Power plant life cycle cost management framework: a literature review

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Abstract. Today, the power plant industry has to operate in the stricter environment, safety, and standards. Hence a power plant needs to address those problem by implementing a sound and good asset management practice to ensure level of power plant performance set are met. Usually the power plant performances set by company are difficult to be met by aging power plants. They are hardly capable of delivering the requested performance due to their operational age. Several questions are raised to deal with the aging power plant such as should the power plan be maintained, improved and or discarded? Those questions are difficult to be answered as for any power plant there were great deal amount of money has been involved since the very beginning of power plant construction until their operation stage. Due to this fact a novel approach on how to deal with the problems is proposed in this paper. A novel framework of assets management will be developed by considering many factors and criteria of power plant performance related to efficiency, reliability and economics aspect of the power plant through its entire life. The framework is called as Holistic Operation and Maintenance Excellence (HOME). In this paper, the authors would like to present literature survey related to the HOME framework. It is expected that the will be proposed HOME framework will be capable of dealing with problems raised previously based on the works in the power plant asset management previous research reported in this paper. The HOME framework objectives are integrating power plant asset management, finance (cost), and technical aspect such efficiency, reliability as a guide to make decision during it is service life. The LCM framework to optimize power plant asset in term of fuel, operation and maintenance was provided. Potential gap has been discussed and proposed for next research.

1. Introduction
The power plant must produce electric with high cost effectiveness to win the market and maximize return of investment. The power plant also has to consider safety, reliability, regulatory standards as good as well. It needs an asset management to minimizing a potential problem in the future. The life cycle management (LCM) will address this issue. Life cycle management (LCM) combines physical and financial asset management to optimize service lifetime of the asset (figure 1). Today, the energy infrastructure has realized that the key to enhancing asset performance, longevity, and profitability in our uncertain world is the formal implementation or enhancement of Life Cycle Management (LCM) practices. Many authors have studied how the power plant could be optimized during its entire lifetime. However, there are still gaps between the academic or theoretical and the real implementation. In this paper, a conceptual classification life cycle cost management framework for optimizing decisions in the power plant is proposed. The LCM framework to optimize power plant asset in term of fuel, operation, maintenance, and disposal is proposed, classified and discussed bases on the available literature. Then, the potential gap is discussed and proposed for next research to fill the gap.
2. LCM framework

Formal definition of LCM is integration of operations, maintenance, engineering, regulatory, environmental and business activities that manage asset condition, optimize operation life and maximize plant value while maintaining plant safety. Asset lifecycle includes the activities related to asset acquisition, commissioning, operation and disposal (figure 2). Planning, designing and procuring of assets come under the acquisition stage of assets. The installation or building assets and checking whether they are in a good condition come under the commissioning stage. Operation of an asset is the most important stage of an asset lifecycle. During the operational stage, monitoring, maintenance, refurbishment and potential upgrading is important in order to meet the conditions of operational requirements. The last stage is the disposal of an asset. Having a good knowledge about asset lifecycle and costs which are occurring in the whole asset lifetime is very important to manage assets. Asset lifecycle cost (LCC) would be optimized during implementation of LCM. The Total Life Cycle Cost (TLCC) of the power plant can be calculated as [3]:

$$ TLCC = C_i + \sum_{t=1}^{T} \left( O_t + M_t + F_t \right) \left( 1 + d \right)^{-t} + C_d $$  \hspace{1cm} (1)

Where $C_i$ is the initial investment cost. $O_t$, $M_t$, and $F_t$ are the operation, maintenance and fuel cost for the year $t$. $C_d$ is demolished cost at the year $T$ and $d$ is the discount rate. A LCM framework for the power plant has been introduced and developed by EPRI [4]. The LCM planning consist of three main stages (figure 3). The first stage is the selection of system, structure and components (SSCs) that important to plant safety, reliability and economics base on level of criticality. The second stage is LCM technical evaluation that specify the scope, boundary and functions, collect relevant technical information and performance data, conduct assessment and identify candidate LCM plant alternative. The third stage is LCM economic and strategic planning evaluation that develop and conduct failure rate and cost analysis, assess performance and cost of each LCM plan alternative and select optimum LCM plan. Each alternative will be evaluated the plan performance and maintenance cost, include planned and unplanned cost base on reliability data especially failure rate data. All each LCM alternative plan is evaluated. Once alternative strategies are formulated, the equipment reliability and plant availability are evaluated, included the forecasted preventive and corrective maintenance cost and all associated cost of operation, engineering, procurement, etc. Optimum alternative plans were identified on the basis of greatest NPV and/or Benefit to Investment Ratio (BIR) forecasted for candidate LCM alternative plans. In the LCM framework demonstration, EPRI focused and reviewed on maintenance strategies as an alternative LCM plan scenario to get maintenance optimization. Base on equation (1), optimization of power plant life cycle as a candidate of LCM alternative plans can be done not only in maintenance strategy, but also in operation, fuel and disposal strategy. The ultimate goals of all alternative LCM plan is reducing the total life cost of the power plant (TLCC). All methods and strategies to optimize power plant asset in term of fuel, operation, maintenance and disposal will be discussed in the next page.

![Figure 1. LCM concept [1].](image)
2.1. Maintenance Optimization

Availability and reliability are the important factors that was considered in term of maintenance optimization. Higher reliability means lower maintenance costs and longer lifetime. Higher reliability also impacts to higher availability. There are many possible ways to classify the current practices of maintenance strategy. According to Duffuaa et al [6], there are six maintenance strategies that are generally used in maintenance optimization. They are runs to failure (RTF) / corrective maintenance (CM), time based maintenance (TBM) / preventive maintenance (PM), condition based maintenance (CBM) / predictive maintenance (PdM), fault finding maintenance (FFM) / inspection maintenance (IM), opportunity maintenance (OM) / Overhaul (OH), and design out maintenance (DOM). All of the maintenance strategy above applicable at the components level. In the higher system level such as structure, sub-system or system have two or more component that correlated and interacted each other. Each component has a different problem. For complex structure/system need some maintenance approaches that combine and integrate of several maintenance strategies as a maintenance management system to ensure all the objective of maintenance achieved. Some of maintenance approaches that common used are Reliability Centered Maintenance (RCM) [Mobray et.al], Business Centered Maintenance (BCM) [Kelly et.al], Total Productive Maintenance (TPM) [Nakajima-Suzuki et.al] and Risk Based Maintenance (RBM) [Krishnasamy et.al]. Another approach that are less well known are Availability Centered Maintenance (ACM) [Cheschini et.al], Availability Based Maintenance (ABM) [Organ et.al], Total Maintenance Management (TMM) [Raouf et.al] and Reliability Based Maintenance (RBM) [Ford et.al]. Reliability for complex system could be assessed use both qualitative and quantitative methods. Fault Tree Analysis (FTA), Event Tree Analysis (ETA),
Fish Bone Analysis (FBA), Root Cause Failure Analysis (RCFA), and Failure Modes & Effects Analysis (FMEA) are common used for quantitative method. While Monte Carlo simulation, Markov Chain, and Reliability Block Diagram (RBD) are common used for quantitative methods of reliability analysis.

2.2. Operation Optimization
Operation and maintenance period are the longest period in the whole of the life cycle of a power plant comparing with construction and demolished period. Because of this, so many activities have to be planned and done during operation & maintenance period to optimize asset lifetime. Operation optimization to reduce the cost and/or increase the profit have been studied and reported at least in the area of operation setting, operational flexibility and power plant configuration. Coal power plant could operate in the optimal condition when all operation parameter have been set in the optimal point [Chao et.al, Zang et.al, Thanrawee et.al, Jia et.al]. Operation flexibility strategy was also reported could be used to optimise operation of a power plant, e.g. minimum load, load dependent & start-up differentiation [Julia et.al], transient operation during a start-up [Moritz et.al], and load followers [Evgenia et.al]. Another strategy to optimize operation of a power plant are by doing optimise power plant configuration in the grid system [Jing et.al].

2.3. Fuel Optimization
Fuel cost is the highest cost in the coal power generation. It was reported up to 50-65% of total cost [7]. In this point of view, fuel optimization management is an important part of LCM for coal power plant. The most responsible for changes in the fuel cost during coal power plant’s lifecycle are the price of coal and the efficiency of power plant. Changes in transportation had relatively minor effect. The goals of fuel optimization are increasing unit efficiency, decreasing fuel cost and/or decreasing pollutant / emissions. Fuel optimization could be done by technology choice, fuel treatment/upgrading and fuel handling operation. New technology that used in coal power plant such as ultra-super critical (USC) boiler [Ploumen et.al], steam turbine modification [Stover et.al], integrated gasification combine cycle (IGCC), solid oxide fuel cell (SOFC) [Choudhury et.al], and integrated gasification fuel cell (IGFC) [Li et.al] have been studied and reported has significant impact to increase efficiency, reduce fuel cost and emission (NOx, SOx and CO2). Coal treatment/upgrading such as coal drying, coal blending ([Xia et.al], [Hans et.al], [Qiu et.al]), co-firing with biomass ([Munir et.al], [Sheng et.al], [Shen et.al]), and coal water mixture (CWM) / coal water fuel (CWF) [Umar et.al] have been studied in a few years as another strategies of fuel optimization in coal fired power plant.

2.4. Disposal Optimization
In the end of life, all assets will deteriorate and the failure will increase. It has to be disposed or replaced. In traditional asset replacement models, utilization schedules assumed a constant or predetermined when examining the life cycle cost. However, the periodic usage of these assets is generally uncertain. In the framework of replacement analysis, there are several different approaches as e.g. economic life models [Philip et.al], productivity analysis [Leung et.al], simulation model [Loren et.al], profit maximization models [Sethi et.al] and risk critically ranking [Martin]. EPRI have been proposed LCM frame work that considered the economic life of the asset, called Integrated Life Cycle Management (ILCM) [8]. Basically, ILCM structure consists of two actions, and these are likelihood curve development and optimum replacement or refurbishment strategy. The calculation that integrate the probability of failure from the likelihood of failure with the capital cost, maintenance cost and consequences of failure to determine the optimum replacement time is called Integrated Life Cycle Cost (ILCC). The optimum replacement time is when the life cycle cost is minimum (figure 4). The life cycle cost consist of all cost including investment cost, estimated maintenance cost and consequences cost of failure. Replacement too early was not economically due to higher investment cost but replacement too late also was not economically due to higher maintenance and consequence cost of failure (forced outage). The ILCC is not deterministic but probabilistic.
All alternative strategies to optimization in the life cycle management framework based on the literature review as has discussed above can be summaries and showed at figure 5.
3. Conclusion
Life cycle management (LCM) could optimize asset utilization and sustain business objective of organization. Optimal asset utilization would increase productivity, reliability, availability and return of asset investment. The operation and maintenance asset optimization for power plan have been researched by a lot of authors, but still there are some remarks can be summaries as below:

- Most of the power plant optimization has been studied separately, e.g. optimize the asset through maintenance optimization (reliability improvement) or operation optimization (efficiency improvement). None of authors that has been studied how to optimize the power plant through combination of fuel, operation, maintenance and disposal optimization. The LCM framework to optimize power plant asset in term of fuel, operation, maintenance, and disposals is needed.
- The aims of optimization, mostly only considered single criteria such as maximizing the reliability and/or availability, minimizing the failure and/or minimizing maintenance costs for maintenance optimization, or maximizing the efficiency, minimizing operation cost for operation optimization. In the real condition, both O&M, reliability and efficiency should be considered together as an important factor in the asset management. The economic added value on overall performance of a power plant must be quantified through reduced O&M costs, increased revenue and/or increased profit with several decision criteria.
- The accuracy of LCM's optimization decision result could be validated after implementation of LCM plan done. In this case, a real field data analysis of LCM implementation is required. The biggest challenge for a researcher to do this type of research is management barrier and time of analysis. In the real application, any significant changes in operation and/or maintenance policy that have a big impact to financial perspective usually need a long period to be approved, implemented and validated the result.
- Consistency is a very important factor for the ability to conduct operation and maintenance analysis in real power plant practice. Uncertainty in loads, operator behaviour during operation and maintenance activity, etc. is one of the major factors which can affect the efficiency and failure of equipment and cost too. To improve the existing models, more accurate, validate and assumption data are required to provide the result as close as actual condition.
- The optimum time to replace the asset rather than repair is other subject needed to be analysed in LCM. In case of a power plant, replacement decision analysis of the asset mostly in the level of a component (equipment). None of literature or reference discuss how replacement is taken place in the level of system (power plant) that contain a huge investment cost. Determine when the best time to keep, rehab or demolish a power plant is a challenge.

4. Future research
To fill the finding above, the main purpose in the next research are:

- Develop new LCM framework for coal power plant that combine of operation and maintenance optimization and demonstrate how its work in an application practice. The framework is called as Holistic Operation and Maintenance Excellence (HOME). The HOME framework objectives are integrating power plant asset management, obsolescence and economic planning to optimize operation and maintenance, efficiency, reliability and service life of systems, structures and components (SSCs).
- Describe a real case study of LCM implementation in coal power plant and compare with theoretical. Paiton coal power plant (CPP), 2 x 400 MW, was selected as a case study. A set of LCM alternative plan scenario would be formulated and implemented in real practice. Evaluate and justify the best scenario in term of minimizing total cost and/or maximize the profit. Energy and heat balance analysis would be used for efficiency and operation
optimization modelling. Reliability, Availability & Maintainability (RAM) is analysed and modelled with Reliability Block Diagram.

- Develop an LCM's tools calculator that could be able to calculated and predict all future equivalent annualized cost (fuel, operation and maintenance cost) of the component/equipment level and system/plant level over the entire plant lifetime. LCM's calculator could be used as a tool for management to make decision in term of selecting the optimum plan easier in a practice.

The next research will be divided into three phases as follow (figure 6):

- Phase 1: Literature review, gap identification and propose new method. This paper is the first step of the research. All literature related to the life cycle optimization including fuel, operation, maintenance, and disposal/replacement optimization has been reviewed. A new method has been proposed to fill the gap. It is called as Holistic Operation & Maintenance Excellence (HOME) that combine fuel, operation, maintenance and disposal/replacement optimization.

- Phase 2: Developing new method, industrial modelling and model validation. In this phase, HOME will be developed and modelled for coal power plant. Operation & maintenance data from PaitonCPP as a case study will be used to validate the model. Operation data is taken from DCS directly, while maintenance data is taken from CMMS.

- Phase 3: Implementation of model, test & sensitivity analysis, decision aid development & validation, optimization tools & software. Output of the model is a set of alternative plan for asset optimization. Each alternative plan will be tested using sensitivity analysis and see the result outcome. The decision criteria to define the optimum option will be developed and validated. Final output of the research is a tool or calculator such an optimization software for coal power plant. It could be used in a practical for management to optimize their asset during the entire lifetime in both system/plant and component/equipment level.

Figure 6. Work flow process of the next research (HOME).
5. References

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