows to estimate robustness of strategies utilized and their feasibility, taking in account inventory levels, costs, quality of the service, etc.

For combining the best solution in terms of computational speed and user-friendly reporting, the simulation tool has been developed in C++ with a reporting system exporting data on MS Office ©. This system is integrated with the FUSE © package for fuzzy logic evaluation of obtained planning and works on last generation PCs.

INDEPENDENT VARIABLES

In the following there is a short description of some of the most important independent variables, based on different kinds of input:

- Units - that means main plant components: Gas Turbines, Steam Turbines, Generators
- Sites: geographical position of each plant and environmental characteristics
- Plants: a plant is the combination of all the kind of units (i.e. combined cycle: gas turbine, gas-turbine generator, steam turbine and steam turbine generator) in a single site.
- Users: this is the definition of characteristics of the owner of each plant considering utilization profile, warehouse location, attitude in claim negotiation etc.
- Inspection & Revision Scheduling: this is a scheduling of planned interventions for maintenance considering the three types of important events in plant lifecycle: general revision (corresponding to a major inspection on the gas turbine), partial revision (corresponding to hot gas inspection on gas turbines) part and inspection (corresponding to minor inspection of gas turbine)
- SPTs (Spare Part Type): they correspond to types of critical components (i.e. rotor, blades and vanes) and major systems (i.e. Digital Control System)
- SPI (Spare Part Items): correspond to each item of SPT in the inventory or mounted on a unit, including its information about residual life, current states, inspection history, etc.
- General Parameters: common parameters affecting different phenomena such as: maintenance duration, expediting policies, impact of different schedule constraints.

CONTROLLED VARIABLES

The goal in term of results to be produced by the simulation model is to estimate scenarios and management policies; some of the most important performance indexes and reports obtained from the simulator are:

- Effective Planning for Units

- Effective Planning for SPI
- Log on Time Constraint Respect detailing:
  - Deadlines not respected
  - Delta Times not respected
  - Dates not acceptable
  - Stockout Times and Quantities
- Availability of SPI
- Costs over the Time detailing:
  - Acquisition Costs
  - Refurbishment Costs
  - Refilling Costs
  - Warehouse Fees
  - Expediting Fees
  - Initial Costs for the defined Configuration
- Risk Reports
  - Risks in Delay on Planning Maintenance
  - Risk on SPI Shortage
  - Number of Stops and Durations
- SPI Service Level
- SPI Rotation
- Expected Final Status of the SPI at the end

The user should provide some fundamental management parameters, it is important to mention among them:

- Replication Number for each scenario evaluation
- Pseudo Random Number seeds (or automatic initialization)
- Simulation Duration
- Power Plant Pool Characteristics
- Inventory initial configuration
- Initial Scheduling
- Operative Management Criteria
  - Inventory Management Policieis
  - Policy for restoring Safety Levels
  - Policy for managing Expediting
  - Policy for managing Expediting
  - Policy for Interchanging compatible SPIs
  - Policy for Cannibalization of SPI in planned maintenance occurrences
  - Policy for Cannibalization of SPI due to failures
  - Policy for processing Automatic Collected Data
  - Policy for managing contract duration

These are considered the initial conditions and, referring to a specific scenario, the simulation model is able to reproduce power plant operations and services, managing and integrating the initial scheduling as well as unexpected failures.
For the convenience of VV&A of the model, simulation generates a log file containing all the simulated events, costs and performances. It also provides estimations of the different stochastic components versus the initial planning and management strategies. The reports include also the temporal evolution of the following parameters:

Unit EOH
SPI Consumption
SPT Quantities on the Warehouses
Refurbishment Quantities
Failures (minor and critical major)

Modelling The Units

It is important in the presented model, to define some characteristics of the units such as the reference plant. For this reason there has been created a Unit database containing the different entities subjected to maintenance planning and service management in current scenario; gas turbines, steam turbines and generator are the most important in the proposed case; some of the parameters defined for the units, among the most important, are:

ID_{unit}	Unique identifier of the Unit
Ref_{lant}	Reference Plant
Ref_{Site}	Reference Site
Ref_{Owner}	Reference User
Type	Type and model of Unit (i.e. GT-107B)
LEOH	Last value of the EOH (Equivalent Operating Hours) collected by Plant DCS [EOH]
LDT	Time of the Last EOH Data Collection [date]
Kt_{oheoh}	reference factor defined as statistical variable for conversion from operating hours in equivalent operating hours based on the unit operative profile (i.e. frequent shut-down and start-up) [real number]
Kt_{stoh}	reference factor defined as statistical variable for conversion from solar time to operating hours based on the unit utilization profile (i.e. always on or peak coverage) [real number]
TFF	Date of the first fire [date]
HFF	EOH at first fire [EOH]
TMgr	Date of the Last General Revision [date]
HMgr	EOH at Last General Revision [EOH]
TMpr	Date of the Last Partial Revision [date]
HMpr	EOH at Last Partial Revision [EOH]
LMxR	Type of the Last completed revision [Partial or Full]
NMprp	Number of general revision in between each partial revision [integer number]
TMi	Date of the Last Inspection [date]
HMi	EOH at Last Inspection [EOH]
ΔHp_r	Interval between Revisions of the same plant [EOH]
ΔHp_i	Interval between Inspections of the same plant [EOH]

α_r	tolerance on the ΔHp_i to be accepted for two Revision events at steady-state operative conditions [%]
α_i	tolerance on the ΔHp_i to be accepted for two Inspections events at steady-state operative conditions [%]
β_r	tolerance on the ΔHp_i to be accepted for the first two revision events [%]
β_i	tolerance on the ΔHp_r to be accepted for the first two revision events [%]
ΔTp_{ri}	Minimum acceptable interval between a Revision and an Inspection on the same plant [solar hours]
ΔTs_i	Minimum acceptable interval between two Inspection on different plants on the same site [solar hours]
ΔTs_r	Minimum acceptable interval between two Revision on different plants on the same site [solar hours]
ΔTs_{ri}	Minimum acceptable interval between an Inspection and a Revision on different plants on the same site [solar hours]
ΔTo_i	Minimum acceptable interval between two Inspection on different plants of the same owner [solar hours]
ΔTo_r	Minimum acceptable interval between two Revision on different plants of the same owner [solar hours]
ΔTo_{ri}	Minimum acceptable time interval between an Inspection and a Revision on different plants of the same owner [solar hours]
ODR_k	Opportunity to run a Revision in k-th month of the year based on contractual regulations and unit use profile [%]
ODI_k	Opportunity to run an Inspection in k-th month of the year based on contractual regulations and unit use profile [%]
Ct	Contract Duration Type (EOH or date)
Cl	Contract Duration Limit [EOH/days]
Cs_{es}	Contract Penalty for extra stops of the power plant [Euro/day]
Cds_{gr}	Threshold level on general revision duration for computing Contract Penalty [days]
Cds_{pr}	Threshold level on partial revision duration for computing Contract Penalty [days]
Cds_i	Threshold level on inspection duration for computing Contract Penalty [days]
Sqt_i	i-th Date Shifts on i-th event of planned maintenance [days]

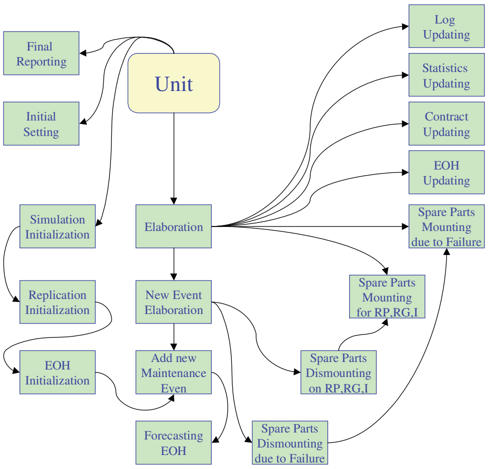

Figure 2 Unit Object Methods

ODRk and ODIk are representing the opportunity to fix the scheduled inspection in a specific month of the year; this is a strategic decision of the pooling manager that sets it up considering mostly: month workload, month demand, plant owner expectations and requirements, contract details.
The Unit methods are summarized in figure 2.

Spare Part Items

The Spare Part Items (SPIs) are fundamental objects, including all the entities required for planned maintenance and/or subjected to failures.
It is to be considered in fact that there is a variability on parameters also on the same type of spare part: for instance scrapping percentage during refurbishment along the item life cycle, or consumption rates for a specific kit due to some individual defect are not fixed even if it is possible to define statistically average values.
So it was decided to keep these attributes on the SPI for guaranteeing serialization of the spare parts, while SPT are used mostly for management aspects.
Taking in account such considerations, SPI are characterized by attributes among whom we have to mention:

ID_{spi}	Unique identifier of the SPI
Des	Description of the SPI
SPI_{type}	Type of SPT
Fg_{gr}	To be checked during General Revision
Fg_{pr}	To be checked during Partial Revisions
Fg_i	To be checked during Inspections
$List_p$	List of units where it is recommend to be used
Others	Possibility use this SPI also in other plants Where is technical possible the use
PU_{gr}	Probability to be required during General Revisions
PU_{gr}	Probability to be required during Partial Revisions
PU_{gr}	Probability to be required during Inspections

PU_f	Probability to register a failure over one year of operations
FU_f	Impact of the failure (i.e. no impact on unit, to Be substituted at first occurrence, to be substituted as soon as the new SPI is available, it shut down the unit and need to be substituted as soon as the substitute SPI arrives)
Ref	Indicates if the SPI is subjected to Refurbishment
Max_{ref}	Maximum number of possible refurbishment Processes before to be forced to substitute a component of the SPI
Scrap	Mean value of entities to be Scrapped, in percentage, during each Refurbishment
$Status_j$	Percentage of items on the SPI that already completed j refurbishment or that are new (if j is equal to zero)
IS_{gr}	Consumption expected during General Revision modeled by beta distribution (three parameters estimated by experts: minimum, maximum and most probable values)
IS_{pr}	Consumption expected during Partial Revision modeled by beta distribution (three parameters estimated by experts: minimum, maximum and most probable values)
IS_i	Consumption expected during Inspections modeled by beta distribution (three parameters estimated by experts: minimum, maximum and most probable values)
IS_f	Consumption expected during Failures modeled by beta distribution (three parameters estimated by experts: minimum, maximum and most probable values)
LT	Lead time expressed by a standard distribution in term of mean value and standard deviation
RT	Refurbishment time expressed by a standard Distribution in term of mean value and standard deviation
Ca	Acquisition cost for completing renovating the SPI
Cr	Acquisition cost for refurbishment of the SPI
Om	Warehouse fees expressed in Euro/year for the SPI
SOP	Operating status of the SPI (i.e. available, on refurbishment)
TOP	Terminating time for the current SOP of the SPI if unconditional
Unit	Unit where the SPI is currently installed
$Code_s$	Sequence code for the SPI to be used for planning the units where to use each SPI
Qnt	Number of entities included in the SPI
Inter	Possibility to interchange the entities composing the SPI
War	Total number of Entities available on the Warehouse
Stock	Safety Stock Level

Spare Part Types

The Spare Part Types (SPTs) objects include just part of the general variables, in order to guarantee dynamic evolution of several parameters of SPI as already mentioned. This was the reason of the authors' choice. SPT object includes the following attributes:

ID	Identifier of the SPT
Des	Description of the SPT
Type	Type of the units where the SPT can be Mounted
Ref_{SPI}	Reference SPI corresponding to standard expected performance for this SPT
Kits	Number of Kits, if specified, to be generated in addition to the unit mounted for the power plant pool management
Seq	Mounting Sequence for the existing SPI of SPT Type

Maintenance Planning Event

Events of scheduled maintenance are objects defined in aprioristic way by the user (this is the real method for operating in service of power plants) and then are dynamically generated by the model during simulation; these objects in fact don't correspond to real events being defined in term of start and end of the maintenance activity, therefore they includes:

ID	Identifier
Date	Starting Date
Unit	Unit involved
Type	Type: i.e. general revision, partial revision, inspection, first fire
Duration	Effective duration
EOH	EOH value registered at the startup

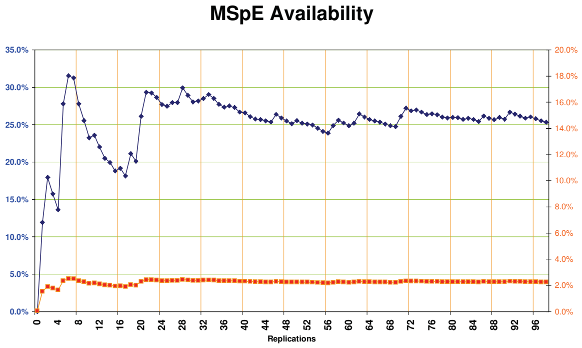

Figure 3 Mean Square pure Error respect Replications

EXPERIMENTAL RESULTS

The general approach used in this research is based on previous simulation models in the field of power plants developed by the same Authors. The result was satisfying because it was quite efficient in representing a very complex reality: for instance, the model is now on test on a reality with about 1'000 SPI for a pool including over 40 units.

Through the Mean Square pure Error evolution technique was achieved the Statistical validation of the model. MSpE is applied to the replication number over the timeframe. This corresponds to a contractual hypotheses for the pool service, and the availability results are summarized in figure 3. Level of estimation is good in terms of confidence band on several results (i.e. plant availability).

The great benefit of using C++ is a very high computational efficiency, even if the best results are obtained by investigating schedule on specific critical items that are key factors to optimize the process and find best strategies.

CONCLUSIONS

The results obtained from this research represent a success for the management of very complex strategies. The model VV&A has demonstrated the reliability of available data and allowed to organize reporting system & results.

In this phase the model is subject to a special tailoring on a real case study. The authors are also working forward on an improvement of optimization capabilities.

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