CT/CCPP O&M Cost Analyzer: Software Capabilities and Development

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The CT/CCPP O&M Cost Analyzer software development is part of EPRI R&D Program P80 «New Combustion Turbine (CT)/Combined Cycle Power Plant (CCPP) Design, Repowering, and Risk Mitigation».

The idea is that realizing maximal benefits from advanced gas turbine based power plants involves a detailed assessment of the technology risk inherent to various CT models, especially the newer, high temperature models (F-class and higher technology). Quantifying this risk requires a quantification of the CT operation and maintenance (O&M) costs and a comparison of these costs with various risk mitigation options (insurances, warranties, long term service agreements, …).
CT/CC O&M Cost Analyzer Software

- Excel Spreadsheet
- Cost Estimates
  - Fixed and Variable (non-fuel)
    - Operations
    - Maintenance
  - Insurance
  - Maintenance Contracts
- Combustion Turbines and Combined Cycle Power Plants
  - Emphasis on the CT but also includes the ST, HRSG and BOP

In December 2003, EPRI released a major update of its CT/CCPP O&M Cost Analyzer software.

This presentation illustrates some possible applications and capabilities of this software in the context of CT/CCPP life management and full cost analysis. The CT/CCPP O&M Cost Analyzer software operates as an Excel 2000 workbook, compatible with Excel 97 as well as higher versions.

Its original purpose was to quantify technical risks associated to the maintenance of combustion turbines from a project developer perspective. To properly address that issue, a full O&M estimate was required. Today, the software allows to assess lower cost combustion turbine component repair/replacement options and CT/CCPP project risk mitigations.
The CT/CCPP O&M Cost Analyzer software provides an extensive framework utilizing present worth economics. Costs are annualized based on a geometric gradient i.e. inflation rate adjusted.

The “smart defaults” change depending on the inputs before them, and basic estimates can be made by changing just a few inputs. However, the intermediate values are also available if the user wants to override the defaults.

The software includes a statistical simulation capability for looking at the variability in unplanned maintenance costs and duration, as well as the impact of variation in scheduled maintenance intervals.
Operations Costs

• Direct Labor – Plant Staffing
• Indirect – Benefits and Home Office
• Operating Services and Modes: open cycle, combined cycle, peaking, two-shifting, base loaded, …
• Variable Operating Costs
  – Non-fuel (water, catalyst, etc.)
    (Fuel not included)

(Details Used to Build Up Costs)

The estimate of operating costs is based on a level of personnel staffing that is sensitive to the type of plant, duty and number of CTs.

Operating services are generally contracted services, such as accounting services, emissions testing, outside chemical analyses, etc. that would be considered as fixed costs. There is substantial detail provided in order to build up these various cost categories.
Maintenance Costs

• Annual/Periodic Services
• Scheduled CT Maintenance/Overhauls
  – CI (Combustion Inspection)
  – HGPI (Hot Gas Path Inspection)
  – MJ (Major Overhaul)
• Other Scheduled Maintenance
  – HRSG
  – Steam Turbine
  – Balance-of-Plant
• Unplanned Maintenance Allowance
  – CT
  – HRSG, ST, BOP
The above figure shows the typical cost fractions per year (annualized) for a base loaded CCPP consisting of 2 7FA+ gas turbines (75% service factor).

The annualized costs consist of:

**Fixed Costs:**
- Direct Operating Labor (Base, OT, Bonus)
- Direct Maintenance Labor (Base, OT, Bonus)
- Annual Services, Materials & House Power
- Indirect Labor (Benefits & Home Office)

**Variable Costs:**
- Scheduled Maintenance Parts & Materials
- Scheduled Maintenance Labor
- Unplanned Maintenance (Allowance)
- Catalyst Replacement
- Other Consumables
- Disposal Charges
The above figure illustrates the different OEM algorithms that determine their inspection and maintenance intervals, and which are incorporated in the CT/CCPP O&M Cost Analyzer:

- **General Electric**: Factored Hours (FH), Factored Starts (FS)
- **Siemens-Westinghouse**: Equivalent Baseload Hours (EBH), Equivalent Baseload Starts (EBS)
- **Alstom**: Equivalent Operating Hours (EOH)
- **Siemens KWU**: Equivalent Operating Hours (EOH)
- **Mitsubishi**: Equivalent Operating Hours (EOH), WS (*future*)
CT Maintenance Costs

Details per Component Type (i.e. 1st Stage Blade, Transition Piece)

- Costs
  - Repair
  - Replacement
- Tax Category (Capital or Expense)
- Repair and Replacement Frequency
  - Hours
  - Starts
- Inspection Costs
  - Consumables
  - Labor
- Spare Parts Rotation
- Repair Fallout Percentage for Blades and Vanes (Scrap Rate)

The fallout percentage (scrap rate) is determined by components that need to be replaced at an inspection date prior to its scheduled replacement.

The replacement costs incurred consist of a portion of repair costs also incurred (user-defined) and applies to blades and vanes with repair:replacement intervals of 1:1, 2:1 and 3:1.

Example:
Blade Repair @ 24,000 hr, Replacement @ 48,000 hr
20% Incur 30% of nominal repair cost before scrapping and replacing with new blades
the new parts are also subject to a certain fallout at the next HGPI
This leads to a complex accounting through the project life.
Spare Parts Rotation

Rotation Sparing
- Option to Incur Replacement Parts Costs Early (At Time of First Repair)
  - Repaired Parts Become Spares for a Next Interval (Roll In – Roll Out)
  - Timing Increases Net Present Cost of Maintenance
  - May Choose More Than One Set If Multiple Units
- Depends on Maintenance Strategy/Timing

Example with 2:1 Repair:Replace

The user can choose which parts are subject to rotation. When selected, procurement of replacement parts is accelerated to the time of the first repair cycle. Removed parts are repaired and used in a later repair cycle in the same machine or another machine. The timing of procurement of replacement parts and parts repair based on rotation sparing is therefore changed, which affects the cash flow and present worth economic analysis.

CT parts rotation sparing can accept any number of spares, up to the number of CTs being considered, to provide flexibility in the sparing decisions.
As new CT models attain higher firing temperatures, maintenance risk has become a central concern for project profitability. Over its life cycle, a turbine’s maintenance costs can run two to three times higher than its capital cost.

To help manage this risk, OEMs and third-party service providers are offering long-term agreements for parts repair and/or replacement, as well as more comprehensive maintenance agreements and contractual service agreements, commonly known as long term service agreements (LTSAs). These agreements may include planned and unplanned maintenance, extra work (as mutually agreed), enhanced field assistance, monitoring and diagnostics, initial spare parts, and other elements, in addition to specified parts supply and repair.

Results

- Quarterly Cash Flow for Scheduled CT Maintenance
  - Repair
  - Replacement
  - Labor
  - User-defined Cost Adders
- Annual Cash Flow
  - Operations
  - Maintenance
- Project Summary Report
  - Present Worth Basis
  - Annualized Basis
    - Fixed
    - Variable
- Graphical visualizations by O&M costs pie charts, bar charts, curves illustrating the probabilities of risk mitigation costs (uses the Crystal Ball Add-In)
Risk Mitigation Costs

- OEM Warranty
- Insurance
  - Machinery Breakdown
  - Business Interruption
  - Property
- Maintenance Contracts
  - Parts Only
  - Scheduled Maintenance Only
  - Scheduled and Unplanned
  - Maintenance and Operations

Version 3.0 of the CT/CCPP O&M Cost Analyzer provides:

**O&M Estimates for Existing Plants**: estimates of O&M on a “going forward” basis are now allowed. For existing plants that have run for a period of time and perhaps have already had maintenance inspections, the user can enter the accumulated factored hours and starts for aged parts on a component type basis, as well as factored hours and starts since the last inspection of each type. The software then uses this information as a starting point for estimating maintenance intervals and parts repair and replacement intervals, in the same method as for new plants.

**Insurance Premium Revisions**: the methodology and cost estimates for boiler and machinery insurance (i.e., machinery breakdown) and for the associated business interruption insurance have been significantly reworked to provide more accurate estimates based on current market conditions and industry input.

**Property Insurance**: Premium estimates for property insurance, with and without additional business interruption coverage, are now provided. Property coverage insures against a broad range of property damage exposures including fire, explosions, floods, earthquakes and other perils. Property insurance covers not only the process equipment but also support equipment and buildings.
Probabilities of Risk Mitigation Costs

Total Operations & Maintenance Cost Variability

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<th>Without Contracts &amp; Insurance</th>
<th>With Contracts &amp; Insurance</th>
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Ideally, the intersection point has to be as far as possible to the right to stimulate CT self-maintenance by the owner/operator.

**Quarterly Analysis**: a quarterly calendar basis is provided for scheduled CT maintenance intervals and inspection/overhaul costs. Present worth calculations are based on costs assigned quarterly, providing a finer resolution to changes in operating scenarios for sensitivity analysis. Factored hours and starts can be modified per quarter if desired to fine-tune inspection intervals. Quarterly escalation factors are also readily available for use with the user-defined maintenance cost and contract cost adders.

**Maintenance Intervals Refinements**: additional flexibility is provided in defining the frequency of inspections and CT parts life. The user may modify factored hours and starts intervals for combustion inspections, hot gas path inspections, and major overhauls. Timing of inspections is determined based on cumulative factored hours (and starts as applicable) since the last inspection. Parts repair/replacement timing is also determined based on cumulative factored hours (and starts) since the last repair or replacement.

**User override feature**: has been added to the quarterly inputs sheet to provide more realistic scheduling of major inspections for certain unique circumstances. The user can specify the minimum time interval following the hot gas inspection prior to a major inspection. In circumstances where the maintenance interval is a mixture of starts-limited and hours-limited intervals (a condition that can occur with GE and S-W algorithms only, depending on inspection limits), a major inspection (starts limited) could occur shortly after a hot gas path inspection (hours limited). A provision has been added such that the hot gas inspection is redefined as a major inspection if it would have occurred within several quarters time frame.
Effects of Risk Mitigation Options

• Most Options Classified as Fixed Costs
• Potentially Reduced Costs for Unplanned Maintenance
  – Some Costs (Above Deductible) Covered by Insurance
  – Some Costs Covered by LTSA
• Reduced Exposure to Potential Revenue Loss from Business Interruption

Results With Risk Mitigation
• Annual Cash Flow
• Project Summary Comparison of O&M Costs w/wo Risk Mitigation
• Cost:Benefit Comparison (with Risk Simulation)

Repair Fallout: parts replacement costs due to fallout during the repair cycle are rigorously calculated throughout the project life based on a user-specified fallout rate. In addition, the user specifies the extent that repairs must be made before deciding that the parts must be scrapped and replaced prematurely.

Maintenance Costs: model-specific maintenance estimates now include the 501D5A and V84.3A(2) machines, as well as an update on the S-W 501F costs. These are in addition to the GE 7EA, 7FA+e, and ALSTOM GT11N2 machines currently included. Any Alstom/ABB, GE, Siemens KWU, or S-W machine can now be modeled using the framework provided.

User-Defined Costs: additional user-defined CT maintenance costs for variable parts/materials and labor, either capital or expense categories, can be entered on a quarterly basis for self-performed maintenance. Additional user-defined costs associated with maintenance contracts can also be assigned on a quarterly basis.

Capital and Expense Categories: scheduled CT maintenance estimates now include user selection of the tax category (capital or expense) for parts replacement, repair and labor.

Rotation Sparing
For various scenarios, the above Figure illustrates the uncertainty of maintenance costs for CT owners, including self-directed (no insurance) OEM list price (for parts); an LTSA agreement using OEM services; and self directed using lower-cost third-party parts. The decision whether to chose an LTSA or “self-maintenance” requires understanding of the alternatives and having a sound basis for assessing the technical risk.

The predictions of maintenance cost also has a range of uncertainty. At the high end, the insurance covers the low probability-high cost, unplanned events.
The above figure illustrates the actual O&M costs for a base loaded 7FA gas turbine, based on listed OEM prices (reference) versus a scenario which uses alternative repair and replacement part suppliers of the emerging after-sales market. The latter prices are based on realistically achievable 35% reductions on replacement parts, 40% repair cost reduction and 50% scrap rate reduction against the reference situation, thanks to market competition stimulation, improved repair techniques, avoiding that components are running into an unrepairable situation by tracking the hot section components damage at the most critical locations (thermal-mechanical fatigue, creep, coating).
The above figure shows the annualized costs of the reference situation versus the alternative situation for a 7FA gas turbine. It shows that the biggest savings can be achieved by alternative lower cost replacement parts and alternative repair services. This can however only be achieved by stimulating competition on the after-sales market, achievable with the support of the utility industry itself.
Assumptions for 9FA/V94.3A Life Cycle Cost Reduction Potential

• Parts Prices – Typical OEM List Values
• Repair Prices and Scrap Rate – Typical Values
• Maintenance Intervals and Repair/Replace based on GER-3620J
• Economic Assumptions:
  – 30 year project life, 2.5% escalation, 15% discount rate
  – Daily Start-Stop Load Case: 20% capacity factor, 240 starts/yr
  – Intermediate Load Case: 35% capacity factor, 130 starts/yr (starts-limited maintenance)
  – Base Load Case: 70% capacity factor, 17 starts/yr (hours-limited maintenance)
• Extrapolation to 9FA: 30% higher parts costs (55% higher output)
• Extrapolation to V94.3A: Assume similar savings as 9FA
The CT/CCPP O&M Cost Analyzer software can assist in:

- **Technical Risk Factors and Reliability**: provide reliability statistics, highlight specific events, and comment on known issues for particular vendor model, based on proposed duty cycle and based on a suitable sample size of units currently in service.

- **Unplanned Maintenance**: estimate unplanned maintenance costs on annualized basis for future operation based on extrapolation of statistical events and current cost estimates.

- **Third-Party Parts Suppliers**: provide a status summary of the potential vendors for third-party parts that may be equivalent or improved over OEM designs, a timeline for parts introductions for a particular vendor model, and an estimate of potential cost reductions based on industry sources.

- **O&M Cost Evaluation**: compare costs, on a present-worth basis, with other maintenance alternatives.

- **Insurance Cost Evaluation**: estimate costs for boiler and machinery insurance and business interruption insurance as it relates to plant size and configuration.

- **Pro Forma Financial Evaluation**: provide project financial comparisons between relatively fixed cost maintenance contracts and self-performed maintenance.