Pool Logistics for Power Plant Service

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ABSTRACT

The present study concerns a conceptual model to be used for managing power plant service; the system is devoted to support pool management by using simulation as testing criteria and intelligent optimization for alternative solution investigation.

INTRODUCTION

Power plant service represents today a very critical aspect in energy sector and it is from several years the most profitable area for constructors. Today are becoming popular strategies for inventory management devoted to share the general costs among different users from service providers; this paper propose an innovative approach for identify best solutions.
In fact this problems involves a mutual relation between inventory management and scheduling due to the fact that many critical items are subjected to revamping/refurbishment/recoating; so the decision to rotate kits or blades and van layers based on special philosophies could allow to improve the overall situation. In fact the service contracts are usually terminating based on a deadlines or an equivalent operating hour limit for the different units. Considering this aspect, closing the contract optimizing the life cycle of items subjected to refurbishment (i.e. leaving in the user units items near to their end of life) is very important; in addition this process is regulated by many stochastic factors: for instance the utilization profile for the units depend on market demand and on other power providers, the related variance on the equivalent operating hour evolution affects heavily the requirement for planned scheduling (usually regulated by hard logic, technical constraints about life cycle of the items).
The extra maintenance due to failures represents in this sector a small, but very significant, component due to the very high costs of power production stops.
Also refurbishment processes as well as new item supply processes are affected by stochastic phenomena.
In addition to these aspects the high cost of several components (i.e. blades and vanes or single big entities such as the rotor) represents an additional challenge.
Due to this considerations, the best approach for estimating the effective consequences of different decisions and policies needs to be based on stochastic simulation.
This paper focuses on the simulation model devoted to analyze such phenomena.

POWER PLANT POOLING

The pooling in power plant is based on the concept to reuse available items devoted to service among a set of units; in this way it is possible to refurbish items to be reused in another plant by a proper schedule that combines the refurbishment time with the schedule interval between the two units.
At the same time a common pool allows to reduce the safety stocks levels by a common benefits for sharing these ones among different power plants; obviously this aspect can be attributed not only to spare parts, but also to general resource (i.e. available maintenance teams, mobile warehouses, etc)

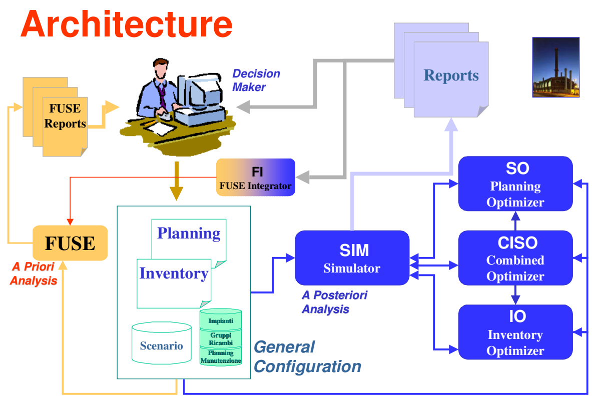

Figure 1 General Architecture

GENERAL ARCHITECTURE

The proposed model is devoted to support planning and inventory management in Power Plant Service based on the boundary conditions defined by the users(i.e. utilization profile of machines, expediting, etc.).

The general architecture combines simulation and AI (Artificial Intelligence) techniques in order to test different scenarios and identify the "optimal" solution; it is important to stress that in this context, due to the high impact of stochastic components, a mathematical optimum doesn't exist, however it is possible to define robust solutions able to provide statistical good results in term of costs and service quality. The planner to be developed involved three elements:

- IO Inventory Optimization
- SO Scheduling Optimization
- CISO Combined Inventory/Scheduling Optimization

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

SIMULATION MODEL DESCRIPTION

The simulation model is a stochastic combined simulator driven by events corresponding to failures, planned maintenance as well other critical time points (shut downs, start-up, contract closure, item delivery, etc); the power demand and unit EOH (Equivalent Operating Hours) evaluation is computed by integrating the expected profiles between two consecutive events.

The model extracts the values during each time moment for each simulation run from distribution probabilities of stochastic variables based on Montecarlo Technique.

The historical data available for variables under study have been analyzed by statistical techniques (i.e. Test Chi^2) and by SME (Subject Matter Experts) for properly define the statistical distribution to be used. Due to the reduced number of historical data usually available (i.e. short history, errors in records, confidential nature of the information) from the beginning it was expected to use extensively beta distribution that optimizes the combination of historical data with expert estimations. The simulation model obviously needs to be subjected to VV&A (Verification, Validation and Accreditation) process in a specific scenario; in the present study the authors extensively used dynamic validation based on Analysis of Variance (ANOVA), Mean Square pure Error (MSpE), Confidence Band, Statistical Comparison, Sensitivity Analysis. Based on this approach, simulation allows to estimate the robustness and feasibility of management strategies considering inventory levels, costs, quality of the service, etc.

The model has been designed in order to operate in last generation PC and to be implemented in C++, while the reporting system is integrated with the FUSE™ application and exports results in MS Office Suite™.

INDEPENDENT VARIABLES

The independent variables are based on different kinds of input; among the others these include the following objects:

- Units: plant major components represented in our case by Gas Turbines, Steam Turbines, Generators
- Sites: characteristics of the sites where are located the plants in term of geographic positions, environmental aspects, etc.
- Plants: a power plant is defined as a combination of units (i.e. combined cycle: gas turbine, gas-turbine generator, steam turbine and steam turbine generator) in a single site.
- Users: characteristics of the owner of the different units in term of utilization profile, warehouse location, attitude in claim negotiation etc.
- Inspection & Revision Scheduling: the schedule of the planned maintenance including the three major types of event: 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)
- Spare Parts Items (Spare Part Item): correspond to each item of SPT in the inventory or mounted on an 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 simulation model has to provide results for estimating the scenarios and management policies; in particular the simulation allows to obtain different performance indexes and reports such as:

- 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

As management input parameters to be provided by the user in general parameters it is important to mention among the others:

- 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 of 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

Starting from these initial conditions and in reference with the specific scenario, the simulator reproduce the power plant operations and services, managing and integrating the initial scheduling as well as unexpected failures. The simulator generates a log for validation and verification on all the simulated events, costs and performances providing estimations of the different stochastic components respect the initial planning and management strategies. The reports includes 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

The proposed system includes in the Unit database the different entities subjected to maintenance planning and service management in current scenario; gas turbines, steam turbines and generator are the most common in our case study; for each single unit it is necessary to define the reference plant; these objects include among the others the following attributes:

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]

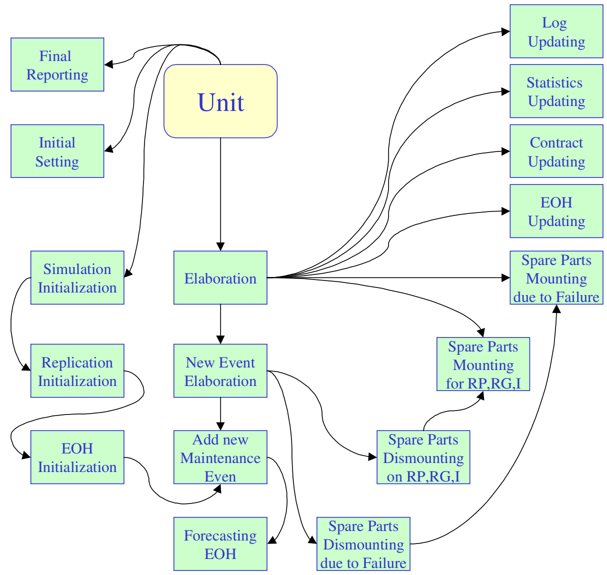

Figure 2 Unit Object Methods

ODRk and ODIk represent the opportunity for scheduling a planned maintenance event on a specific month of the year; this value is set by the pooling manager and it is combining different aspects (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) represent critical objects that include all the entities required for planned maintenance and/or subjected to failures.
In fact several parameters are subjected to changes also on the same type of spare part: i.e. scrapping percentage during refurbishment along the item life cycle, or consumption rates for a specific kit due to some individual defect.
So it was decided to keep these attributes on the SPI for guarantee serialization of the spare parts, while SPT are used mostly for management aspects.
Based on these consideration SPI are characterized by the following attributes:
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) represent objects that includes just few of the general variables, due to the author choice of guarantee dynamic evolution of several parameters of SPI as already mentioned.
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

The scheduled maintenance events are objects that can be defined a priori by the user and that 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

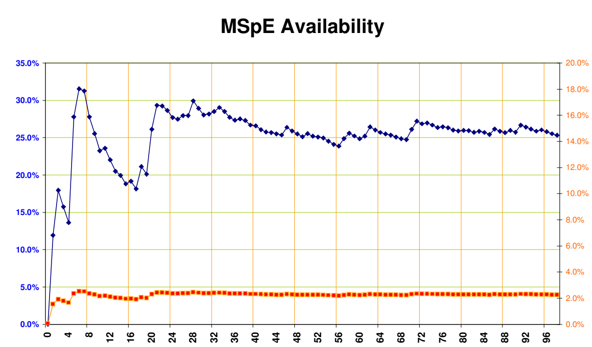

Figure 3 Mean Square pure Error respect Replications

EXPERIMENTAL RESULTS

The proposed general approach was based on previous power plant simulators developed by the authors and demonstrated to be quite efficient in representing a very complex framework; in fact this model is currently on test with about 1'000 SPI for a pool including over 40 units.

Statistical validation of the model was achieved by applying the evolution of the Mean Square pure Error versus the replication number over the timeframe corresponding to a contractual hypotheses for the pool service, the availability results are summarized in figure 3 as demonstration of the pretty good level of estimation in term of confidence band on several results (i.e. plant availability).

The computational efficiency is pretty high, in fact operating within these parameters 12 simulated years corresponds to about 30 second of real time; however if the simulator is used just for investigating schedule on specific critical items it is possible to reduce the execution time for the same timeframe to about 5 seconds; this aspect is pretty important considering the necessity of the optimization process.

CONCLUSIONS

The obtained results represent a success for guarantee the possibility to model very complex management strategies and in particular the pooling.

The validation of the model demonstrated the reliability of available data and allowed to properly organize the reports and logs files for reviewing the simulation results.

Currently this model is subjected to special tailoring for a real case study and the authors are working forward for improving optimization capabilities

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