Evaluation of the Outsourcing Decisions for Power Station Operations and Maintenance Services

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Abstract

The electrical power industry has changed radically over the last two decades as a result of regulatory and technological changes. Once a conservative and staid industry dominated by large regulated utility companies, power generation has been transformed through the introduction of market derived regulation and competition. This change has allowed many new investors to enter the market and forced established utilities to look in neighbouring markets for growth. At the same time new high technology gas turbine combined cycle (GTCC) plants with high efficiency and relatively low capital costs have removed much of the economies of scale enjoyed by conventional central generating stations. The falling of investment restrictions and barriers to entry have created a dynamic and changing industry driven by competitive pressures rather than the traditional cost of service models. In this modern competitive industry asset owners have the possibility of improving their return on investments, but they also face more risks and uncertainties.

To manage their risks and uncertainties, while still focussing on improving profits, many asset owners have chosen to outsource part of the physical asset management responsibility to specialised operations and maintenance (O&M) companies. The asset owner may choose outsourcing to reduce costs and risks. A service supplier can have a greater ability to capture economies of scale, and use a broader fleet base to spread risk; therefore, reductions in these areas are possible. The company may also consider outsourcing for more fundamental strategic reasons. Advantages can be gained through the transfer of non-core activities to the scope of the supplier, allowing each firm to focus on areas where they are most effective. Whatever the rational for outsourcing, the owner requires a method to evaluate outsourcing options to determine which is right for its plant, given its own internal capacity and strategy.

An outsourcing decision process must be capable of selecting the right type of service level based on a number of tangible and intangible strategic criteria. To make this type of multifaceted decision it is necessary to employ a process based on a sound theoretical foundation that can compare different options against the critical criteria of: lifecycle costs, revenue influences, quality, health and safety, and other key industry drivers. This paper focuses on the use of the Analytical Hierarchy Process (AHP) as a tool that is capable of evaluating this type of diverse multileveled decision to produce a consolidated result. The AHP uses an easy to understand hierarchal structure to sort both tangible and intangible criteria based on their relative importance, with a simple pairwise comparisons between each criteria. This methodology allows a complex model to be rapidly decomposed and assessed. It is simpler and more straightforward to use when compared to more complex utility decision models. In spite of this simplicity the system is robust and proven in many industries, making it a useful method for asset owners to assess their outsourcing decision.

As part of the analysis done for this paper, the effectiveness of AHP method was tested through the development of models based on outsourcing decisions faced by three different types of generation asset owners. In these models a hierarchy was developed based on the key industry drivers that can impact the long-term success of a power
plant project. Five outsourcing alternatives were evaluated in each model, ranging in
degree of service provision from no outsourcing to full outsourcing of the service. These
test models produced results that were logical and similar to the situation that exists in
the real world, thus demonstrating the applicability of AHP as a viable method for
evaluating this type of decision. While the AHP model is suitable for the decision
process the results of such conceptual models cannot be used directly by an asset
owner. Each company has its own capabilities, culture, and strategy. Therefore, it
needs to perform its own assessment of the relative value of each criteria and
alternatives through its own pairwise comparisons.

As well as providing a useful model for asset owners this type of evaluation is also
valuable for service companies to focus their service offerings. For this reason it is
recommended that such a company further develop this process and sponsor its use
with a number of customers. By pursuing this research a richer and more complete
model will be created for the benefit both suppliers and owners.
1 Introduction and Background

1.1 Introduction

Over the last twenty years the global electrical power generation business has undergone many transitions and adjustments driven by financial, regulatory, environmental, social and technological changes. In nearly all of the International Energy Agency (IEA)\(^1\) countries the electrical markets have opened up to some level of competition in power generation and retail sales in order to improve economic efficiencies of the industry (IEA, 2003). These changes have put significant pressures on an industry that developed from regulated or government owned vertically integrated monopolies.

To remain competitive in the changing market power generation asset owners often seek advanced technologies that can offer low marginal production cost, combined with low environmental impacts, while keeping initial investment costs to be as low as possible. Natural gas fired combustion turbine technology has been the dominant technology choice in OECD nations for the last two decades and is forecasted to remain so for the near-term as illustrated in Figure 1. These plants have the advantages of high efficiency, relatively low first cost, short construction time (Brommeli, 2003) and a comparatively clean fuel source with natural gas. However, they also have higher risk associated with them because of the higher technology, high combustion temperatures and their need for higher levels of engineering knowledge and support to maintain.

![Figure 1: Net Changes in OECD generation capacity (IEA 2007, p35)](image)

Overlaid with external stress owners often have to meet increasing investor demands for improved returns on investment coupled with reduced cost volatility and risk for the highest payback from their in assets. In many cases owners consider outsourcing part of their asset management or operation and maintenance (O&M) functions to specialist firms as a method to reduce cost, free up their own resources, and mitigate risks. These

\(^{1}\) The International Energy Agency (IEA) is an intergovernmental organisation that acts as energy policy advisor to 28 member countries. Its purpose is to support the development of policies that ensure reliable, affordable and clean energy for their citizens. [http://www.iea.org/](http://www.iea.org/)
long-term service agreements (LTSAs) can serve to reduce potentially negative impacts of unplanned maintenance while at the same time fixing the O&M costs throughout the contract period (Grace, 2005).

This paper will examine the strategic decision faced by power generation asset owners when they are evaluating their asset management options.

### 1.2 Generation Industry Background

For more than a century electricity has been predominantly produced by vertically integrated utility companies in centralised power plants to capture economies of scale and distributed to consumers through transmission and distribution networks. These economies of scale, as well as the impracticality of running more than one set of wires to a customer, meant that in almost all jurisdictions electrical power generation was integrated with transmission and distribution in the form of government owned or regulated utilities who had a mandate to provide reliable and safe energy at a regulated cost. Company risk was largely mitigated by the ability to pass costs on to energy consumers (IEA, 2003, p.27) and the ability to hold reserve capacities that would be included in rate base. Large utilities also had the ability to take portfolio risk provisions across a large generation and transmission fleet. This resulted in an industry that was quite conservative in its structures and technology choices, and one that preferred reliable and tested business methods including internal vertical integration of most the development, energy management, operations, maintenance and engineering functions.

This general structure lasted up to the early 1990s when there was a significant change of regulatory thought in many jurisdictions. At the same time advancing technologies created a situation where the economies of scale associated with large central stations were no longer necessary to produce electricity efficiently (Becker-Blease, Goldberg, and Kaen, 2008).

One technology that gained prevalence in the 1990s was the natural gas powered gas turbine combined cycle power plants (GTCC), which matured and became available at a much lower initial capital cost than conventional coal or nuclear plants. This lowered the cost barrier of entry and allowed many new entrants into the power generation market. As the GTCC technology uses natural gas primarily and produces power at a much higher efficiencies than conventional plants the environmental impacts are significantly reduced, which contributed to the continued preference for this type of plant in North America, Europe, Oceania and South East Asia.

The changing electrical market together with advances in technology encouraged competition and many different types of investors entered into electrical generation. In the United States much of the early growth involved investment from utility companies who were no longer able to expand their own areas and therefore established independent power producer (IPP) operations elsewhere (Ishii, 2002). As the market continued to develop, these established utility companies were joined in the market by industrial developers, foreign utilities attempting to increase their holdings, energy trading companies that recognised generation assets as an opportunity to hedge and
arbitrage in both power and gas markets, and large investment funds who valued the underlying assets as part of a diverse portfolio. This resulted in proliferation of investor structures and a fragmentation of the ownership and management of generation assets within regions.

Many of the entrants into the generation markets lacked the technical competencies to manage advanced technology GTCC plants, or owned assets far removed from their main engineering and technical centres. Increased competition also led to a reduced willingness of generation companies to share learning or research and development (R&D). These trends resulted in a reduction of technical capabilities in power plants. In many cases owners sought to find alternate ways to improve their performance through long-term outsourcing service agreements to counteract some of the negative aspects of the new market structure. This demand for services led in turn to the development of companies specialising in O&M technology and management that could offer a wide range of alternatives in scope of supply.

The continued development of these service markets, coupled with a continued strong demand for new power projects\(^2\) and continued liberalisation of generation markets, will require asset owning companies make the correct choices in regards to outsourcing to optimise their returns. These choices are frequently made at a time when a power plant is in its development stage and demands on management are the highest. Therefore, it is imperative that the owners make the effort and take the time to consider all options prior to making a decision that can have far reaching impacts.

1.3 Power Generation Ownership Structures

In each geopolitical jurisdiction the development of the industry has had its own history of either public or private development with subsequent re-regulation and liberalisation resulting in many different forms of asset ownership and control of generation assets. In spite of this myriad of ownership models it is possible to simplify the large number of ownership structures to three primary use-cases that cover, in a general way, the bulk of power generators.

1. The first model includes the large integrated utility based companies that have a fleet of generating plants. This type of company tends to have many plants located both in its geographic centre and in external areas and has a large internal engineering and O&M capability developed from its history as a utility. Often these companies believe that the engineering, operation and maintenance of power plants is their core businesses and they will tend to invest heavily in developing and maintaining expertise as a form of competitive advantage. Some major international companies included in this group include: GDF Suez (France, Belgium), Duke Energy (U.S.A), American Electrical Power (AEP)(U.S.A.), E. On (Germany), Électricité de France (EDF) (France); and in Canada: TransAlta, Canadian Utilities, Ontario Power Generation.

\(^2\) Even with the financial crises of the 3rd quarter 2008 there is a strong demand for new power plant construction due to both growth and the aging of the existing installed technology. Within IEA countries it is expected that one-third of installed capacity, equal to approximately 872 GW will need replacement by 2030 (IEA, 2007)
2. Model two includes large industrial companies that have entered into power generation as a method to improve their value and to optimise their own operation. These companies view management of the asset’s financial or energy flows as their core competence as opposed to the engineering and O&M of the facility. In other cases the power generation is used as an add-on to an existing facility in order to improve the efficiency or financial performance through cogeneration. These companies often have extensive industrial experience in their own industry with some overlap to O&M requirements of a power plant, but generally do not have the full range of equipment expertise required. As power generation does not represent the core activity of the business the commitment of management and resources to plant O&M may result in a loss of focus in other parts of the business resulting in opportunity losses. Some examples of companies that fit this model are on an international level: Gas Natural (Spain), Petrobras (Brazil), BG Group (U.K.), and TransCanada Pipelines (Canada).

3. Model three represents the group of smaller companies that build and operate power plants as a sole business activity but are not directly related to the main power producing or distributing utilities in their area. Collectively known as independent power producers (IPPs) these investors have many different corporate structures and financial arrangements but normally treat each power plant as an individual and semi-independent project. These facilities normally have project specific power sales and fuel supply contracts or arrangements not connected directly with the owners other business activities.

IPPs may have some form of fixed contracts for fuel supply and power or one where the facility acts as an energy conversion facility and another company provides all of the fuel and takes all of the electricity based on some predetermined energy conversion factor (wheeling). In these cases the projects have limited volatility risk for fuel or power prices. Other IPPs are designed to operate largely in the open or spot market for power and/or fuel (merchant plants), which creates a much higher risk profile. In all cases IPPs derive competitive advantages through having high reliability and the best possible energy efficiency (heat rate). There are normally significant penalties for non-delivery of electricity either in the form of direct penalties or the requirements to purchase replacement power. For these reasons IPPs tend to have a strong management focus on the energy flows and contractual management of the plant with O&M management taking a lower priority, except where it can impact the reliability of the facility.

Though there are differences in the general commercial and investor set-up of generation plants the asset ownership use-cases described require many of the same

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3 Cogeneration refers to the transfer of a portion of the waste heat from the power plant to an attached facility or community, or vise versa. For example a portion of the steam generated from the exhaust heat from a gas turbine can be supplied to community heating (combined heat and power – CHP) or steam generated from a refinery process can be provided to a steam turbine to produce power.

4 For the purposes of this paper IPPs that are owned by large utility based companies are included in the IPP classification if their ability to share resources, systems, engineering and knowledge bases with their parent company is restricted due to distance, joint ownership or other limitation.
functional elements in order to fulfil their business objectives. For simplicity these can be grouped into three blocks of similar activities as shown in Figure 2. The success of any generation project will be dependent on what decisions are made by the owners and developers on how they manage these functions to achieve optimal results.

![Figure 2: Key Generation Plant Functional Requirements](image)

The first key functional groupings cover the financial management aspects of the project, which include debt, equity financing, and financial risk mitigation methods. In the development of any large capital-intensive project, such as a power plant, considerable analysis and management involvement is committed to the development of optimal financial structures of the project. The decisions regarding initial financing as well as ongoing operational financial management represent key components of the business and normally cannot be outsourced.

Risk mitigation on the other hand may have many aspects that have viable options for outsourcing. According to Grace (2005), the two key aspects of asset risk mitigation are long term maintenance agreements (LTSA), also known as O&M contracts, and insurance. For most aspects of asset management it is possible to mitigate many risks in a cost effective manner through the purchase of insurance. The amount of risk that is managed, the deductible amount and types of coverage required varies significantly depending on the owner and the type of facility. To find the optimum mix it is often desirable for asset owners to utilise an insurance broker to work with many insurers to configure the best packaged solution. This type of outsourcing allows the owner to benefit from the brokers’ greater knowledge and economies of scale. An O&M contract normally provides the asset owner with some level of risk mitigation through the reduction of the negative impacts of unanticipated maintenance issues such as reduced parts life, unplanned maintenance events, parts cost increases and poor execution of planned maintenance by assigning maintenance responsibilities to the supplier (Grace, 2005).

The second and likely the most important functional area for most power generators is the energy management function. This group of activities includes the management of fuel purchases and sales of power that together represents the largest cash flows for the
organisation (Grace, 2008). It is in the energy related areas that the owner has the greatest profitability risks. Because of the large risks associated with energy purchasing and sales the generation owners have the most significant incentive to internalise the management of these functions rather than outsourcing to others.

For risk adverse projects the exposure can be limited through the use of fixed long-term power purchase agreements (PPA) with utility or industrial off-takers and similarly configured long-term fuel supply contracts. At the other end of the spectrum of risk are the merchant producers that rely on short-term or spot market pricing for their fuel and power commitments. In reality most generators utilise a mix of risk minimising long-term contracts and some amount of short-term contracts in order to maximise revenue potentials. Large integrated utilities represent a special class of generators as they usually have built in hedging through a diverse portfolio of assets, which they can dispatch on or off to cover demand volatility and the ability to pass fuel costs on to rate paying customers. These choices of energy function risk management represent a core requirement of the project and cannot be readily outsourced.

The third principle functional area covers the key areas of physical plant asset management related to operations and maintenance activities, asset engineering, procurement and logistics. It is in these areas that asset owners have perhaps the greatest potential for choices. As deregulation and diversification of the electrical generation business created a varied landscape of generation asset owners this in turn created a market place for service providers to develop. These specialised companies offered O&M and asset management services to the generators for a wide range of options from simple capacity augmentation up to engineering and full service provision. Asset owning companies therefore have a range of possible alternatives when deciding on the optimal solution for running and maintaining their facility. Making of these choices will be the primary concern of this paper.

1.4 Outsourcing Literature Review

The outsourcing option has been considered a viable option by firms for a variety of reasons ranging from a pure cost motivation to more strategic reasons, including the focusing on core business and risk reduction. Many researchers have studied these topics and provided a wealth of literature with relevance to this paper. What is particularly of interest is what was described by Hiemstra and van Tilburg as non-capacity outsourcing (Fill and Visser, 2001). Capacity outsourcing is the type of service used by most companies only to provide additional capacity for specific seasonal or peak demand periods, whereas non-capacity refers to suppliers that actually take over part of the firm's value chain through long-term arrangements.

Power generation asset owners will consider outsourcing for a combination of three primary reasons: cost reduction, strategic sourcing of non-core activities, and risk reduction.
1.4.1 Outsourcing for Costs

As with any business activity power generation owners will strive to find the optimal financial balance between revenues and costs. Often outsourcing is considered as a way to reduce costs for parts or all of a product, function or department. If the cost of contracting out parts of the operation is cheaper than doing it internally then the case is clear for outsourcing (Fill and Visser, 2000). This concept of outsourcing is based on the proposition that for a range of activities it is possible for a firm to reduce its overall costs by hiring in a service rather than performing it themselves. This model assumes that through inter-firm specialisation efficiencies of sale and scope will be produced by having each firm focus on areas where they have the highest competence. It also assumes that companies will be willing to make relation-specific investments in order to capture these productivity gains (Dyer, 1997).

According to Besanko et al. (2007) economies of scale are achieved when the average cost declines as output increases to an optimum level referred to as the minimum effective scale. In terms of an outsourced function the units to be examined will be individual power plant O&M projects. These economies are expected to exist when the indivisible fixed costs associated with providing services can be spread across more projects. The concept of economies of scale increasing with specialisation is also discussed by Jacobides and Winter. They observe that the “economic selection process of profit-driven growth implies that the scale of the most successful firms, or successful vertical units of firms, will increase – in many cases dramatically. To the extent that specialised firms have superior productive capabilities, selection will soon push for greater specialisation.” (Jacobides and Winter, 2005, p401).

In addition to the gains possible from economies of scale, Besanko, et al (2007) also discusses the effects of economies of scope and economies of learning that also influence outsourcing costs. Economies of scope exist when a firm decreases its costs for production of one product by the co-production of other products. Sometimes referred to as leveraging competencies, this occurs when the products are related in a way that allows the production of one to reduce the cost of the other. In the case of O&M providers, leveraging exists when the company supplies both O&M services and other related products. Examples could include the companies that develop gas turbine, steam turbine, and generator parts and services as a separate business offering. The mutual development of knowledge and competences from these activities lowers the input cost for the O&M services. Economies of learning are accrued due to the principles of the learning curve where cost advantages flow from the accumulation of experience and knowledge. With the repetition of tasks learning rate increases and results in improved performance, reduced mistakes and increased productivity. The degree of learning curve benefit can be expressed in terms of the slope of the curve. Normally this slope is determined for a production process by calculating how much the average costs decline when the cumulative production doubles. In production examples slopes have been estimated for hundreds of products with a median slope at about .80 implying that for a typical firm the doubling the cumulative output reduces the unit cost by approximately 20% (Besanko, et al., 2007).
Another, often hidden, type of costs associated with vertical integration is the decreasing efficiencies that result from the internal impacts of agency and influence. Agency costs are those that result when managers and workers knowingly do not act in the best interest of their firms through slack efforts as well as the firm’s measures to deter these activities (Besanko, et al., 2007). Such costs are incurred as individuals within an organisation use less than optimal means in performing their activities either to make it easier for themselves or because they are not faced with any competitive pressure. Influence costs are those that result from managers exert influence in order to achieve a better allocation of resources than their department may need to be optimal.

Offsetting these potential outsourcing gains are transactional costs that a firm may be faced with by virtue of its contractual relationship with an outsourcing supplier. According to Dyer (1997) these transactional costs can be decomposed further into four separate costs:

1. Search costs that include the cost of gathering information to identify and evaluate potential suppliers.
2. Contracting costs that includes costs associated with negotiating, writing agreements and legal fees.
3. Monitoring costs that include all the aspects of monitoring required ensuring that the parties fulfil their obligations.
4. Enforcement costs that include all costs associated with ex-post bargaining and sanctioning when the partner does not fulfil its obligation.

Oliver Williamson suggested that key contributing factors related to these costs are asset specificity, uncertainty and frequency (Williamson, 2008). Asset specificity refers to investments that one or both parties make to facilitate the transaction, which cannot be used in a different way. The larger the investment in specific assets the more tightly linked the parties are to the associated transactional exchanges. In the case of O&M outsourcing these might include investments in capabilities, tools, and processes that are specifically connected to a contract, and on which the customer is dependent. Uncertainties are the aspects of disruption that would cause the parties in the contract to have to adapt or change conditions resulting in ambiguity regarding the details and performance required after a time. Frequency involves the number of transactions involved in the market. The more infrequent the transactions the less subject to market forces that they will be.

The concept proposed by Williamson is that transactional costs will increase with increases in asset specificity or uncertainty or a decrease in frequency because of actions of human actors who have a limited ability to process all information regarding aspects of the arrangements, what he refers to as bounded rationality, and a desire to maximise their benefits through cognitive self interest (Williamson, 2008). This leads to opportunism and increased costs against which the contracting firms will be need to develop safeguards such as contracts with sanctions, monitoring and controlling processes, all of which add considerably to the costs and define the relationship
between the parties. According to McIvor (2000, p. 23) “the central theme of transaction costs theory is that the properties of the transaction determine the governance structure”, which indicates that outsourcing arrangements that are asset specific, have high uncertainty and a low number of transactions will involve higher transactional costs. It should be noted that while most transactional cost writers acknowledge these potential cost drivers they also argue that a company should outsource activities if it would result in lower investments and lower unit costs (Williamson, 1985, 2008 and McIvor, 2000).

An alternative concept has been proposed by Jeffery Dyer wherein he contends that transaction costs can be significantly reduced by using alternate safeguards to control opportunism, as is done by Japanese companies (Dyer, 1997). This suggests that transactional costs may be reduced depending on the type of contract, the congruency of the incentives, the information that is shared and the trust that exists within the alliance. Figure 3 illustrates this concept wherein the overall transactional value is related to several relationship specific components. In a similar vein Jacobides and Winter state that “Transaction costs themselves are not fully exogenous; their magnitude depends on the conscious action undertaken by firms. If industry participants stand to benefit from transaction cost reduction they will actively try to reduce them” (Jacobides and Winter, 2005, p396). This principle holds a relationship can be developed wherein both parties gain from reducing transactional and this will result in these costs decreasing as a proportion of the total costs. Jacobides and Winter point out that with close alliances capable of sustaining these low transaction costs there may be other costs of cooperation driven by joint task complexity and inter-partner diversity that also need to be considered in the total outsourcing cost equation.

![Figure 3: A Model for inter-firm collaboration (Dyer, 1997, p.551)](image)

There is no definitive method for the calculation of outsourcing costs compared to benefit and each company has its own unique internal structures and costs, contracting style and capabilities. What is clear is that there are both potential rewards and risks associated with the costs associated with outsourcing. These costs are linked with both the type of contractual relationships held with the supplier and the amount of outsourcing done and therefore are relevant to the decision process proposed in this paper.
1.4.2 **Strategic Outsourcing**

Though costs are always important, researchers contend that they cannot be the only standard on which to base an outsourcing decision. To maximise their competitive advantage firms should focus on capabilities and competences as well. Many writers who support the resourced based view of business propose that firms develop their own core competences and look to outsource much of what is not core to create leverage. This concept is often described as strategic outsourcing which has been defined by Holcomb and Hitt (2007) as “the organizing arrangement that emerges when firms rely on intermediate markets to provide specialized capabilities that supplement existing capabilities deployed along the firm’s value chain”.

In their article, Strategic Outsourcing, Quinn and Hilmer (1994) emphasise that a firm can use outsourcing to leverage their own resources by allowing the company to focus on a few well-selected core competencies allowing them to be especially competitive and add the highest value to their customers. Core competencies can be described as those activities that they do better and cheaper than its rivals (Gottfredson, Puryear, Phillips, 2005). Many developers of advance technology power plants begin projects without having the competences needed for the engineering, operations and maintenance or they build facilities because their main business is in energy trading and management, or because they have a particular expertise in project development. Even in cases where the developer is an existing utility it may only have expertise with conventional plants and do not have the expertise with GTCC technology. In all these cases the developer may sub-optimise its potential by using part of its finite resource to develop O&M skills. According to Quin and Hilmer (1994) such developers may suffer because by “trying to excel in too many functions they are unable to mach the performance of more focused competitors or suppliers”.

In their paper examining the co-evolution of capabilities and transaction costs Jacobides and Winter (2005) examine the complex interaction of transactional costs with capabilities that impact the vertical scope of companies within an industry. They contend that the vertical integration or disintegration of firms within an industry is impacted not only by costs but also by the capabilities of firms along the value chain and whether it is more advantageous for a firm to develop internal capabilities or seek these from the market. When the capabilities between the upstream and downstream components of the firm are weakly correlated, as is the case when the different parts of the value chain are built on different knowledge bases, there is a strong tendency to specialise to capture efficiencies. With specialisation it is often difficult for one firm to be equally good in both segments and therefore it may be an advantage to outsource (Jacobides and Winter, 2005).

In the generation business the core competences required for being successful in energy management and sales are quite different from those required to manage the physical asset life-cycle. Not all companies are willing to make the large investments in the development of competencies in both functional areas and may look to outsource some portions of the asset management. A certain amount of care should be taken because, as Gottfredson, Puryear and Phillips (2005) point out; migrating from a
vertically integrated company to a specialised provider of a single function is not a winning strategy for everyone. Some utilities may contain internal departments that have all of the tools and capabilities to be have a sufficient level of specialisation in asset management to be considered best in class while at the same time being able to support other expertise in other aspects of business management. Other more specialised energy companies will likely have a more difficulty to support this duality.

Gottfredson, Puryear and Phillips (2005) go on to explore the relationship between core competence, transaction costs and capabilities in determining what areas firms should consider as potentials for outsourcing. In their opinion the first step in the process is for the firm to decide first what parts of its business are truly core to its long-term success and where it has a special advantage, what they term the “core of the core”, and what other functions are not. The functions that do not fit into this core are then evaluated to see if there are advantages to outsource or keep, while the core is strengthened and leveraged. To determine what can be outsourced these authors provide a model wherein a firm can map its functions relative to the propriety and whether they were common enough in the market to allow economies of scale development externally. This mapping concept is illustrated diagrammatically in Figure 4 where the vertical axis provides a measurement of how proprietary the functional knowledge and ability are within the organisation and the horizontal axis providing a measurement of how common this functional ability is within the industry. The bottom left corner represents the core of the core for a business where it has a unique position and a fully proprietary profit model; it is here where they can best focus their efforts. On the other end of the spectrum in the top right corner are non-proprietary and readily available functions that should always be considered for outsourcing. Between these extremes are a large number of other areas that could be considered depending on other factors in the decision model.

![Figure 4: What to outsource (Gottfredson, Puryear and Phillips, 2005, p 138)](image_url)

To support the decision Gottfredson, Puryear and Phillips (2005) also provide a concept for the determination outsourcing versus in-sourcing options dependent on the company’s capabilities and relative transactional costs. Figure 5 illustrates this concept with the vertical axis measuring the capability or ability to perform the task with the
horizontal axis measuring the firm’s average transactional cost. In this model the authors suggest that when the capacity is insufficient the firm should always consider sourcing in order to increase capabilities even if there is a cost penalty, whereas high capability should only be considered core if the capacities are high and the transactional costs below the industry average.

Figure 5: Strength of capabilities related to costs (Gottfredson, Puryear and Phillips, 2005, p138)

The combination of the two matrices developed by Gottfredson, Puryear and Phillips provides asset owners with some guidance regarding how to examine their own functions and capabilities in regards to the outsourcing question so as to focus analysis. These models raise some significant strategic issues that should be included in the full framework of a decision process.

1.4.3 Risk Reduction

Risk management encompasses many aspects including financial, commercial, physical, environmental health and safety concerns. Risk has been described in many ways but perhaps the simplest and most apt definitions of risk are: “the possibility of suffering a harmful event” (Sharp et al., 2009), or “the hazard to which we are exposed due to uncertainty” (Pereira, McCoy and Merrill, 2000). These descriptions imply that the measurement of risk is a calculation of the probability of an event happening multiplied by the impact of consequences of such an event. Risk is present in all real world applications and the object of risk management is to either reduce or limit the consequence of the event and/or the probability of the event happening.

Asset owners will develop plans to reduce the probability of occurrence through engineering methods, quality systems, the acquisition of technical skills, and knowledge development. They will aim to reduce the consequences of risk through various mitigation methods including energy contracting, financial hedging, insurance and risk transfer to suppliers. Often the use of O&M service providers in long-term service agreements is considered as one of a number of methods to reduce, mitigate and share risks (Grace, 2005).
Dale Grace identifies long-term service agreements (LTSA) as a component of risk management adopted by many asset owners in order to mitigate the perceived risks associated with the introduction of advanced gas turbines in the early 1990s (Grace, 2005). This type of risk management, in Grace’s opinion, generally covers two main elements: cost volatility stabilisation and reduction through risk transfer.

Cost volatility has been a significant issue for generation asset owners because of the high technology nature of the components used within the gas turbine. As pointed out by Schimmoller (1998) O&M costs can have a disproportionate impact on the overall cost volatility. He states that even though this category “represents only about 15% of the total lifecycle costs⁵, O&M is subject to ± 20% volatility due to parts costs, parts lives, staffing requirements etc.”. To protect themselves, their lenders,⁶ and investors, asset owners can choose O&M contracts that fix the costs of planned and unplanned maintenance. In many contracts the fee charged by the supplier may be broken down into fixed and variable components so that there is a closer linkage to the actual operation of the facility.

As well as stabilising the operating costs O&M contracts are often perceived by both the suppliers and the buyers as a form of insurance coverage that allows some of the risks associated with unplanned failures to be transferred from the owner to the supplier. This risk transfer is achieved through contractual means wherein the service company agrees to take some portion of the risks associated with planned and unplanned maintenance as well as some penalty clauses connected to the plants performance key performance indicators (KPI). However, Grace points out this “risk reduction comes with a price tag” (Grace, 2005, p.1-4). The more risk that a supplier takes on, the greater the premium is for the supplier so it is important that the asset owner determine if this cost represents a reasonable offset compared with other mitigation methods such as insurance or internalisation of the risk. The party that is best able to manage the risk at the lowest cost should handle risk, and the cost of risk.

Buehler, Freeman and Hulme (2008) propose that all firms have different capacities to manage different types of risks. Those risks for which the firm has a strong competitive advantage in managing should be identified as their natural risks. If a firm possesses the ability to manage these natural risks at a cost much lower than others in an industry it is to their advantage to increase the amount of this risk they hold whenever they can obtain a higher value for it than the costs. It is also important, according to Buehler, Freeman and Hulme (2008) that risks held by a firm that are not natural should be reduced through trading or transfer. This concept of strategically identifying, valuing and trading risks to achieve the highest value is referred to by the authors as “owning the right risks”.

A third key element of risk management is the reduction of risk through improved asset management. Though this seems obvious, it is often neglected in risk assessment.

⁵ Schimmoller was writing in 1998 at a time when fuel prices had not experienced their rapid upswing, therefore the percentage of total lifecycle costs associated with O&M is higher than reported by subsequent authors.

⁶ In many cases power generation developments have been project financed, usually with significant leverage. To reduce their exposure lenders often require the borrowers to limit their cash flow risks as a way to ensure repayment of the debt and therefore often insist on some type of LTSA (Grace, 2005)
Such items as the supplier’s knowledge and expertise in maintenance and repair (Grace, 2005) as well as their fleet and component technical knowledge can reduce equipment breakdown, outage duration and other risks significantly for the same or lower costs. Buehler, Freeman and Hulme (2008, p. 104) state “Indeed, third-party providers can often draw on scale and knowledge economies to lower their cost base, giving them a natural advantage with respect to the risks involved”, implying that it should be possible for a specialised supplier to provide this risk mitigation at a lower total cost than the owner could do internally.

The best mix of internalised risk, risk trading to suppliers or third-part risk mitigation through insurance will be dependent both on the owner’s appetite for risk as well and their own structure, capabilities and capacity to self mitigate. Each firm will have their own risk profile but in general it can be assumed that larger more diversified owners with greater internal asset management capabilities will have a greater capacity to absorb risks, while smaller or special purpose companies will have more need for mitigation methods.

2 Research Objective

The objective of this research is to develop a decision model for asset owners to evaluate the potential benefits and risks associated with the strategic outsourcing of the various asset management options available to them based on their particular needs, competencies, capabilities and appetite for risk. The purpose of the model will be to provide both the asset owner and the O&M supplier with the ability to analyze the viability of strategic outsourcing given the projects circumstances and thereby customise their relationship for the optimum value creation. This methodology will allow for the evaluation using both mathematical calculations of measurable aspects as well as a conceptual evaluation of other less tangible aspects. It will include as a minimum the following components:

- An evaluation of the total internal costs associated with obtaining O&M services from the customer or supplier’s perspective and the impact of economies of scale on these costs.

- An evaluation of the impact of economies of scope in providing O&M services and the relative advantages, if any, of a specialist company in taking advantage of these economies when providing such services.

- The impact of transactional costs and agency costs related to external supply of services.

- An evaluation of the importance of key intangible aspects of the O&M service including but not limited to: competence retention, quality issues, environmental health and safety (EHS) performance, reputation issues and flexibility.
3 Decision Process

3.1 Decision Making

Asset owners considering the best options for long-term asset management will have a multitude of parameters to evaluate as part of the decision making process. They will need to decide whether to choose outsourcing as an option and if so what type of service would be appropriate. When dealing with this type of multi-attribute decision managers look to utilise some form of systematic approach to organise and evaluate the information and inputs to determine the best outcome. Forms of structured decision methods have been studied and described by theorists, philosophers and economists for hundreds if not thousands of years with the intent of assisting decision makers to achieve “if not optimal outcomes, at least acceptable ones” (Buchanan and O’Connell, 2006, January). It is not the intent of this paper to describe all of the possible decision making models available to managers but rather to review the process and propose a tool and techniques that can support managers in making the best possible decisions. Without some structure it is not uncommon for individual decision makers do as Mintzberg, Raisinghani and Théorêt (1976) state “use a number of problem solving shortcuts ‘Satisficing’ instead of maximising, not looking too far ahead, reducing a complex environment to a series of simplified conceptual ‘models’”.

Decision theories are divided into two main classifications, normative and descriptive. Normative decision theory describes how rational people should make decisions and descriptive theory focuses on what people actually do when making decisions. In decision theory this distinction is often blurred and there can be ambiguity and confusion even within one theory (Hansson, 2005, p7). The distinctions, though debated between theorists, are not relevant in most modern corporate decisions. In the real world managers, while attempting to be rational and structured, are influenced by many internal and external factors that limit rationality. In their influential study from the early 1970s Mintzberg, Raisinghani and Théorêt found that empirical studies provided little evidence to support any prevailing normative views of decision making being used in business. More often a very descriptive model is prevalent where; “A more pragmatic rendition of this view sees the analyst presenting his factual analyses of the consequences of various alternatives to the manager who determines the value trade-offs in his head and thereby makes a choice” (Mintzberg, Raisinghani and Théorêt, 1976)

Optimal decisions are seldom made instantaneously and therefore are usually the result of a process in which the decision makers go through several phases or stages (Hansson, 2005, p9). Theorists such as John Dewey and Herbert Simon described these stages in terms of sequential steps (Hansson, 2005). For Dewey and Simon these steps included intelligence, design and finally choice. These models are useful for describing the steps in the process but did not match well with real world activities where steps are often made simultaneously, or are repeated or blocked due to internal or external forces. These deficiencies were addressed by the model developed by Mintzberg, Raisinghani and Théorêt (1976) in which the phases were described as non-sequential and iterative with several feedback loops and interrupts possible. In the
pictorial representation of this model shown in Figure 6 it is apparent that Simon’s three steps of intelligence, design and choice are replaced with the general stages of identification, development and selection, and within each of these stages there are sub-routines that may come into play, depending on the decision methodology used. Multiple feedbacks or repeating loops are used, should the initial action not result in an outcome that is acceptable for the next step.

![Figure 6: A general model of the strategic decision process (Mintzberg, Raisinghani and Théorêt, 1976, p266)](image)

The model gives a general overview of the many steps in the decision process. It was the opinion of Mintzberg, et al. that not all steps were always used, or considered necessary by managers, who often used experience and intuition rather than elaborate processes. Even though experience showed that managers were prone to skipping some steps, there are two essential aspects of any decision depicted along the central line of the model. The first is the recognition of need for a decision and the second is the evaluation of the alternative choices associated with the decision. Along side these two essential steps are other important sub-processes that should be undertaken for any important decisions. Following the recognition of a problem at point X1 the decision maker should perform the diagnosis subroutine that according to Mintzberg and his colleagues is the single most important routine because it will be the primary determinant of the subsequent courses of action. It is in this routine that the main criteria for the decision are evaluated and the basis for the following valuation and decision processes are based.

After the diagnosis the decision maker also has the option of searching for ready-made solutions or designing new solutions that fit the requirements of the criteria. Screening is the process of selection, the elimination of inappropriate possibilities leaving the best possible alternatives to be then are evaluated in the next step, that of the evaluation and choice routines.
It is in the next areas of evaluation and choice where decision theorists have been especially active in the production of a large amount of literature and where many different possible methods of evaluation. Minzberg and his colleagues found this curious because in many of the real world examples that they studied this routine was far less important than the diagnosis and design phases (Mintzberg, Raisinghani and Théorêt, 1976, p257). However, as Hansson points out this may not be a fair assertion as it is in the evaluation-choice routine where the whole process becomes a decision process (Hansson, 2005, p12).

In decision theory it is generally accepted that the object of the evaluation-choice routine within the process is to choose the best option within a situation wherein the decision process involves both risk and opportunity possibilities. The measure of “best” involves establishing a measurement of the amount of benefit that the decision maker gains. This benefit is often referred to using a numerical representation known as the utility (Hansson, 2005, p21). The utility of an outcome may be related to monetary results, human happiness, reduction of risk or any other criteria to which a decision maker attributes value. The process of assigning a utility value allows decision makers, using this process, to reduce many types of attributes to a single numeric system for further evaluation. Normally this evaluation will involve weighting criteria as to its importance to compare against each alternative to create a weighted utility comparison.

This method appears simple and straightforward, but it does present several difficulties that can make it far from easy to apply. The first such difficulty is the determination of the weighting and utility measurements across criteria or alternatives are not homogenous in their measurement scales or comparable attributes. There is considerable complexity involved with establishing the evaluations, and weighting methods required for a multi-attribute utility theory (MAUT) model using both tangible and intangible elements. This often forces managers to either use only primarily subjective assessments for scoring or to avoid performing any detailed evaluation; instead relying on “gut feeling” to make a decision. The former response may not significantly impair the quality of the final decision as decision makers often have a strong understanding of the issues and hence are able to form sound judgments. The latter response on the other hand carries a higher risk as the lack of structure and methodology can result in insufficient deliberation and one that is more prone to organisational and political bargaining that could result in sub-optimal solutions. What is required is a methodology that allows a logical interpretation of multiple attributes and criteria without creating excessive complexity. The following section describes one such process known as the Analytic Hierarchy Process (AHP) that has the potential to provide decision makers with the desired outcomes.

3.2 The Analytical Hierarchy Process

The decision theorist Thomas L. Saaty developed AHP in the early 1970s7 partly due to his frustration with the apparent lack of an approach to decision-making that could be simultaneously systematic and straightforward for use by general decision practitioners

(Forman and Gass, 2001). The result was the development of a process that simplified the way decision makers break down, synthesise and makes decisions regarding complex multi-attribute choices.

The AHP has three principles as its base. The first is the principle of constructing hierarchies, the second is the principle of establishing priorities and the third is the principle of logical consistency (Saaty, 2001, p17).

3.2.1 Constructing Hierarchies

The construction of hierarchies refers to the decomposition of complex decisions into main criteria and homogenous clusters (Saaty, 2001). The concept is that complex systems can best be understood by structuring the elements that form the system into a hierarchy made up of its constituent elements. Saaty believes this to be a fundamental method of the organisation used by human minds as it comes natural to most people to group constituent elements of a system in order to make sense of the whole.

To build a functional hierarchy of a complex problem, as is required for decision making, each level of the hierarchy be occupied by items of similar importance. The top level is the focus or goal of the problem. This is the only element at the top level and is used to describe the overall objective of the process. In the question being examined the overall goal can be described as the provision of optimal asset management for the facility. To determine what constitutes this overall goal the next step is to develop the main criteria that are important to the decision maker in respect to asset management. These main criteria then make up the second tier of the hierarchy and normally are limited to a reasonable number, Saaty recommends between five and nine (Saaty, 2001 p31). If the main criteria are in themselves complex, they too can be decomposed into their constituent elements at the next layer of the hierarchy. As each component of the hierarchy is compared against the others at the same level it is important to have the elements at the same level at a similar level of magnitude. At the lowest level of the hierarchy are placed the alternatives or choices. The items at this level are compared with each other in relation to the lowest levels of the hierarchy. A simple hierarchy as shown in Figure 7 demonstrates the relationship between the levels of a decision hierarchy.

![Figure 7: Simple Decision Hierarchy Example](image)
3.2.2 Establishing Priorities

The principle of priority setting in the AHP involves the utilisation of the human ability to “perceive relationships between things that are observed to compare pairs of similar things against certain criteria” (Saaty, 2001, p17). In the AHP comparing aspects of the criteria or alternatives against each, in pairwise comparisons, is used to determine relative value or utility in relation to a higher level criteria or goal. This process uses judgments that are derived from logical thinking, feelings developed from informed opinion and/or some other comparative analytical method. A mathematical process is used to synthesise these comparisons as an efficient method of determining a solution as opposed to using gut feeling or intuition. In Saaty’s AHP model the pairwise comparisons are performed by making judgments against the next higher level in the hierarchy using a scale of absolute numbers from one to nine, where one represents no difference and nine represents an extremely important difference. According to Saaty (1986, 1994, 2001) this scale is adequate for analysis against reasonably homogenous comparisons while staying within a single order of magnitude.

As well as providing a simple methodology for making judgments about the relative value of alternatives, this method of pairwise comparisons also allows the evaluation of both tangible and intangible aspects of criteria within a model. The fundamental scale developed by Saaty for this purpose is provided in Appendix 1.

To convert the pairwise comparisons to a meaningful weighted result Saaty developed a model using a matrix methodology. With a matrix it is possible for additional information to be obtained through the evaluation of all possible comparisons and allow for the development of priorities based on dominance between aspects. Through normalisation of the matrix the main priority vector for each row can be determined, this vector represents the weighting that each criterion, or alternative, has compared to the next higher layer in the hierarchy. This priority vector is also referred to as the eigenvalue for the criterion. The matrix also provides for testing of consistencies and sensitivity of the overall priorities that can result from changes in judgment. A detailed description of the creation and synthesis of pairwise comparisons is provided as Appendix 1 of this report.

3.2.3 Consistency

In decision theory rational consistency is an important concept that demonstrates the coherence of relationships between ideas or criteria. There are two main principles associated with consistency in decision-making, the first is completeness and the second is transitivity (Hansson, 2005).

Completeness is a property of a group of elements that refer to the relationship between the elements and to their domain (Hansson, 2005). For example it would be possible to have a preference between a motorcycle and a car when the domain for this choice is vehicular travel but to be complete it is normally assumed that a person can compare any types of travel. Saaty simplifies this requirement somewhat by stating that it is only necessary that similar ideas or objects are grouped according to homogeneity and relevance (Saaty, 2001, p18).
Internal consistency of decisions in utility theory is closely related to one of the key axioms of these normative decision methodologies, the concept of transitiveness. Transitiveness in mathematics refers to relationship between elements that states that whenever an element bears a specific relation to a second that in turn bears this same relation to a third, the first element bears this relation to the third identity and equality are transitive relations. In mathematical form this can be shown in the relationships between elements as follows:

- If A>B, then B<A
- If A>B, and B>C then A>C.

This ideal consistency level of consistency would greatly simplify most decisions but it is not always possible or reasonable for the human mind to be completely consistent in all judgments. Rather than insisting on strict transitiveness Saaty only states that “the intensities of relations among ideas or objects based on a particular criterion justify each other in some logical way” (Saaty, 2001, p18).

Even though Saaty does not insist on strict transitivity he does acknowledge without a high degree of consistency decisions based on judgments may appear to be random and therefore not reliable. His solution was to develop a method to measure the amount of inconsistency that exists through the calculation of what he termed the Consistency Index (CI) (Saaty, 1986, 1994, 2001). He proposed that in any consistent matrix the Principle Eigen value (\(\lambda_{\text{max}}\)) will always be equal to or greater than the number size of the matrix (n) and that a CI could be derived using the following formula.

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]

In a perfectly consistent matrix the CI would be equal to zero\(^8\) and any greater result would indicate some level of inconsistency, but the question remains on how large an inconsistency can be to make any material difference. To address this question Saaty proposed that the results from this calculation could be compared against a scale derived from the results obtained from many randomly generated matrixes of various sizes resulting in a Consistency Ratio (CR). Saaty proposed that a good consistency would be one where the resulting CR would be a maximum of 10%. If the CR is above this value the judgments should be re-examined and adjusted.

3.2.4 Consolidating the AHP Model

The previous sections describe how to derive the priority and estimate the consistency of a single matrix within the decision hierarchy. However, to determine the overall preference of alternatives relative to the main goal or focus it is necessary to synthesize the results of all of the pairwise comparisons. This process involves performing pairwise comparisons at each level of the hierarchy and using the higher-level priority vector

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8 In a consistent three by three matrix \(\lambda_{\text{max}} = 3\) and therefore the CI would be equal to zero
CI = \(\frac{3-3}{3-2}\) = 0
results to act as an adjusting weighting for the next lower level. This process is illustrated in Figure 8. In this table the adjusted weight for criteria C1-C3 is represented by their derived priority. The composite weighting for each alternative is derived from summing the adjusted weights of its priority related to each criterion.

\[ CW_{Ai} = (0.2449 \times 0.6986) + (0.4143 \times 0.2370) + (0.3295 \times 0.0643) \]

<table>
<thead>
<tr>
<th>Adjusted Weight</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>Composite Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 Alternative 1</td>
<td>0.2449</td>
<td>0.4143</td>
<td>0.3295</td>
<td>0.2905</td>
</tr>
<tr>
<td>A2 Alternative 2</td>
<td>0.0649</td>
<td>0.1350</td>
<td>0.1037</td>
<td>0.0840</td>
</tr>
<tr>
<td>A3 Alternative 3</td>
<td>0.1297</td>
<td>0.1350</td>
<td>0.1054</td>
<td>0.1348</td>
</tr>
<tr>
<td>A4 Alternative 4</td>
<td>0.1225</td>
<td>0.0743</td>
<td>0.0518</td>
<td>0.1085</td>
</tr>
<tr>
<td>A5 Alternative 5</td>
<td>0.4380</td>
<td>0.2414</td>
<td>0.3205</td>
<td>0.3845</td>
</tr>
</tbody>
</table>

Figure 8: Overall Composite Weight of Alternatives

The resultant composite weighting represents the preferential value of each alternative related to the level above the criteria in the hierarchy that in this simple case would be against the overall goal or focus. After completing the composite weighting for the entire hierarchy and determining the preference it is possible to calculate the overall consistency.

Using this method it is possible to configure hierarchal decision model for complex multi-attribute problems and to produce both a priority for the alternatives as well as an overall assessment of the consistency of the judgments applied. This consolidated model is developed in nine key steps that can be mapped to the three decision stages defined by Mintzberg et al. as shown in Figure 9.

Figure 9: AHP Decision Model Steps

3.3 Concerns and Limitations of AHP Method

According to researchers such as Forman and Gass (2001) AHP methodology can be used for many purposes including decision choices, assigning priorities, resource allocation, quality control, and benchmarking. They list 26 prominent firms that utilise
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this method extensively for many key strategic and decision purpose, especially when performed with the aid of commercially available software such as Expert Choice ®. In spite of this popularity other decision theorists, primarily those who are proponents of expected utility models of decision making, do not universally accept the method and theory.

The main criticisms of the AHP concern its measurement scale, rank reversal and transitivity of preferences (Gass, 2005). According to Dyer, et al. (1990) the first of these concerns is that the AHP model relies on pairwise comparisons between criteria or alternatives using only Saaty’s 1-9 fundamental scale and that these choices can be considered purely arbitrary or abstract because they lack a clear reference point resulting in a flawed outcome. Dyer’s criticism of the pairwise comparison is based on the fact that the decision maker has to arbitrarily choose a zero point. In the hypothetical question “how much better is A₁ compared with A₂” he proposes that a decision maker would answer “relative to what?” as a reflection of the individual not having the ability to ascertain a comparison without having a clear baseline without additional information or a skilled facilitator. Dyer also argues that the fundamental scale from 1-9 is too narrow and incapable of fully covering the differences that could be present in decision choices. Regarding the use of scales the advocates of AHP argue that in most cases the use of pairwise comparisons with the fundamental scale produces results that are no less arbitrary or abstract than are produced in traditional utility methods. The main reason is that to synthesise a result from a hierarchy only ratio numbers can be used because the priorities must be multiplied with the priorities at the next level (Foreman and Gass, 2001). As many attributes are measured in ordinal or interval scales it is necessary in any case to convert these to some type of arbitrary ratio scale to be useful. In regards to the issue of the fundamental scale being too narrow, Saaty argues that this scale represents approximations of the value perceived by the decision maker, which is more useful than even being able to use absolute numbers (Saaty, 2001). Absolute numbers, if available, do not in themselves constitute the benefit that the decision maker perceives because rankings are often not on a linear scale. For example a business may rate a one million dollar project as being many times more significant than a half million dollar one but only rate a two million dollar project marginally more significant than a one and a half million dollar project.

Other concerns are raised by decision theorists regarding AHP for its non-conformance to two key axioms of expected utility theory, namely transitivity and rank reversal. Both of these axioms can be broken within AHP (Foreman and Gass, 2001, Smith and von Winterfelt, 2004) which raises concerns amongst some theorists as to the methods reliability.

As described in an earlier section transitivity implies consistency between choices is always maintained (A>B, B>C but C>A). This is a fundamental axiom of utility decision theory, which holds that without transitivity decisions will be flawed, and appears random. For example if a person says that for a choice in car colours he prefers red to blue, blue to green but green to red, he would not be able to make a decision if faced with three cars that were only differentiated by colour. In AHP there is no firm axiom regarding transitivity and in making pairwise judgements such choices would be allowed.
However, the model does test for inconsistency and any consistency ratio above 10% is considered questionable.

The rank reversal axiom states that it should not be possible to reverse the ranking of the priorities of dominant choices by the addition or removal of non-dominant or irrelevant choices. In classic utility theory such reversals could not be possible because as implied a new choice with low utility value would not change the ranking of the significant choices as the utility benefit of these dominant choices are not changed. With AHP options are not measured using absolute numbers on a utility scale and instead are compared with each other using relative measurements so the addition or removal of any criteria will necessitate additional pairwise judgments of this criterion against all other criteria. It is possible that in this exercise a change in the order of dominant criteria may result due to the impact of lower rated ones. Though this may not seem logical at a theoretical level Saaty and his proponents argue that such reversals do happen in real life because of factors such as synergies and the impacts of close substitutes (Saaty, 1994, 2001, Foreman and Gass, 2001). As AHP is a descriptive decision theory (Saaty, 1994, p445) this possibility of role reversal is accepted because of its occurrence in normal human decision making.

Another concern regarding the use of AHP is the number of pairwise comparisons that are required if the complexity of the model is large. Each criterion must be compared with every other criterion against each object at the next higher level of the hierarchy so that the number of judgments can become quite large. For each comparison matrix the total number of comparisons can be calculated with the following formula, where $n$ is equal to the number of objects in the comparison.

$$\text{Number of Comparisons} = \frac{n(n-1)}{2}$$

With this calculation we can determine that even for a relatively simple hierarchy such as the example in Figure 7 there will be a total of 24 separate choices. The number of choices and levels in the hierarchy will add richness and more detail to the decision process but more detail will rapidly expand the size of the model. A decision maker therefore should carefully review an AHP model to ensure that the choices recommended are significant and relative. In most cases because of the number of comparisons and the subsequent calculations it is necessary to use computer software to obtain results. A decision maker can choose to develop such a model using readily available spreadsheet programs or commercially available AHP software such as Expert Choice® or Super Decisions® in order to simplify the decision process. In this paper the author has chosen to develop a Microsoft Excel® workbook specific to the evaluations to be done. This model was validated through a comparison with a trial version of Expert Choice®, the results of this validation are given in Appendix 3.
4 Industry Drivers

4.1 Power Station Asset Management

The fundamental goal of any business is to produce satisfying levels of returns for their owners in a sustainable fashion over the assets lifecycle. This purpose can be most successfully achieved through effective asset management, which in the most general sense can be defined as the group of practices involved with achieving the optimum value from an asset.

An asset can be any item of economic value owned by an individual or corporation. Some examples are cash, securities, accounts receivable, inventory, office equipment, plant and equipment, real estate or other property or even abstract items such as brand value or goodwill (if these can be converted to cash). The long-term physical assets, particularly plant and equipment, and how these assets can be managed to produce the highest value for their owners are of special interest in this paper.

Physical assets management is achieved through a balance between investment and net value of the revenue/cost stream over the life of the asset. As stated by Wei Zhu (2004, p.30), “The asset value of a power plant can be regarded as the total profit (revenue less cost) of generating power over its life time”. To achieve optimal return a large number of influences on investments, revenues, and costs must be understood and managed. Figure 10 illustrates the features of asset management that impact both revenues and costs for a typical power station. This model is based on the Master Economic / Technical Map developed by EPRI as part of their Risk-Informed Asset Management (RIAM) program (Sliter, 2002), but has been adapted by the author based on 25 years of personal experience to show more fully the key aspects of a GTCC power plant. This map demonstrates how physical activities together with internal and external processes interact to impact both the revenue and cost streams of the project. It is important for asset managers to be aware of the close linkages within this map. For example, the revenue stream is highly dependent on the availability and capacity of the generating unit, and this in turn is highly influenced by the planned and unplanned maintenance activities. Likewise, equipment failures impact both unplanned outages and risk costs.

It is also important to note that only some of these items can be controlled or managed after the plant is designed and built and are of special interest in regards to O&M management decisions. However, some aspects, such as the type of plant, equipment installed, location, design capacity and financial and corporate structures are committed to prior to construction and therefore become fixed. Though these fixed aspects are critical asset management decisions, with long-term consequences for the project, once they are made and implemented there is very little optimisation that can be achieved. Some exceptions may be improvements of the financials through optimising debt or equity financing terms, capital improvements of existing equipment and possibly adaptation of the project ownership.
All of the remaining aspects of the asset management map are either wholly or partly controllable after the start-up of the facility and therefore become the main components of power plant asset management. These then become the key physical asset industry drivers and the critical criteria for asset owners to manage well to achieve the overall goal of maximising the value obtained from the asset.

4.1.1 Lifecycle Costs

The lifecycle costs of owning a physical asset include the total of all of the cash flows that can be directly attributed to the on-going operation of the facility and cover the outlays from the inception of the project to its eventual retirement and salvage. These costs all are affected in some way by the O&M management of the plant, except financing costs, which normally are independent.

Fuel

For thermal power plants\(^9\) fuel costs will be the largest single cost item for the business and have the greatest impact on the long-term success of the project. This is most true of gas fired power plants where even with highly efficient combined cycle plants the fuel bill can represent well over 60% of the total life cycle costs of the plant (Grace, 2008).

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\(^9\) Thermal power plants are generally those using fuels such as coal, oil or natural gas. Nuclear generation is also a thermal process but is normally separately classified.
In spite the fact that fuel cost is an operating expense it is convenient to deal with fuel separately from other OPEX accounts for several reasons. The first reason is its importance as demonstrated in Figure 11. A one percent change in fuel cost or efficiency can create a change to the projects performance of an order of magnitude greater than a one percent change in O&M cost. The second reason is the close linkage fuel costs have to the initial facility design. There are normally limits to the possible improvements that can be made to a plant design without major capital investments in upgrades. The third unique feature is the connection to the revenue generation making it the primary variable cost of production of electricity. The marginal cost of electricity per unit is almost completely dependent on the fuel input per unit and therefore it becomes a focal point for managers in determining the best production strategies.

All these features make the control of fuel costs dependent on the corporate activities of: electricity trading, fuel procurement and trading, dispatch planning, and major investment decisions. These are core management responsibilities for the asset owner and are difficult to contract out. In most cases they are considered part of the core competencies and areas of competitive advantage for the asset owner.

Operating Expenses (OPEX)

In the context of this paper OPEX refers to all the costs associated with the ongoing operations of the power plant (excluding fuel) that are recognised in the year when the expense occurs and show up on the profit and loss statement of the business. This scope shall include costs that are incurred at the power plant and also any activities that are undertaken at the owner’s company headquarters or engineering units that together will make up the full cost of sustaining the facility. It is not uncommon for managers and decision makers who are evaluating the relative costs of internal provision of services to an outsourced solution to exclude back office departments and infrastructure that are borne by cost centres in their corporate offices.

In power plants the main drivers for OPEX are the operational and maintenance activities, all of the plant overheads and administration costs, direct human resource (HR) costs associated with the plant personnel and plant engineering costs. These costs
can be further segregated into fixed and variable costs. The fixed costs are those that do not change based on the amount of operation of the facility\textsuperscript{10} whereas the variable components are directly linked to either the running hours or the output of energy\textsuperscript{11}. The fixed costs are primarily due to the fixed labour costs of the facility and the supporting departments together with the overheads associated with operations, plant engineering and routine maintenance of the facility independent of the operational regime. The number of permanent staff at a power plant will depend on the technical configuration, location and operating regime of the plant and the maintenance strategy. Asset owners may also have different philosophies regarding the allocation of personnel between the plant and head office, and how much contract labour is used. This can make it difficult to compare facilities in terms of employee head count.

An increase in technical complexity will result in higher numbers of both on-site O&M personnel as well as support engineering. This complexity includes the technology used, for example F or G class gas turbines compared to E class\textsuperscript{12}, the number of machines, the auxiliary systems and fuel used. Where a single plant has a number of units, or the operating firm has many similar units under its control, there can be significant economies of scale and learning that can reduce some incremental staff number increases for each additional unit. To effectively control costs the asset owner will need to either have resources at the facility or have access to expertise across a broad range of equipment.

The location of the plant can significantly impact the staffing requirements for several reasons. The legal requirements for a plant will be different depending on the locale, and may affect operational costs in many ways, including required staff, environmental and safety compliance, and equipment inspection requirements. For example some jurisdictions have requirements for a minimum number of operators on shift. Environmental conditions can also impact fixed costs significantly through the effects of corrosion and contamination.

The largest of the variable costs for any GTCC plant is the planned maintenance of the major machines, especially the gas turbine. The gas turbines may account for over 50% percent of the non-fuel O&M costs for the facility (Grace, 2008) with the largest portion of these costs directly related to the components that are exposed to the high temperatures in the gas stream. Hot gas pass parts such as blades, vanes and combustor parts are in effect used up during operation due to the effects of fatigue and creep resulting from the extreme temperatures and number of starts respectively. In spite of their advanced alloy construction and complex cooling configuration these

\textsuperscript{10} Though most costs can be varied related to production, for example the lay-off of personnel during long outages, in this paper fixed costs are related to a shorter time frame so that items such as labour and overhead are considered fixed.

\textsuperscript{11} Modern combined cycle power stations are normally controlled to maintain temperatures as high as possible within the cycles for part load efficiency, so that the related variable maintenance costs are almost completely tied to running hours and cycles rather than units of output.

\textsuperscript{12} Letter classifications for gas turbines was originally associated with General Electric turbine nomenclature and signified a change in efficiency and output associated with increased firing temperatures. The classification has since been adopted to describe equipment from all OEMs. In general terms an E class turbine would be expected to have a firing temperature of 1070° C (1955° F) whereas an F class turbine would be approximately 1290° C (2350° F) while at the same time producing lower emissions (Grace, 2005).
components have a lifespan much shorter than the life of the plant. The owner or the
service provider must have sufficient knowledge and experience to be able to determine
when these critical components should be inspected, replaced, or refurbished in order to
contain costs while maintaining reliability. This is also true of the other main machines in
the plant.

The cost of a planned overhaul outage can run into the tens of millions of euros
depending on the machine size and type. Therefore the lifecycle planning for these
outages and parts replacement is critical to the success of the plant. Often referred to
as configuration management, this lifecycle planning function involves expert
engineering knowledge of the expected life of each component and the optimal
replacement regime necessary to obtain optimal costs without revenue damaging forced
outages. Because of its importance an asset owners will need to consider their own
internal capacity to perform this function as part of any outsourcing decision process.

The ability of the O&M supplier to properly scope and plan such planned preventive
maintenance activities, together with a well organised and thought through maintenance
strategy with routine predictive and preventive maintenance plan, can greatly reduce the
occurrences of machine breakdowns, unplanned maintenance and forced outages.
Unplanned maintenance may be caused by early wear out of components, failure of
components, inadequate preventative maintenance or failure to replace or repair parts at
the necessary intervals. A well-planned maintenance program based on preventive and
predictive methodology is widely regarded as being more effective and less costly than a
program that relies on a breakdown repair methodology (Campbell, 1995 and
Chambers, 2002). Based on their own research EPRI have established a overview
of the main cost drivers of O&M for a GTCC plant as shown in Figure 12.

\[ \text{Figure 12: Major Cost Components of Operations and Maintenance (Grace, 2008, p6)} \]

**Capital Expenses (CAPEX)**

For the purposes of this paper capital expenses will be considered the cash outlays
used for betterments of the facility, or for extraordinary repairs after the completion of
the power plant. The initial investment for the plant is excluded not because it lacks
importance but rather because of the limited influence the O&M service supplier can
have over the initial decisions. There are, however, many ways where the O&M supplier can influence or be influenced by the on-going capital investments associated with the facility. Power plants are capital-intensive projects that will have a lifespan of between 25 and 40 years. It is extremely likely that over this lifespan changes in needs and technology will necessitate the need for additional investments to be made for the plant to maintain its original purpose or be improved to meet changing performance requirements. Ideally the O&M supplier, whether insourced or outsourced, will have the capacity to support the owner in the identification and implementation of these investments.

The amount of these CAPEX expenditures can be substantial and are invariably subject to detailed review and evaluation. An OPEX has to be made in order to keep the plant operating in its present form; whereas, CAPEX outlays can have alternatives, be delayed or not made at all depending on the strategy needs of the owners. In the past when power generation was controlled primarily by regulated utilities CAPEX added value to the company due to the principle of regulated rate of return on equity (Berk, 1995) but deregulation has resulted in a tendency for generation companies to scrutinise CAPEX projects in detail and select only those that provide high value. The main categories of investment are:

- Performance improvements including upgrading of components to produce more power, improve efficiency, improve operational flexibility\textsuperscript{13} or improve plant control.
- Life extension or extraordinary repairs to equipment such as the replacement of whole sections of a heat recovery steam generator (HRSG), infrastructure repair or improvement or replacement of obsolete components.
- Strategic spares holdings for components that have very long lead-time and therefore are kept as a form of insurance against failures. Strategic spares items such as complete generator rotors or spare transformers may be purchased to reduce potential future losses based on a risk calculation but may never be used.

CAPEX projects will be evaluated not only in terms of their own return on investment but also in comparison to other investments that the company may have the opportunity to make at the same time. If funds are limited then only projects with the best net present value (NPV) will be selected or sometimes the asset owner will use alternative methods to achieve the same result. Capital improvements can be packaged with O&M service contracts so that the cost is amortised into the fee or a lease arrangement. The capacity of an external supplier to handle this type of deal may be considered by some asset owners beneficial and therefore be relative to the outsourcing decision.

\textsuperscript{13} Plant flexibility includes the ability to run at low load, provide load following or grid stability services, fast start up and other services that allow the plant to benefit from a deregulated electrical ancillary market.
**Asset Value Retention**

Asset value pertains not to the book value of the plant at any point in time but rather the amount an owner could achieve from it should it be sold at any point in time or, its salvage value on retirement. Though value retention is closely related to good optimal use of both operating and capital over the life of the plant it also includes certain intangible characteristics.

The optimal use of operations funds over the year would include sound maintenance strategies that have allowed the assets to not only retain their functional ability but also to maintain its visual and structural integrity. There are certain components in any facility that, due to their design or lifecycle, do not require extensive work within the period of an O&M contract to maintain their functional ability so that savings could be made in inspection without incurring immediate losses. High temperature flange bolting, cooling water piping, structural components and tie down bolting may continue to serve their purpose even if they are affected by chemical corrosion, fatigue or wear to the point of failure. The failure to provide adequate maintenance would result in a saving in operating costs for a period of time but there would be a significant loss in asset value as an eventual replacement or refurbishment would be necessary, usually many times the cost preventive maintenance. Items considered cosmetic, such as painting and grounds keeping that provide important value retention for the facility may be deferred to reduce cost. The potential for value damaging maintenance and operations practices exist whenever there is a mismatch between the incentives of the O&M provider and the strategy of the owner. If the O&M supplier’s only motivation is to keep costs low then it is more likely that this mismatch will develop, however, if a more comprehensive contract is developed the short-term operating costs may increase but the overall lifecycle costs will be reduced. An asset management model as proposed by the British Standards Institute in PAS 55-1 (BSI, 2008) provides guidelines on which the owner and operator can build a plant specific plan.

Plant value can also be impacted in less tangible areas such as public opinion, company good will and brand integrity. If the plant is operated in such a way that environmental control, health and safety standards, human resource management or community relationships are not up to the expectation of the regulators or public it will be the owner, not the operator, who will suffer the greatest value loss. It is very important that the owner and operator have common goals and strategies in these areas.

**Risk Costs**

The risk of a project or business is often represented by the product of the total potential cost of an event or events and the probability of the event occurring. The problem with this simplistic representation is that it only accurately embodies the real exposure in cases where the firm has sufficient assets or capabilities to amalgamate its total risk profile across a broad portfolio. Without such capabilities the total potential liability for a firm is the total cost of the event, irrespective of the probability of occurrence. Without having other mitigation methods owners would normally need to make financial provisions adequate to cover these potential losses. Keeping risk provisions large
enough to cover major risks would cost a significant amount both in carrying costs and lost opportunities. For this reason all but the largest firms require other methods to mitigate and share the risk of their projects usually through a partial transfer to service suppliers or to third party insurers. This transfer of risk is never free, as insurers and service suppliers will charge a premium above their internal costs for accepting the risks. Though this cost may be significantly less than the alternative of carrying all the risks internally. Each firm will have its own circumstances and will need to carefully evaluate its profile and exposure to optimise these costs.

Before discussing how risks are mitigated and transferred it is advisable to review the main areas of risk that a GTCC plant faces.

- **Machinery breakdown** is one of the most common type of loss in the power industry (Brenner and Wassmer, 2009) and occurs when there is a sudden unexpected failure of one or more of the components in the plant. Some factors that impact this risk are high cost components with long lead times, cost volatility of parts primarily due to raw material costs but also availability, changes in operations parameters due to changing demand\(^{14}\), the quality of the parts and service used and the expertise and skills of the O&M engineers and staff.

- **Property risks** are another common type of risk that impacts all business. This covers such items as fire, flooding and earthquakes. The risks in this category can be either manmade or natural. They can be influenced by the design of the facility, its location and the control measures put into place to limit damage.

- **Revenue loss risks**, also known as business interruption, are related to the inability of the business to earn revenue from its normal activity. In the case of a power plant this would involve a failure to generate either fully or partially due an unexpected failure of a part of the plant. This impact is normally a consequence of either a machinery breakdown or property damage event but could also be the result of extended planned maintenance outages or poor planning.

- **Technical risks** include many items where the owner experiences unanticipated financial impacts. Some of these include: inability to maintain equipment due to lack of expertise resulting in high costs or poor availability, component obsolescence requiring early replacement, inability to operate equipment effectively resulting in unit trips, and inability to plan parts refurbishments or replacements optimally. The decline in skills required for operating and maintaining power plants is a significant technical risk in itself. Almost half of the utility’s workforce in developed markets is approaching retirement age, which will add to already severe shortages of skilled staff (Brenner and Wassmer, 2009).

\(^{14}\) Changes in the electrical market including the addition of new more efficient units and the difficult to predict wind and solar energy as resulted in many GTCC plants originally designed to operate on base load to change to cycling or two shifting operations. This type of operation can add significantly to stresses on the equipment and subsequent risks.
- O&M cost volatility that can result in cash flow and other financial risks. This volatility is primarily driven by the costs associated with hot gas parts but may also involve labour and service components.

- Financial risks associated with operating the business may be the consequence of other risk events such as equipment failure or property damage or the result of changing market conditions. An asset owner may be able to mitigate for the latter items but the market conditions are often outside of the control of the asset operator. While most of these risks are outside the scope of an O&M service the ability of the service provider to adapt to changing conditions will have an impact on the decision.

Asset owners have three primary options to manage these risks: avoidance, retention, and transfer (Grace, 2005). The first option is possible only through design and procurement phases of a project where there is the possibility of building in more redundant systems, using higher grades of materials, or keeping a large number of strategic spares. These measures are effective strategies, but at some level of coverage it becomes cost prohibitive.

The option of risk retention for an asset owner would involve the creation of internal provisions sufficient to cover a loss. This option is seldom used in isolation because only very large firms have the capacity to aggregate risks across a portfolio of assets to the extent that they can self insure for all events. However, retention of some of the risk is common, and in many cases unavoidable. For insurable risks, such as machinery breakdown, property damage and business interruption, owners can use some degree of risk retention through deductibles to reduce their annual costs for such insurance. The owner will have certain risks that cannot be insured, such as certain technology risks if the equipment is considered unproven, earnings loss risks due to electrical or fuel market conditions and other financial risks. For these risks there are some potential to transfer the risk or retain it and each business will need to determine the optimal mix for their circumstances.

The last option is to transfer the risk through insurance, financial contracts or the utilisation of some type of LTSA or O&M outsourcing with provisions for the supplier to take on part of the risk (Grace, 2005). Generally insurance is used for the bulk of the risks associated with machinery breakdown, property and business interruption losses. Transfer of risk to O&M service providers is also common and may cover parts of uninsurable risks through contractual transfer of responsibility for a portion of the equipment failure costs, and by the use of liquidated damages for loss of availability or performance. Where the O&M service provider is connected to the OEM for the equipment it may be possible to cover some technical risks associated with new technology that cannot be covered with standard insurance products. As with insurance companies, this risk transfer is never provided free of charge by the service provider. However, if the suppliers have a broad fleet to allow pooling of risks, and expert

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15 Financial risks, though important, are outside of the scope of this paper. Asset owners can use such methods as fixed price fuel contracts, power purchase agreements and hedging for risk reduction and transfer but these contracts seldom involve the O&M supplier directly.
knowledge of the detailed equipment risk, they may be able to offer this coverage for a fee lower than the owner’s internal risk cost.

4.1.2 Reliability, Availability and Maintainability Influence on Revenue

As important as lifecycle costs are to the success of a power project, savings on costs are of little value if the plant is unable to produce a revenue stream consistently and dependably. Electrical systems in developed countries are based on the concept of reliable delivery of energy to the end customer. Consumers are concerned with high costs for power, while at the same time plant owners, regulators, and utilities are looking to improve margins through cost optimisation. This leaves system operators with the task of balancing the requirements to have enough generation capacity on-line to cover the peak demand load at any time while not building into the system wasteful reserve capacity. In deregulated markets centralised control is largely removed and power producers can sell their power either through a pool market or through bilateral contracts. System operators in these situations need alternative methods to ensure that system security is maintained. These methods include the unbundling of energy, capacity and ancillary services, and using either mandatory grid rules or participant bidding to establish the needed volumes to set prices (Raineri, Rios and Schiele, 2006). This separation allows asset owners to make money by selling capacity and capability as well as energy.

Markets have developed for services such as voltage control, frequency regulation, system restoration and black-start capabilities. Each of these has the potential to provide additional value to power plants that are available and capable to provide the services. Often in these unbundled markets there are potentially heavy penalties for non-performance of the offered services. These negative impacts can include penalties issues by the system operator or regulatory bodies or the high cost of purchasing replacement services from a spot market to cover the difference created due to unavailability of a generating unit. The dependability of the units is therefore very important both to facilitate revenue generation and to protect against potentially financial penalties.

Liberalised markets, together with substantial amounts of inconsistent renewable generation16, have created a situation where part load operation, cycling and two shifting17 are becoming common. These operating modes can negatively impact reliability and availability of the plants due to the added mechanical stresses and added potential for human error. For a generation plant to produce optimal revenue it must be available and capable of producing the desired output at the right time to match the market or grid demand. This capacity is directly linked to the dependability of the plant that will be measured by its reliability, availability and maintainability (RAM). These popular terms define the key dependability elements associated with the operation of the power plant.

16 Renewable generation has poor predictability due to its dependence on climactic conditions, which can cause grid instability necessitating the need for more thermal and hydro units to operate at part load to supply grid support and reserve capacity.
17 Two shifting refers to the practice of shutting the unit completely off over night and restarting the next day to cover the peak.
Reliability is defined by Smith (1995) as the “probability that a device will satisfactorily perform a specified function for a specific period of time under given operating conditions” and the IEEE standard 762-2006\(^\text{18}\) defines reliability as the measures of the ability of generating units to perform their intended function. This implies that to be reliable a plant must have both a high probability of running at its specified capacity when required and can stay running as long as needed. The main factors affecting reliability of a generating unit uncontrolled and unplanned periods where capacity is curtailed or reduced through forced outages or deratings\(^\text{19}\). Units that are dispatched off line for economic or dispatch reasons are still fully available if they can be restarted on demand. Therefore starting reliability is also a very important revenue parameter for a power plant.

Maintainability is defined by Campbell (1995, p.178) as the “rapidity and ease with which maintenance operations can be performed to help prevent malfunctions or correct them if they occur, usually measured as mean time to repair”. This definition captures some important aspects of maintainability in power plants. As the revenue potential of the plant depends on the availability of the equipment it is important that any planned or unplanned outages to be as short as possible. At the same time it is also critical that the plant be reliable and therefore it must be possible to perform maintenance to prevent outages. For example during the time of planned outages it should be possible to perform work adequately to reduce the risks of functional failures before the next planned outage.

The availability, reliability and maintainability of a power plant are largely dependent on the design of the equipment and the technology applied, but they are also functions of the effectiveness of the operating and maintenance delivery. The expertise, engineering and maintenance processes, competences and knowledge of the O&M service provider are critical components in effective asset management allowing the plant to achieve its design capabilities\(^\text{20}\) and supporting plant improvements in capabilities.

**Equipment Expertise**

Power generation facilities have become more complex and technology driven to provide the levels of performance and reliability expected by the market. The reliability and performance of an advanced GTCC power station can only be maintained if the complex equipment used is understood and maintained. It is not possible to provide a high level of O&M management for complex physical assets within a GTCC plant unless the provider of the service has a detailed understanding of the engineering and design of the equipment. The performance of turbine and combined cycle plants is continually evolving and improving through upgrades on existing equipment so that even existing

\(^\text{18}\) The IEEE Standard definitions for use in reporting electric generating unit reliability, availability, and productivity (IEEE Std. 762-2006) is used worldwide for the standardisation of RAM terminology and calculation methods regarding power generation plants. It is used as a basis for reporting rules for such organisations as the North American Electrical Reliability Council (NERC) and the Canadian Electrical Association (CEA).

\(^\text{19}\) A derate is a period when the unit is available but cannot operate at rated capacity.

\(^\text{20}\) It is not possible to maintain into a system better reliability or availability than the design allows. According to Moubray (1995) “the initial capabilities of any asset are established by its design and by how it is made” and “maintenance can only restore the asset to this initial level of capability”. This is normally true unless additional capital investments or processes are made.
facilities may not remain technologically stagnant over time. It is therefore critical that whoever provides the technical support service for such a facility is able to access current knowledge through a strong engineering core to optimise the configuration management for the equipment. This optimisation involves more than planning for parts replacement based on the OEM predicted lifecycle and includes the selection of the best parts replacement regime, including lifetime assessment, reuse, refurbishment and upgrades to meet the owner’s long-term strategies. To provide this service the supplier must have sufficient knowledge of the equipment to understand the possible failure modes for all the key components as well as what effects and risks would occur with such failures.

Another area that requires detailed knowledge and understanding is that involved with major overhauls and repair. The tasks involved with disassembly/assembly, inspection, assessment and repair of complex close tolerance equipment requires a high level of competence and skill that is used only during overhauls. The management of these outages impact the equipment availability directly through their duration and frequency but can impact the ongoing reliability of the plant if work is improperly or incompletely performed. As such overhauls occur only once every three to four years in GTCC plants it is difficult for firms to develop and maintain this competence (Grace, 2005) unless they own several similar plants.

The need to maintain current engineering knowledge presents a significant challenge for many asset owners. Developing and embedding of skills is a large investment requiring continual updating. It is an area where there are significant economies of scale and scope so that smaller firms, or firms with diverse fleet technology, may be significantly disadvantaged.

Proactive Maintenance Expertise

According to Moubray (1997, p.6) maintenance can be defined as “Ensuring that physical assets continue to do what their users want them to do”. This is a simple definition but within it there are two fundamental requirements for physical asset management. The first is the need to sustain or continue the function of the asset and the second is the need to match this sustaining activity to the requirements or goals of the user. Because of its focus on preserving the function of assets to satisfy the user’s requirements this concept of maintenance is different than older maintenance management systems that focused efforts on either fixing things when they were broken or maintaining the equipment rather than the functionality (Moubray, 1997). Modern maintenance, referred to by Moubray (1997, p.5) as third generation maintenance, provides significant improvements through the use of proactive techniques and strong focus on availability, quality, and effectiveness. By concentrating on the maintenance of the equipments functions rather than simply repairing of faults this generation of maintenance allowed significant improvements in reliability.

The term proactive maintenance is used to describe tasks and processes that are undertaken before a functional failure occurs, either to prevent the failure or to detect the incipient indications of the failure early enough to allow a planned repair before the
occurrence of major damage. Proactive maintenance techniques can be grouped into four general categories: time based actions, condition based actions, failure-finding actions, and planned run to failure. To determine the optimum proactive strategy for each system and equipment component the maintenance and engineering provider should be able to determine which of these techniques can be used based on what type of failures can be expected from the equipment. This evaluation is done through the application of techniques such as failure modes and effects analysis (FMEA), reliability centred maintenance (RCM), failure modes effects and criticality analysis (FMECA) or value driven maintenance planning (VDMP). A simplified representation of this process is illustrated in Figure 13, which shows the linkage between the analysis of failure types and the decisions on what proactive techniques to use. Also illustrated in this example are the links to the business needs and previous fleet experience that can continuously improve the system.

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Figure 13: Simplified Maintenance Strategy Decision System

The success of a proactive maintenance methodology can be measured in the overall maintenance effectiveness of the facility. Effectiveness can be measured in terms of the total financial impact of the strategy employed. This is equal to sum of the maintenance costs for the proactive (PM) and reactive (RM) activities and the costs associated with the lost revenue resulting from lost availability for breakdowns and planned outages and PM activities. If a facility performs no proactive maintenance the costs of repair will normally be high because of the emergency nature of the work, additional overtime and more extensive damage that will result from late detection of the faults. The outage costs will be high due to the unplanned nature of the equipment failures and the resultant forced outage losses. Proactive programs on the other hand are by definition planned events and therefore have a predictable and linear characteristic regarding costs. Outage losses for PM work are less than RM because of the improved reliability of the equipment and the more planned nature of any outages. When proactive  

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21 Run-to-failure can be considered a proactive maintenance program if it is a deliberately chosen strategy for a piece of equipment. Normally will apply when the failure of the component will not result in a significant business loss and the costs of preventative or predictive maintenance is greater than the repair costs.
maintenance is introduced to a facility the amount of reactive work will usually drop rapidly thus lowering the overall point. This trend will continue to some optimal point where the additional proactive maintenance no longer creates value or starts to reduce availability to such an extent that the revenue losses offset additional savings. This concept is depicted in Figure 14 in which the graph on the left depicts an optimal point for maintenance if only the costs were considered and the right side graph shows the full cost optimal point.

![Figure 14: Maintenance Cost vs. Maintenance Efforts (Adapted from Campbell, 1995 and Chambers, 2002)](image)

The ability of the O&M supplier to properly scope and plan proactive maintenance activities can greatly reduce the probability of unplanned or forced outages and equipment failures but the development of a strategy is only part of the full scope of effective maintenance delivery. The best plans are only good intentions unless supported by the tools and execution processes. The O&M provider should have effective data collection and management systems including a well managed computerised maintenance management system (CMMS), the ability to perform the prerequisite predictive and preventative inspections and tasks and the ability to continually improve and renew these competences. The development of a comprehensive maintenance system with the tools and methods is a significant investment for most companies and also one where economies of scale can play an important role. Figure 15 illustrates some of the components of a maintenance system. When assessing the options available for the provision of O&M services the asset owner should carefully assess its own internal capabilities, processes and capabilities as they relate to maintenance strategy.
Fleet Knowledge and Experience

Knowledge of and experience with GTCC equipment is an important contributor to several other success drivers. With greater experience it is possible to easily plan engineering and maintenance tasks to reduce costs, reduce risks and increase revenues. The challenge is to build up this level of knowledge quickly and efficiently. This build up is accomplished much easier if the O&M service provider has access to the learning of many plants or a fleet of similar machines and a structured method to use this experience data to continually improve practices. Samples of the sources of data that can be derived effectively from a fleet are given in Table 1.

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Data Source</th>
<th>Derived Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Failure</td>
<td>RAM Data that includes outage dates, duration, outage cause, and failure modes.</td>
<td>▪ Identification of main failure causes to allow targeted maintenance.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Development of probability curves to calculate risks</td>
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<tr>
<td></td>
<td></td>
<td>▪ Expected mean time between failure for key components</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Input into improvements of FMEA studies</td>
</tr>
<tr>
<td>Incident reports</td>
<td>Incident reports that describe in detail all plant equipment problems that impact reliability, environment health or safety.</td>
<td>▪ Failure causes that can be addressed through improved maintenance or engineering.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Inputs into FMEA studies</td>
</tr>
</tbody>
</table>
### Table 1: Fleet Data and Information

<table>
<thead>
<tr>
<th>Maintenance</th>
<th>CMMS information including job order types (PM or RM), equipment history, parts used, component breakdowns, person hours used.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>▪ Failure causes that can be addressed through improved engineering or maintenance</td>
</tr>
<tr>
<td></td>
<td>▪ Cost for maintenance types and methods to allow for improvements</td>
</tr>
<tr>
<td></td>
<td>▪ Parts use trends to optimise routine and strategic spares holdings</td>
</tr>
<tr>
<td></td>
<td>▪ Component level mean time between failure and mean time to repair information</td>
</tr>
<tr>
<td></td>
<td>▪ Fleet level efficiency indicators for maintenance performance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inspection reports from equipment overhauls that include detailed findings, issue and corrective actions taken.</th>
<th>▪ Common fleet issues that can be improved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>▪ Opportunities for optimisation of parts use and replacement strategies.</td>
</tr>
<tr>
<td></td>
<td>▪ Efficiency improvements for outage management</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition based (predictive maintenance) that give indications of the health of equipment.</th>
<th>▪ Common indications on components through which adaptations of the PM frequencies can be made</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>▪ Identification of equipment types with potential problems that can be improved</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operations</th>
<th>Equipment operating history and trends including information on the operating cycles and disturbances</th>
<th>▪ Correlation between operating trends and equipment failure of maintenance rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>▪ Identification of parameters that can effect the fleet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Identification of industry trends</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engineering</th>
<th>Machine developments including improvements in parts or systems or weaknesses found through analysis</th>
<th>▪ Application of improvements in a systematic way across the fleet</th>
</tr>
</thead>
</table>

Large utility and industrial firms will have a natural advantage through the access to fleet information across their own installed base of power equipment. Smaller firms, or ones with a diverse portfolio of equipment types, may look to outsourcing as a way to buy in this expertise. Any evaluation of the optimal O&M service provision should include an assessment of not only the degree of access to fleet knowledge but also the capability to use this knowledge to implement plant specific improvements.

**Plant Staff Training**

The best processes, maintenance strategies and fleet experience systems in the industry are of little use if this information is not utilised by the people charged with the actual work of asset management. It is estimated that human errors account for over 50% of all failure events in industry (Campbell, 1995 and Moubray, 1997) and even in highly automated modern GTCC plants the actions of the engineering, operations and maintenance staff has a profound impact on both the short-term results and long-term integrity of the facility. The need to select, hire and train for high performance is a critical attribute of an O&M service supplier that is growing in importance due to the
rapid technological advances in power generation systems and the industries aging workforce. The U.S. Bureau of Labour reports that the average age of electrical industry workers in the United States was 48 in 2007 and that 50% will be eligible for retirement within five years (George, 2007). These statistics are consistent for all developed countries resulting in a shortage of experienced people and the imperative need to capture and transfer existing and new knowledge.

![Knowledge and Training System](image)

**Figure 16: Knowledge and Training System (Decoussemaeker, Mercer and Peter, 2008)**

The capturing and transfer of knowledge requires the development of a systematic training management system that covers several steps including (1) an assessment of the needs required for the plant and industry based on expert, fleet and O&M knowledge (2) the comparing of needs against the existing level of competence of the staff and the training material provided and (3) the development of a structured learning management program for each individual. Figure 16 illustrates one such program used by Alstom Power O&M Ltd. to describe the formal and informal training of plant staff.

### 4.1.3 Quality

The criteria for quality used in this paper refer to the requirements for the power plant in relationship to its stakeholders rather than a description of service quality between the O&M service provider and the asset owner. The latter issue, though important, is considered as part of a supplier selection decision rather than part of a strategic outsourcing decision.

Quality management has significant relevance in the context of GTCC plant asset management as it is closely linked to the successful and repeatable achievement of the other drivers described. It involves the systematisation of processes that are needed for all aspects of operating the business including: the maintenance of product quality, assets are managed according to the needs of the owner, and the plant is compliant with legal requirements.
Legal Compliance

To remain in service a power plant must remain in compliance with the laws of the jurisdiction where it operates and in some cases international standards. If the plant violates legal requirements it may face sanctions or lose its ability to operate. It may also suffer from a significant loss of reputation that could impact its future business viability within the jurisdiction (Eccles, Newquist and Schatz, 2007). Together these tangible and intangible risks create a strong incentive for the asset owner to develop and maintain a compliance risk management structure wherein the O&M provider has an important role to play. Some critical areas where the O&M supplier normally will be required to develop and maintain systems are as follows:

- Each plant will have to meet local environmental laws, as well as any specific requirements prescribed in its operating licence and consent. Record keeping and reporting of inputs and emissions are normally required, as are periodic assessments and reviews.

- Pressure vessels and hazardous systems require inspection, certification, testing and recertification on a periodic basis in virtually all jurisdictions. These aspects will have legal and insurance coverage requirements and require that all work be done according to local and international codes with detailed documents retained for future reference.

- The O&M service provider must have processes in place to manage the human resource standards prescribed in the locality as well as any specific issues related to union contracts. This will include the working conditions, insurances, qualification of staff, privacy and discrimination guidelines, and health and safety requirements. The hiring company will need to insure that the personnel employed within the plant have the necessary legal documents to work in the jurisdiction and perform the work for which they are employed.

- Commercial and financial requirements for the country must be managed jointly between the owner and asset managing party to ensure that all necessary transactional information recorded, maintained and registered according to local guidelines. Fair-trading and competition laws must be understood and complied with.

The ability to meet legal requirements is, in most cases, the responsibility of the asset owner rather than the service provider and they will normally suffer the most should any infraction be discovered, even if the service is outsourced. Therefore, it is of critical importance that the asset owner be satisfied that the service provider either has its own system to ensure compliance or is willing to follow the system it provides.

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22 If a pressure vessel is constructed and certified for use in a country based on ASME section I or VIII standards it is usually subject to ASME code standards and National Board rules for repair and alteration, even if the country in question does not formally acknowledge these standards within its statutes.
Systems and Tools

To ensure that the quality system implemented is consistent and repeatable the service provider must have processes in place that describe how activities are to be performed and tools that can both support and monitor how well these systems are performing. Commonly these processes are described through rules, guidelines, policies, procedures and work instructions that are descriptive documents used to detail, in a hierarchal way, the system from its top-level goals through to the step-by-step task descriptions as, depicted in Figure 17.

![Hierarchal Structure of Quality System](image)

*Figure 17: Hierarchal Structure of Quality System*

Ideally such a system should be integrated to reduce inconsistencies between quality, environmental and safety systems. It should be designed specifically for use in power plants, be relevant to the people doing the work, and be easy to read and understand. The best procedures written will provide no value if the personnel who use them do not understand them, do not feel they are relevant, are confused by the complexity and overlap between systems, or do not know where they are. To avoid this situation training and review of processes and procedures should be of the system, as should review and continuous improvement.

Measurement of the system can include monitoring quality measures such as compliances, system audit results, system improvements, performance benchmarking and non-conformance reporting. The outcomes being measured through quality tools are the key indicators for plant performance and will include revenue and cost data, RAM trends, maintenance performance results, efficiency trends, safety events and audits, environmental trends and many others.

Additional quality system tools that should be considered as part of a progressive O&M service provision should include those associated with continuous improvement. The provider should be able to perform FMECA studies and roots causes analysis (RCA), on the plant systems, and demonstrate the implementation of results. Suppliers that employ more advanced techniques such as Six Sigma, RCM or total quality maintenance (TQM) could provide a higher level of performance and therefore a competitive advantage. These programs involve significant investments to develop so targeted and staged applications are often the best option.
**Maintenance and Stock Control Systems**

The management of maintenance activities and the control of spare parts are complex activities that are considered separately from other quality related systems within this paper due to their high level of importance. As described in section 4.1.2, the performance of effective maintenance involves the planning for and execution of preventive, predictive and repair tasks of the components within the plant. These components, often referred to as maintenance objects, can number in the tens of thousands even for a moderately sized facility. Each maintenance object will have its own specific identifier as well as specifications, quality information, manufacturer information, design data, bills of material and assigned tasks associated with it resulting in hundreds of thousands of discrete pieces of data. All of this information is important and must be managed within the steps of a maintenance cycle as shown in Figure 18.

![Figure 18: Simplified Steps in Maintenance Management (Campbell, 1995)](image)

To manage the immense volumes of information, and to perform the functions of planning, scheduling, assigning, executing, and recording the feedback of maintenance activities, the O&M supplier will employ a computerised maintenance management system (CMMS). These specialised software systems are purpose built to perform the functions of maintenance and may be self standing systems or a module linked to, or part of, the firm’s enterprise resource planning (ERP) software. There are many products on the market designed for this purpose and all the leading brands contain modules to support maintenance management steps as shown in Figure 19. In spite of the built in functionality of a CMMS it will not provide the best value unless the system is set up and managed professionally. This set up will involve several key aspects including the following:

- The implementation of the equipment data within the system in a logical and hierarchal system based structure to allow system related reporting and the rolling up of information based on systems of functions. The information should include all necessary quality and specification data.

- The set up of codes and standards for equipment fault identification, outage type, maintenance type, repair methods and other key indicators to allow consistent reporting for analysis and statistical representation.

- The linkage of maintenance objects to inventory and parts requirements through material masters and bills of material to speed planning.
The development of comprehensive PM plans based on the maintenance strategies developed.

The development of key performance indicator (KPI) reports and dashboards to provide outcome feedback to workers and managers.

When reviewing the sourcing options for O&M service provisions the ability to set up and maintain these parameters of a maintenance system should be considered.

Figure 19: CMMS Typical Modules

**Quality Certification**

Quality systems certification is often considered a good test of a supplier’s ability to perform the aspects of a quality system in a consistent and professional manner. It serves the purpose of a drivers licence in that it offers some form of proof that the holder of the certificate has been able to prove quality competence to a level that is acceptable against an international standard such as ISO9001. Normally this requirement is necessary whenever the O&M service is provided by in an outsourced fashion and often there will be similar expectations on internal service departments.

As well as demonstrating quality system competence, certification may also be a requisite attribute of the O&M provider to satisfy insurance underwriters, investors or lenders that the facility is being well managed, thus limiting their risks.

**4.1.4 Environmental, Health and Safety (EHS) Performance**

The management of environmental, health and safety issues has become a priority of management in many industries. Power producers, energy companies, and service providers usually have web sites with sections dedicated to corporate responsibility wherein they publicly announce commitment to the environment, the community, and the people working for them. There is a growing tendency for firms to become more ethical and proactive in how they view their interactions with the external environment including the needs and desires of their stakeholders. These actions and commitments
are more than high-minded ideological statements as there are many sound business reasons driving this movement, including direct and indirect financial benefits.

There are many direct financial benefits that can be accrued from a well-managed EHS system including: reduced risk costs and liabilities, reduced cost of accidents, elimination of fines, decreased workers compensation, decreased insurance costs, and improved efficiency. In addition to these cost benefits there are many intangible aspects that can create substantial value for the firms including public relationship, stakeholder trust, reduced waste generation, brand value, improved staff moral, and reduced turnover of staff. Many corporations implicitly understand these values even though it is impossible to quantify or measure them except through the use of probabilistic risk calculations. A well managed operation may have invested significantly in EHS systems and, as a result, be able to survive for years without any serious incident. In this case the costs associated with the system will be much higher than actual costs associated with incidents. Without a sound understanding of the potentials risks managers could, over time, see EHS systems as an unjustifiable cost. Fortunately, most progressive asset owners recognise the intrinsic value of EHS programs and insist on their application as part of the greater asset management function.

The recognition of financial benefits that can be gained from improving safety dates back to the beginning of the 20th century when workplace accidents were common, and all part of a days work. It was recognised by some industries that the implementation of safety measures not only reduced the number of injuries for employees but also increased the overall productivity of the process. Charles Hook, writing before the great depression, gave examples of such productivity increased in manufacturing and steel making in the period during and after World War I (Hook, 1922). Hook calculated these productivity gains, together with the direct losses of lost working days of the labourers to be in excess of the then staggering figure of one billion dollar loss to the American economy. Even with much lower modern injury rates, direct business costs are now estimated to be over 170 billion dollars in the U.S.A. alone (Pennachio, 2009). What are less evident are the indirect costs that can occur, and which would not have been concerned Hook in the early 20th century. One of the largest impacts can be the reputation of the firm that, if damaged, could result in serious impediments to business continuity. For example the impact on BP’s reputation following the Texas City Refinery explosion of March 2005 and its subsequent problems with the Prudhoe Bay pipeline leak in August 2006 (Eccles, Newquist and Schatz, 2007). These two incidents were in themselves financially damaging in terms of human, equipment, and environmental costs but the subsequent negative publicity created significant brand damage and loss of respect for a company that was, up that point, thought of quite positively in the public eye (Eccles, Newquist and Schatz, 2007).

Increasingly strict laws and regulations have been enacted concerning the safety and environmental impacts for total impacts, and for EHS incidents and accidents. In spite of these tougher regulations some companies have higher rates of incidents and accidents than the industry average while others perform significantly better. The poor performing group will face higher costs for absenteeism, workers compensation payments, insurance costs, increased staff turnover, civil suits, and likely significant
fines by regulatory bodies. The key differentiators between firms that perform well and those that do not include well established EHS systems, policies and procedures, and EHS cultures that embody behavioural based principles.

Asset owners and managers also need to be aware that there are different classes of EHS risks within a facility and one system will not work for reducing all the potential risks. For health and safety the two separate areas of concern are occupational health and safety and major incident reduction (loss prevention).

Occupational health and safety focuses on the prevention, reduction, and mitigation of hazards associated with individuals. The systems and programs used to reduce the risks in occupational health and safety areas are generally grouped into two categories. The first element, often referred to as safety from the system, encompasses rules based programs such as safe work permitting, confined space entry permits, emergency response, and the similar descriptive prevention methods. The second is sometimes referred to as general safety and includes work based activities, including hazard and risk identification, tools usage requirements, personal protective equipment requirements, safety signage, and other similar activities.

Loss reduction focuses on preventing major incidents and losses that can occur due to failures of equipment or structural components. In a power plant setting, high risk incidents would include loss of containment of high pressure steam or water, high pressure flammable gasses or hazardous materials, fires or explosions, failures of heavy load cranes, or any other event that could cause significant property damage, extended loss of production and/or loss of life. These types of failures are infrequent in industry but can have catastrophic consequences for plants were they occur. Programs that focus on individual safety systems are not adequate to address these types of failures. Determination of prevention methods for major losses requires evaluation using system based methodologies including FMEA and HAZOP studies.

In the area of environmental management there are also two classifications of event that need to be considered and managed effectively. These are incident prevention and environmental impact reduction.

Incident prevention programs are, as the name implies, designed to identify where unplanned and unauthorised emissions may occur and the measures required to eliminate or mitigate the risk of such emissions. Incidents of this type include: uncontrolled release of plant wastewater, oil or chemical spills, short term exceeding of stack emissions outside of the requirements of the air permit, ground water contamination, and release of fuel oil or natural gas.

Environmental impact reductions involve the systematic and planned efforts by the asset owner to reduce the overall impact of the plant on the environment, beyond what is required by their original operating permit. Such programs are often implemented to

23 Most jurisdictions will have some form of notification requirement for serious accidents and incidents. Accidents involving serious injury or loss of life will likely be investigated by a local regulatory body that have the ability to stop work and issue penalties for breaches in safety. In the case of such a breach the asset owner as well as the primary contractor may be held jointly liable.
meet the needs of changing regulations but may also be the result of the desire of the owner to improve their facility for ethical or other reasons. Programs that fit into this category include: efficiency improvements, water reduction programs, change of fuel choice, change of the chemical usage, and/or recycling programs.

Owners should consider as part of this asset management decision whether they are best able to manage the programs internally or if an outsourced solution would be more effective.

**EHS Performance and History**

The underlying principle of EHS success depends on three foundational aspects: a robust system, simple but well thought out procedures, and a strong culture. It is not normally possible to have a fully successful EHS performance record if any of these factors are inadequate or missing. A decision evaluation should include an assessment on how best these aspects can be implemented in the most efficiently and quickest way. It is said that the most important indicators of future performance is past performance. Therefore, owners of new power plant assets need some assurance that either their internal resources or an external supplier already has a system in place that can be verified. Developing a strong and sustainable EHS system is an expensive and time consuming endeavour, and any supplier must be able to demonstrate past success, and present commitment, in meeting the owner's strategic EHS goals.

The measurement of past performance of a service supplier may involve a simple numerical benchmarking against industry standard for commonly tracked key performance indicators, or it may involve a more thorough benchmarking of a broader spectrum of indicators.

The readily available key performance indicators that should be reviewed are as follows:

- The lost time injury frequency rate (LTIFR) expressed as the number of lost time accidents that occur per 200,000\(^{24}\) person hours worked.
- The lost time injury severity rating (LTISR) expressed as the number of days lost following an injury per 200,000 person hours worked.
- Number of first aid injuries per 200,000 person hours worked.
- Number of reportable environmental excursions per facility per year.
- Records of fines or reprimands received for safety or environmental breaches from regulatory agencies, including a description of the number and severity of these breaches.

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\(^{24}\) Both LTIFR and LTIFR may be measured against different base units of work hours depending on the jurisdiction, firm or reporting requirements. It is common to use either 200,000 hours or one million hours and the analyst must be aware of the standard use to convert all benchmark numbers to the same basis.
An extended benchmarking regards a much more thorough examination of the supplier’s actual performance surrounding the applications of its systems. This will involve some form of auditing and therefore is a more time and resource intensive measure.

**Hazard and Risk Management Competence**

Environmental, health, and safety issues chiefly represent risks of the occurrence of unwanted and damaging events. To reduce risk it is first necessary to identify what can cause the unwanted impact, and then devise corrective actions to eliminate the risk totally, reduce the consequence of the impact, or reduce the probability of the impact occurring. This activity is referred to as system safety, which is described by Leveson as “using systems theory and systems engineering approaches to prevent foreseeable accidents and to minimize the result of unforeseen ones” (Levenson, 2003, p. 5).

Many of the risks that exist in the plant are created prior to the start of O&M service provision, and result from the original design and construction. However, the tools used to identify risks in the design stage often require O&M expertise to take into account whole system interactions rather than single components. It is therefore highly advantageous for the asset owner to involve the O&M provider as soon as possible in the design analysis. Tools used in the design of the plant to identify and mitigate risks include hazard and operability studies (HAZOPS) and failure modes and effects analysis (FMEA). The application of these techniques involves the systematic review of systems and components to identify potential causes and effects of performance deviation for which changes and corrections must be implemented.

The practices of hazard and risk management do not end with the design and construction of the plant. Many potential risks will exist due to the interaction of equipment and people over a period of years. Maintenance and operational tasks need to be performed, operating conditions can change, and components experience the effects of aging. Therefore, it is essential that the O&M supplier is able to identify the risks associated with the plant and the O&M activities, and develop adequate mitigation measures. The mitigation methods can include operation or maintenance process changes, equipment improvements, or procedures and work instructions. Together with these initial processes the O&M provider needs a system to assess individual tasks and maintenance activity risks, and implement protective measures including permits for work (PfW) and personal protective equipment (PPE).

Even with well managed risks assessments practices and corrective actions it is still possible for unforeseen events to occur requiring the O&M provider to have competence in another critical safety system methodology; root cause analysis (RCA). The investigation and reporting of failures has a higher potential value if all the experiences gained from a large fleet of similar equipment can be pooled so that economies of learning can be achieved. Providers will have a competitive advantage if they are able to create a knowledge base with consolidated fleet incident data, and effectively use this data to improve their risk management.
Environmental, Health and Safety System Certification

As with quality systems discussed in section 4.1.3, EHS system certification according to international standards is an effective way of ensuring that the O&M asset manager has a robust and verifiable system. The most common standards used are ISO 14001 for environmental management and OSHAS 18001 for health and safety. These standards have very similar structures and contents and therefore lend themselves very well to consolidation into a single EHS system.

In addition to providing assurance to the asset owner that the systems measure up to international standards, certified EHS systems have also been credited with improvements in: (1) employee awareness, (2) operational efficiencies, (3) managerial awareness, and (4) operational effectiveness (Rondinelli and Vastag, 2000). Much of these additional benefits are achieved through the required processes to implement the system in a way that can pass an external audit. Less formal implementation methods often result in lower buy-in and a tendency to make shortcuts.

Additional benefits of achieving certified EHS systems include the favourable acceptance of the systems by local labour and environmental agencies as being robust. This acceptance can result in improved relationships and inspection processes as well as proof of due diligence should an unforeseen event take place.

4.1.5 Overhead and Transactional Costs

Many of the asset management costs for the operation and maintenance of a power station are the result of external activities and interactions, and can be easily appropriated to the drivers discussed in the preceding sections. There are, however, many costs that are internally generated and related to the interactions between departments, or between the firm and external suppliers. It is common to simply pool these into a cost element for overheads and then apportion them across the business using a somewhat arbitrary system. This method of overhead appropriation makes it difficult for decision makers to consider the impact of outsourcing choices.

The evaluation of many of overhead costs is not always straightforward. They are often embedded within corporate systems and interwoven between departments, and seldom are they allocated separate cost identification codes within the firms accounting system. None the less, they are important and significant in value so it is in the interest of decision makers to endeavour to calculate the main drivers as part of any outsourcing decision.

Opportunity Costs

The concept of opportunity cost is often used in management accounting to describe the allocation of constrained resources in the production of different products or services. The value of an opportunity in this context refers to the lost potential contribution incurred through forgoing production of one product in order to utilise the resource in the production of another. This same concept can also be applied in other aspects of business, including the allocation of managerial and technical resources to provide
services. For power plant asset management opportunity costs can be defined as the losses incurred as a result of the allocation of a constrained managerial or engineering resource to an activity that produces a lower return than another activity within the organisation. This definition of opportunity losses implies that there are two considerations to be taken into account in the evaluation. The first is the determination of a constraint, and the second is an assessment of what activity creates the highest value for the firm.

Constraints in resources are normally attributed to the numbers of personnel available or their competence in relation to the activity. Each company will have its own level of constraints regarding asset management tasks, dependant on both its size and structure. A company may have either truly constrained due to a lack of people, or it may have adequate staff but not enough with the required skills. This concept applies both to technical personnel and to management. Management skills and competence needs are different for the activities of energy trading than those needed for the operational activities of O&M.

The second component of the opportunity cost equation requires an estimation of the relative values produced by the activities within the organisation. To perform this estimate a firm will need to determine which activities it performs are core to its business’s success, and which it has a competitive advantage. To minimise opportunity losses it must ensure it has fully satisfied the resource needs of this core activity before committing resources to activities that produce lower value. Due to the number of intangible factors, this evaluation of core activities and derived value will differ from one firm to another.

For example, a large diversified power generation company will have engineering and O&M departments capable of managing most aspects of a GTCC plant’s asset management. However, they may have only a few specialists with gas turbine experience capable of managing the complex needs of F class turbines. This creates a constraint and necessitates a decision process, wherein opportunity costs should be considered. If the firm invests in gas turbine skills it may need to reallocate resources from other engineering areas, thus reducing its capacity in those areas. Prior to deciding, the firm will need to determine if the reduction in capacity is more than offset by the increase in gas turbine skills.

Transaction Costs

Transactional costs are those costs incurred for any business activity where one party obtains a service or product from another. Transactions between independent firms incur transaction costs through activities such as: the search for suppliers, the negotiation of contracts, the monitoring of the performance, and the enforcement of conditions ex post. As discussed in section 1.4, transactional costs are some of the most important factors influencing the total cost of outsourcing.

Transaction costs are affected by the completeness of contracts between the parties. However, contracts can never be 100% complete because it is impossible to know all of
the possible situations that might arise during the term of a contract. It is not possible to define some items in advance, including the definition of the parties’ roles responsibilities in changing conditions, or how to attribute any ex post surpluses that may result from the relationship. This results in the possibilities for either buyers or sellers to take opportunistic positions and increase their share of total value of the transaction. On the other hand, more complex contracts designed to reduce this behaviour increase negotiation, monitoring, and enforcement costs. These contractual costs can be reduced through various means such as alliance agreements, shared incentives for reducing transaction costs, increased data sharing, and use of non-contractual self enforcing safeguards (Dyer, 1997).

Transactional costs are not limited to relationships with external suppliers. Similar costs can exist internally when different parts of the company act independently as cost or profit centres and rely on internal contracts\textsuperscript{25} to complete transactions. The extent of these transactional costs should be reviewed and quantified by the asset owners so a fair and complete comparison can be made between the costs of external supply and those for internal supply. Table 2 provides an overview of the main transactional cost type that should be reviewed, and wherever possible quantified, for both internal and external suppliers.

<table>
<thead>
<tr>
<th>Contractual ex ante Transaction Costs</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Search costs</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Negotiation costs</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Supply specific investments</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contractual ex post Transaction Costs</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring costs</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Enforcement costs</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Dispute costs</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Capacity utilisation</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

Table 2: Typical Transactional Costs for Evaluation

**Cooperation Costs**

In order to gain advantages from outsourcing without the creating large transactional costs many firms develop long-term relationships and alliances with suppliers based on

\textsuperscript{25} Internal contracts are often less formal, and therefore less complete than those made with outside suppliers. However, they often result in the same issues associated with external transactions with the added disadvantage of not having any legal basis for enforcement.
open communications, sharing of risks and gains, and organisational collaborations (White and Lui, 2005). These types of relationships are capable of reducing transactional costs due to benefits such as the possibility of joint learning, pooling of resources, and sharing of benefits that result in a good faith bargaining. Many O&M supply arrangements are designed to encourage this type of relationship through long-term secure contracts that include risk and reward sharing. A reduction in transactional costs does not mean that there is an elimination of relationship costs, as these cooperative contracts will require careful management to remain effective and controlled.

Cooperation costs involve relationship specific activities but are differentiated from transactional costs because of their focus on finding mutually beneficial results rather than control and enforcement. Examples of cooperation’s costs include the time and effort required for maintaining the relationship, development of joint task working systems, cooperative problem solving, and mutual adaptation (White and Lui, 2005). These activities do not completely eliminate transaction costs but can greatly reduce them. The total costs will then be the sum of the transactional costs plus the costs associated with cooperation.

**Internal Overheads**

Internal overhead costs are perhaps the best understood, most measured, and least considered of all costs. These costs include all of the costs from service departments that are not direct costs of the O&M service department, but which can be considered avoidable should the department not exist. The personnel and costs associated with the power plant are direct costs and are easy to identify. However, managers may not consider the head office costs that can also be attributed to the operation of the facility. For example, if the O&M function for a new plant were fully outsourced the portion of the HR department that would be required to manage the requirements of O&M, their training needs, and benefits, would not need to be hired. Likewise, many head office or back office departments such as engineering, R&D, legal, purchasing, finance, administration, and functional managers would not need to be expanded to meet the needs of the O&M services should this be outsourced. In addition to the costs of people there are many systems and infrastructure costs that could also be avoided. These include plant specific software applications, special tools, training systems, and the office space required for support departments.

Most companies are aware of overhead costs and allocate them across operating units based internal guidelines. It is common to allocate some of the costs based on the head count or by the revenue generated by the facility. Neither of these methods would produce satisfactory results. An allocation against head count would under-charge O&M, as most plants have very lean staffing levels. An allocation against revenue would over-charge the operation because of the high level of output capacity.

Care must be taken when assessing the indirect costs associated with the O&M service as some of these costs are sunk and will not change significantly if the service is in-sourced or outsourced. For example, the company’s financial systems, IT
infrastructure, and most of the management structure will not grow or shrink, in a material way, if additional departments are added or removed. As part of the evaluation process the asset owner should first create an overview map of all of the direct and indirect costs associated with the performance of O&M activities at a power station as is shown in Figure 20\textsuperscript{26}. The next step is an evaluation of what parts of the indirect costs could be avoidable if the service is outsourced. Each cost type should be evaluated based on the firms existing internal structures and policies and therefore will be different depending on the business case.

![Figure 20: Indirect (Overhead) Costs](image)

### 4.2 Outsourcing Options

After fully evaluating its own capabilities an asset owner should review the available alternative outsourcing options. These options can be classified in two general groupings: The first is what type of service can be provided? The second is what companies can provide this service? For the purposes of this report only the first of these classifications are examined. The second classification related to a supplier selection decision that is outside the scope of this report.

#### 4.2.1 O&M Service Alternatives

The selection of the specific alternative O&M service level is the primary strategic outcome from the decision model proposed in this paper, and as such there is a need to better understand what each alternative involves.

**Self-Supplied Service**

As the name implies this alternative involves the complete responsibility for the provision of all O&M services from within the asset owner’s own organisation. This implies that the main functions involved with O&M management will be staffed and performed internally and the owner’s organisation is prepared to invest in the development of the required expertise and systems. Self-supplied service does not mean that only internal resources are used as some capacity outsourcing may be used to cover peak workloads or for specialised activities. The key distinction of this option is that the owner’s

\textsuperscript{26} Figure 20 provides only a simplified overview of typical overheads associated with O&M service. Each firm will need to develop their own map based on internal structures and expectations.
organisation takes the primary responsibility for planning and execution of all activities, and therefore, also assumes the associated risks. The planning for major component parts replacements and reconditioning is normally done in house for this type of service and arranged through the OEM or a third party supplier on a purchase order basis. Specialised supervisors and outage management may be purchased from external companies, but this too will be done on a purchase order bases with the owner retaining the majority of the performance and works scope risk.

**Configuration Management and Major Maintenance**

The first level of outsourcing considered involves the contracting to either the OEM, or a third party, for the provision of support engineering functions for the main machine sets\(^{27}\), and the responsibility for the execution of major overhaul maintenance. This option is often described in the industry as a long-term service agreement and will be configured to cover one or two gas turbine overhaul cycles.

The engineering functions, referred to as configuration management, provided in this service include two primary maintenance aspects. The first is the planning related to repair, replacement, and/or refurbishment of the high cost parts of the main machines, particularly the gas turbine. The second is the base technological engineering to identify equipment changes and improvements, and recommend their implementation in the machines. Both of these functions require a detailed understanding of the machine technology, access to the life cycle characteristics and failure modes of the components, and knowledge of fleet issues or improvements.

The execution of overhaul maintenance, as provided under this option, would include responsibility for the associated scope risk, the provision of supervision and assessment engineers, and the management of on-site craft labour during planned overhauls. This service provides the owner with a fixed and predictable cost for this maintenance and transfers any volatility risk to the service provider. The service provider will also be responsible for unexpected deterioration of components or changes raw material costs. Some responsibility for unplanned outage costs may also be included in this type of contract; however, as the supplier has no influence on operation or daily maintenance this risk is normally limited.

In this option the owner remains responsible for all other aspects of the asset management functions including: operations, general maintenance, risk management, quality, and EHS management.

**Configuration Management, Major Maintenance and Operations Support**

The next alternative includes all of the aspects of the previous option together with the additional outsourcing of some of the operational support, operational engineering, and a portion of the performance risks.

---

\(^{27}\) The main machine sets distinction varies depending on the owner’s internal capability but normally includes the gas turbine, steam turbine, and their associated generators.
Operational support will normally include the provision of one or two full time engineers at the owner’s site to provide the operational expertise to troubleshoot anomalies and problems that are encountered. These engineers will have access to fleet and expert engineering knowledge contained within their parent company creating the equivalent of outsourcing a significant portion of the specific engineering needs for the plant. As these engineers provide the expertise related to the design and operational characteristics of the main machines, the owner need not carry this resource within its own organisation.

In addition to the extended engineering support this option will normally include performance guarantees provided by the supplier as a form of risk mitigation for the owner. These guarantees vary depending on the supplier and the cost structure but usually include reliability, availability, output degradation, and/or outage duration targets, with liquidated damages provisions for underperformance. Use of these guarantees with penalties and bonuses provide value in two ways: the first is allows the mitigation of some of the operational risk, and the second is the connection of incentives between the owner and the supplier so that improved performance will create a mutual gain.

All Maintenance Activities and Operational Support

The next step on the outsourcing scale involves an extension of the previous option to include the provision of all plant maintenance activities. This increase in maintenance scope will include the delivery of overhaul and general maintenance on all of the plant equipment. General maintenance includes the proactive and reactive maintenance on plant components, management of the owner’s spare part stock, management of subcontractors for specialised activities, management of statutory maintenance requirements, and facilities management.

To perform these activities the supplier will be required to have access to and expertise in all of the maintenance associated systems, processes, tools, procedures and software. As well systems to hire, train, and support the development of on-site personnel will have to be in place. Both of these sets of requirements make it necessary for the supplier to have well developed management system and back office support organisation specifically oriented to full plant maintenance.

With this option the owner transfers much of the equipment related scope and performance risk to the supplier. In exchange for a fixed fee the supplier will bear risks of breakdown, wear out, price volatility, and labour costs. Equipment performance guarantees are expanded to include availability and reliability risks associated with the plant equipment in addition to those from the main equipment.

Full Operations and Maintenance

The final option involves the outsourcing of all of the O&M functions at the power plant, and the associated support engineering functions. This option is an extension on the full maintenance alternative by including all of the plant management, administration and operational requirements.
When this alternative is selected, the supplier will be responsible for nearly all of the physical asset management requirements of the facility including operations, all maintenance, quality, and EHS management. They will also assume a larger portion of the operational performance and scope risks, allowing the owner to focus on fuel purchase and power sales management. This service provision requires the supplier to have a complete back office and engineering support system for all aspects of the service provision.

### 4.3 Application of the AHP Model for O&M Outsourcing Decision

From the review of the key asset management drivers and outsourcing alternatives it is now possible to construct a decision model using the analytical hierarchy process (AHP) detailed in Section Three. The following are the key steps in this development:

1. **Define of problem and desired solution**: The intent of this paper is to provide a tool to support asset owners in determining the most optimum solution of asset management for their power station. This will be the primary goal at level one of the hierarchy.

2. **Determine key criteria**: The main criteria for development of the asset management decision should follow the key drivers for the industry. Therefore, the criteria used in the hierarchy will be based on the industry drivers discussed in Section 4.1. The main criteria are defined in the main headings and can be used at level two in the hierarchy as their importance levels that are reasonably close. The sub-criteria are defined within each main criterion and will make up level three of the hierarchy.

3. **Determine the relevant alternatives**: The alternatives that are relative to this model are the types of service provided, as described in Section 4.2.1. The alternatives will make up the final level of the hierarchy.

4. **Structure the hierarchy**: Illustrated in Figure 21, the hierarchy developed uses a fairly simple structure based on four levels but still retains the ability to analyse each of the alternatives against the key industry drivers.
5. Perform selection steps of pairwise comparisons, derive matrices, synthesise, and evaluate consistency. In spite of the relatively simple four level structure the number of pairwise comparisons needed is quite large. There will be 10 comparisons for the criteria level, 27 for the sub-criteria level, and 190 for the alternatives, for a total of 227. To manage this large number of comparisons and the resulting matrix calculations a specialised excel workbook was developed. The results will be summarised in the following section.

6. Perform validity check and make recommendations: Checks and recommendations derived in this paper will be done based on typical use cases in the Section Five.

5 Applying Model to Use-Cases

5.1 Definition of Use-Cases

To test the applicability and accuracy of the decision model three use-cases were analysed by the author using AHP structured decision process. These cases were based on typical examples of three prevalent industry structures described in Section 1.3. These cases do not represent specific companies within the industry but are structured, based on common characteristics, to provide a close approximation of the decision results for average firms in each classification.
5.1.1 Use-Case One – Large Utility Based Company

The first use-case describes a firm formed from a large integrated utility based company with many existing plants. These plants are located geographically close to each other on the same continent, and are managed by a centralised asset management function within the head office. Because the company developed over many years from a regulated utility it has invested heavily to develop its own internal engineering and O&M capability. Its background in utility operations has resulted in a structure having both energy management and operational management departments. It uses integration of energy planning and O&M management as a competitive advantage by planning outages around optimal periods for fuel and power prices. It regards engineering, operation, and maintenance of power plants as its core business and believes that it is through the control of these aspects that it can add value and increase competitiveness. It has a large fleet of operating units using a variety of technologies, including: combined cycle plants, hydro, conventional steam, and wind plants. Because of the diversity of its portfolio it will seek technical specialised services related to high technology applications. The company is facing growing pressure to increase outsourcing because of cost constraints, downsizing, and its aging workforce.

5.1.2 Use-Case Two – Non-utility Industrial Company

The second use-case involves a large industrial company that specialises in the energy business, primarily as an oil and gas developer, refiner, importer, and trader. It has many industrial sites performing oil and gas production, and has entered into power generation to diversify its portfolio. It views the management of the asset’s energy flows as its core competence and uses power generation as a method to add value to its gas and oil energy trading by either producing power or selling gas depending on the market conditions. The value to be gained from wheeling or arbitrage arrangements is substantial but risky, so the firm considers resource constraints that reduce its effectiveness in this area to be an opportunity loss. Because it also owns and operates other energy facilities it has some in-house industrial experience. This experience creates some expertise overlap with the requirements for power plant O&M, but they do not have the full range of equipment expertise related to advanced gas turbines, large steam turbines, and power generators.

5.1.3 Use-Case Three – Independent Power Producer

The third use-case is a fully independent power producer (IPP) that has a small fleet of power plants located in diverse geographic areas that represent its primary business activity. The company was developed as a consortium of financial and industrial companies, some of whom have ties to the power business, but it operates as a self-standing entity. The owning partners hold seats on the board of directors but are not directly involved in the day-to-day operation of the plants. The power plants owned by the firm are legally separate entries and project financed in order to limit the parent company’s liabilities for any particular plant. The projects are highly leveraged with 70-80% debt financing. This structure maximises the potential return on investments but...
creates significant risks due to the high fixed costs of debt payments. Lenders and investors are interested in reducing risks as much as possible and therefore the majority of the power is sold through long-term power purchase agreements (PPA) to larger utilities, retailers, and/or industrial customers in order to guarantee debt and fixed cost coverage. The fuel for the base generation is purchased through long-term or futures contracts to limit volatility risks. The projects have the potential to improve their profitability in two ways: the first is by wisely using any excess generation capacity beyond that committed to the PPA to gain the highest possible price per unit of power, and the second is to exceed budgeted performance to improve the value per unit. These two key business drivers require the IPP asset owner to have access to a high degree of competence for both risk management to maximise returns and O&M management to optimise equipment performance. Since the company has a small management footprint and limited resources to develop expertise in both areas, it will need to focus on the area where it can get the biggest benefit.

Because of the high investment requirements to develop world-class operations and maintenance systems, technologies, and processes, IPPs are more likely to focus on the areas of energy, finance, and risk management. The performance of operations and maintenance can be supplied from the market and therefore can be more readily outsourced.

5.2 Results for Use-Cases

5.2.1 Use-Case One Evaluation

The AHP is first tested by populating the model with date through the completion of all pairwise comparisons based on the assumed preferences for the asset ownership type described in Use-Case One. This is performed in four stages:

1. The principle eigenvalue priorities derived from the evaluations of the main criteria are illustrated in Table 3. This evaluation shows strong preferences ratings related to lifecycle costs, EHS performance and RAM influences. These values will become weighting factors for the alternative’s priorities related to the sub-criteria in the final step of the synthesis.

<table>
<thead>
<tr>
<th></th>
<th>Principle Eigenvector Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifecycle Costs</td>
<td>0.3715</td>
</tr>
<tr>
<td>RAM Influence</td>
<td>0.2043</td>
</tr>
<tr>
<td>Quality</td>
<td>0.0533</td>
</tr>
<tr>
<td>EHS Performance</td>
<td>0.3224</td>
</tr>
<tr>
<td>Overhead /TA Cost</td>
<td>0.0485</td>
</tr>
</tbody>
</table>

Table 3: Use-Case One - Main Criterion Ratings

2. Following on from the main criteria, the sub-criteria were evaluated based on the assumed preferences of a typical large utility company. The alternatives are compared against each other related to each of the sub-criteria to establish a priority vector. The priority vector values derived from the sub-criteria become

28 The completed detailed analysis of Use-Case One is provided for reference as Appendix Two.
the weighting values for the evaluation of alternatives against the main criteria in the synthesis.

3. The synthesis becomes the final step and results in a composite weighted rating for each criteria based on the results from the second step, and then finally a weighted result for each alternative against the overall goal.

<table>
<thead>
<tr>
<th>Lifecycle Costs</th>
<th>1.1 OPEX</th>
<th>1.2 CAPEX</th>
<th>1.3 Asset Value Retention</th>
<th>1.4 Risk Costs</th>
<th>Composite Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted Weight</td>
<td>0.4910</td>
<td>0.0785</td>
<td>0.2849</td>
<td>0.2356</td>
<td>1.0000</td>
</tr>
<tr>
<td>A1 Internal Supply</td>
<td>0.2422</td>
<td>0.1875</td>
<td>0.0899</td>
<td>0.0695</td>
<td>0.1535</td>
</tr>
<tr>
<td>A2 OS Maj Maint + Config Mang</td>
<td>0.4891</td>
<td>0.3718</td>
<td>0.2978</td>
<td>0.1394</td>
<td>0.3430</td>
</tr>
<tr>
<td>A3 OS Maj Maint, Config + Op Sup</td>
<td>0.1542</td>
<td>0.2487</td>
<td>0.2978</td>
<td>0.2150</td>
<td>0.2169</td>
</tr>
<tr>
<td>A4 OS All Maint + Op Sup</td>
<td>0.0584</td>
<td>0.1192</td>
<td>0.1576</td>
<td>0.1874</td>
<td>0.1219</td>
</tr>
<tr>
<td>A5 OS All O&amp;M</td>
<td>0.0551</td>
<td>0.0726</td>
<td>0.1576</td>
<td>0.3896</td>
<td>0.1647</td>
</tr>
</tbody>
</table>

**Figure 22: Use-Case One - Alternative Composite Weighting Against Lifecycle Costs**

This evaluation shows a very strong rating for both alternative configuration management and the operational support options. This advantage is primarily due to the strong OPEX, value retention, and risk ratings.

<table>
<thead>
<tr>
<th>RAM Influence</th>
<th>2.1 Equipment Expertise</th>
<th>2.2 PAM Expertise</th>
<th>2.3 Fleet Knowledge/Exp</th>
<th>2.4 Plant Staff Training</th>
<th>Composite Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted Weight</td>
<td>0.3629</td>
<td>0.1480</td>
<td>0.5261</td>
<td>0.1630</td>
<td>1.0000</td>
</tr>
<tr>
<td>A1 Internal Supply</td>
<td>0.0860</td>
<td>0.1286</td>
<td>0.1009</td>
<td>0.4274</td>
<td>0.1572</td>
</tr>
<tr>
<td>A2 OS Maj Maint + Config Mang</td>
<td>0.2174</td>
<td>0.1602</td>
<td>0.2030</td>
<td>0.0643</td>
<td>0.1914</td>
</tr>
<tr>
<td>A3 OS Maj Maint, Config + Op Sup</td>
<td>0.3766</td>
<td>0.4971</td>
<td>0.4947</td>
<td>0.1166</td>
<td>0.3906</td>
</tr>
<tr>
<td>A4 OS All Maint + Op Sup</td>
<td>0.0919</td>
<td>0.0707</td>
<td>0.0607</td>
<td>0.1154</td>
<td>0.0934</td>
</tr>
<tr>
<td>A5 OS All O&amp;M</td>
<td>0.2161</td>
<td>0.1433</td>
<td>0.1133</td>
<td>0.2563</td>
<td>0.1764</td>
</tr>
</tbody>
</table>

**Figure 23: Use-Case One - Alternative Composite Weighting Against RAM Influences**

This evaluation shows a very strong preference towards outage management and operational support. This is logical based on the added fleet specific knowledge that can be supplied by specialised engineering support. The provision of only maintenance
is perceived to be inferior because of the lack of coordination and sharing between the groups.

This evaluation gives a very strong advantage to the internal supply of services. This reflects the strong tradition of quality of utility based companies as well as the stronger motivation to meet legal requirements. The provision of major maintenance and configuration management also rates high primarily because control will remain with the owner, but additional knowledge will be brought in for overhauls.

This evaluation gives a very strong advantage to the internal supply of services. This reflects the high priority utility based companies place on the function because of their corporate commitments and risk exposure. Likewise suppliers of full O&M services rate high because of their need to prove competence to be accepted as a legitimate
possibility to take over the running of a plant. The remaining alternatives do not rate as high due to the possibility of overlapping and non-consistent procedures.

<table>
<thead>
<tr>
<th>Overhead/TA Cost</th>
<th>5.1 Opportunity Costs</th>
<th>5.2 Transaction Costs</th>
<th>5.3 Cooperation Costs</th>
<th>5.4 Internal Overheads</th>
<th>Composite Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted Weight</td>
<td>0.4462</td>
<td>0.3789</td>
<td>0.1114</td>
<td>0.0605</td>
<td>1.0000</td>
</tr>
<tr>
<td>A1 Internal Supply</td>
<td>0.1403</td>
<td>0.3508</td>
<td>0.8977</td>
<td>0.0443</td>
<td>0.2429</td>
</tr>
<tr>
<td>A2 OS Maj Maint + Config Mgmt</td>
<td>0.3388</td>
<td>0.0936</td>
<td>0.1996</td>
<td>0.1219</td>
<td>0.2922</td>
</tr>
<tr>
<td>A3 OS Maj Maint, Config + Op Sup</td>
<td>0.2541</td>
<td>0.2192</td>
<td>0.1690</td>
<td>0.2285</td>
<td>0.2775</td>
</tr>
<tr>
<td>A4 OS All Maint + Op Sup</td>
<td>0.0811</td>
<td>0.0702</td>
<td>0.0660</td>
<td>0.2665</td>
<td>0.0925</td>
</tr>
<tr>
<td>A5 OS All O&amp;M</td>
<td>0.0816</td>
<td>0.0675</td>
<td>0.1065</td>
<td>0.3435</td>
<td>0.0948</td>
</tr>
</tbody>
</table>

This evaluation gives prominence to options where the provision of major maintenance and configuration management is outsourced. This reflects the owner’s advantage created through a reduction of the costs needed to build up and maintain specialised engineering resources for each machine type. This advantage is lost in contracts providing more O&M services due to the inherently high transactional and cooperation costs of large utility based companies.

The results from the preceding evaluations are used to create a complete composite result, which is illustrated in Figure 27. This result indicates that there is very little overall preferential difference between three of the five alternatives. A manager faced with this result can presume that any of these alternatives would produce equally acceptable performance related to the goal of optimised asset management. However, as the model does not produce a clearly superior result the decision process is not absolutely clear. A final decision would therefore require additional investigation of the alternatives using real data for named O&M suppliers. This data would involve comparing exact figures obtained through a tendering process and/or benchmarking. The results can be utilised to update the pairwise comparisons with the intent of producing a more definitive result.

Figure 26: Use-Case One - Alternative Composite Weighting Against Overheads and TA Costs
Another aspect of the decision, which should not be overlooked, is the personal preferences and biases of the management involved in the business decision. Every person has some level of cognitive bias, which they will use in their decision-making processes. Faced with a very close result in the AHP evaluation a manager may make the final decision based on gut feeling rather than pursue a more in-depth analysis. This gut feeling is likely reflective of the organisational culture and structures that exist within the company, and is therefore a reasonable outcome for the decision process where differences in value are minimal.

5.2.2 Use-Case One – Validity Check

The final step of the AHP is to perform a validity check of the results to determine if any adjustment in the model is justified. This will be performed in two steps. The first step is an evaluation of the overall results, and the second step is an evaluation of the results based on real world experience29 and choices made by similar companies.

Model Review

To evaluate the overall model it is useful to show the connections between the alternatives and the key criteria in a visual format to show the sensitivity of theses relationships. The sensitivity graphs illustrated in Figure 35 provides this overview.

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29 The real world experience provided in this paper is based on the author’s familiarity with the industry in North America, Europe, Asia, and Australasia. At the time of writing, no detailed surveys have been conducted regarding these issues, and therefore no specific companies shall be named.
Figure 28: Use-Case One - Sensitivity Graph

The sensitivity graph for Use-Case One verifies that the key drivers of lifecycle cost, RAM influence, and EHS performance provide the greatest impact on the results. This is consistent with the type of company described for this case. The large differences in lifecycle cost ratings between internal supply and the two major maintenance and configuration management options are remarkable and should be more closely securitised in a real evaluation.

Real World Comparison

There are many examples within the industry of large utility based companies using all three of the preferred choices. While many of the large utility companies have internalised all of their O&M requirements it is very common for others to choose to outsource the parts of their O&M services covering major maintenance and configuration management, particularly through LTSA type contracts (Grace, 2005). Many major European utility-based companies have chosen to contract for operational support as well as standard LTSA coverage for advanced gas turbine plants, to gain from performance guarantees as well as additional equipment expertise.

The prevalence of all of three types of service provision within the industry supports the AHP result indicating the closeness of their priority ratings. The final choice by companies is often the result of company history, relationships to suppliers, or corporate culture.

5.3 Results for Other Use-Cases

To complete the validation complete models were derived using AHP for the remaining two use-cases using the same methodology. The derived results were also consistent with real world experience and are provided in summary.
5.3.1 Use-Case Two Evaluation

<table>
<thead>
<tr>
<th>Optimal Asset Management</th>
<th>Lifecycle Costs</th>
<th>RAM Influence</th>
<th>Quality</th>
<th>EHS Performance</th>
<th>Overhead / TA Costs</th>
<th>Composite Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria Rating</td>
<td>0.1992</td>
<td>0.5046</td>
<td>0.1237</td>
<td>0.1186</td>
<td>0.0957</td>
<td>1.0000</td>
</tr>
<tr>
<td>A1 Internal Supply</td>
<td>0.0610</td>
<td>0.0872</td>
<td>0.2995</td>
<td>0.2195</td>
<td>0.1266</td>
<td>0.1174</td>
</tr>
<tr>
<td>A2 OS Maj Maint + Config Mang</td>
<td>0.1514</td>
<td>0.1093</td>
<td>0.1387</td>
<td>0.2697</td>
<td>0.1266</td>
<td>0.1401</td>
</tr>
<tr>
<td>A3 OS Maj Maint, Config + Op Sup</td>
<td>0.2419</td>
<td>0.2469</td>
<td>0.1043</td>
<td>0.2720</td>
<td>0.1816</td>
<td>0.2282</td>
</tr>
<tr>
<td>A4 OS All Maint + Op Sup</td>
<td>0.2771</td>
<td>0.2625</td>
<td>0.1524</td>
<td>0.0840</td>
<td>0.2589</td>
<td>0.2380</td>
</tr>
<tr>
<td>A5 OS All O&amp;M</td>
<td>0.2921</td>
<td>0.2784</td>
<td>0.3111</td>
<td>0.1544</td>
<td>0.3400</td>
<td>0.2743</td>
</tr>
</tbody>
</table>

Figure 29: Use-Case Two - Weighting of Alternatives With Reference to Goal

This result indicates that there is very a very strong preference given for full O&M service provision, followed relatively closely by full maintenance and major maintenance with operational support. This reflects the ability of the O&M supplier to provide a higher level of experience and knowledge related to the specific equipment involved in a GTCC power plant. Given the results of this model a manager would have to seriously consider outsourcing the O&M services at the power plant as a first option.

5.3.2 Use-Case Two – Validity Check

Model Review

The sensitivity graph for Use-Case Two shows verifies that the key driver, RAM influence, has the biggest influence on the overall results, with a lesser influence allotted to lifecycle costs, quality, and EHS performance. This is consistent with the industrial company described for this case, as this type of company will be more dependent on revenue performance compared to a utility based firm. The large differences in RAM influence ratings between internal supply and the three options that supply greater outsourcing drive the overall decision process. This result is consistent with the assumptions suggesting that the specialised O&M provider will have greater influence on the reliability factors.
Real World Comparison

There are many examples within the industry of industrial companies using all three of the preferred choices. A major natural gas company in Spain has chosen full outsourcing as a preferred method of operating power plants, as has refinery owners in the United States, Italy, and Brazil. There are fewer examples of the outsourcing of only maintenance with the operation provided by the owner, presumably due to the coordination issues. The third option, provision of major maintenance, configuration management and operational support, is used in many facilities worldwide where the owner has significant competence in operating plants.

Often owners will utilise outsourcing of the O&M services at new plants in order to gain knowledge and understanding before deciding whether to insource the service at the end of the contract term. In these cases the service is used much like a real option wherein the owner can choose to either extend the contract or take over the O&M at some point in the future.

The prevalence of all of three types of service provision within the industry supports the AHP result indicating the closeness of their priority ratings. The final choice by companies is often the result of company history, relationships to suppliers, or corporate culture.
5.3.3 Results for Use-Case Three

Figure 31: Use-Case Three - Weighting of Alternatives With Reference to Goal

This result indicates that there is very a very strong preference given for full O&M service provision, followed relatively closely by full maintenance and major maintenance with operational support. This reflects the ability of the O&M supplier to provide a higher level of experience and knowledge related to the specific equipment involved in a GTCC power plant. Given the results of this model a manager would have to seriously consider outsourcing the O&M services at the power plant as a first option.

5.3.4 Use-Case Three – Validity Check

Model Review

The sensitivity graph for Use-Case Three verifies that the key driver, RAM influence, has the biggest influence on the overall results, with a lesser influence allotted to lifecycle costs, quality, and EHS performance. This is consistent with the IPP company described for this case, as this type of company will be highly dependent on revenue performance to meet its cash flow requirements. In this case study the provider of full O&M services shows a clear advantage across the entire range of criteria. This advantage reflects the difference between a well-established speciality company and the relative inexperience of the IPP firm.
Real World Comparison

The use of full O&M service providers by IPPs is very common, especially in cases where: the IPP is a relatively small, is new to the business, or where higher technology F class turbines are used. Many plants developed in the 1990s in Asia, North and South American, utilised such contracts. Several of these owners chose to reduced the scope after the end of the first contract as the company gained skills and knowledge

Often owners will utilise outsourcing of the O&M services for new plants in order to gain knowledge and understanding before deciding whether to insource the service at the end of the contract term. As with the industrial company examined in the second use-case, the IPP will view a service contract much like a real option.

With smaller truly independent IPPs full O&M contracts have been the predominant types of service provision within the industry. This supports the AHP result indicating the closeness of their priority ratings.

6 Recommended Future Actions

To further improve and refine the model and improve the results, further research can be conducted to verify both the structure of the model and the use-case preferences. This research would require direct feedback from management of companies who are in the position to consider the outsourcing decision. This can be accomplished through structured questionnaires and brainstorming meetings designed to verify the structure of the hierarchy as well as the weighting of the criteria. As it is in the interest of O&M service companies to understand their customer’s needs this further research will need to be sponsored by such a company. The following recommendations are intended to support this additional research:

1. With the support of management and marketing, develop a structured customer questionnaire designed to verify the main criteria and sub-criteria of the model. This questionnaire is to send out to key customers in each of the three use-case
groupings and will provide confirmation of the criteria and an indication of the weighting.

2. Identify and invite managers from key customers to participate in the full AHP evaluation process structured as a brainstorming session. To get the best results and reduce biases, this should be done with a small group representing operational, financial, and top management. During this session the facilitator, who is familiar with both the industry and the methodology, can define the known criteria but should be open to change the structure and hierarchy as required.

3. The facilitator should be provided with commercially developed AHP software to support flexibility. A spreadsheet model cannot be easily modified if the hierarchal structure is changed or layers added.

4. The results from the brainstorming sessions should be compared with questionnaire results to provide a richer overall picture. These results, in a general non-specific form, can be fed back to the participating companies and may be used as the basis for an industrial paper.

5. The results, compiled by the facilitator, can be made available to the sponsoring service company as a basis to identify and focus its own service development.

7 Conclusion and Analysis

The viability of outsourcing O&M services in the power industry has been demonstrated by both the richness of literature on the subject, of which only a small sampling has been referenced in this report, and by real world examples from power and similar industries. The amount of service outsourced varies depending on the type and strategic intent of the companies involved. It is apparent from the literature and examples that, while certain generalities can be made, there is no one size fits all package for O&M services. Each individual firm needs to perform its own evaluation for plant asset management based on its own competences, strengths and corporate strategy. To support this decision process, the AHP model, based on the work of Thomas Saaty, demonstrates that it has the capability to provide an easy to use method, covering both tangible and intangible criteria.

The main challenge of an AHP model is the development of a hierarchal structure on which to base the calculations, and the translation of this hierarchy into tool capable of performing the synthesis. The hierarchy used in this paper is soundly based on the key industry drivers and is comprehensive enough to allow a thoughtful evaluation to be made. To complete this evaluation required the building of a mathematical model to perform the pairwise comparisons and synthesise the results.

The model proved functional and usable when performing the evaluation for all three use-cases without requiring additional research or calculations for attributes of the criteria. This feature makes the AHP model particularly useful for applications where these details may not be available and where the decision maker must rely on expert
opinions. It is recommended by Saaty (2001) that better results can be obtained using a group of experts with different backgrounds as opposed to relying on a single person’s knowledge.

The results obtained from industry use-cases provide results that are comparable to real world experience. The preference of a large utility based company would be expected to lean towards internal supply or a minimal outsourcing whereas an IPP with little experience would be expected to more strongly favour a more comprehensive level of outsourcing. The overall results, as summarised in Figure 50 confirm this result based on a logical analysis on all key criteria. The consistency of these results together with the ease of use for the model demonstrates its applicability for the industry and usefulness in supporting the outsourcing decision.

![Figure 33: Summary of Alternative Preferences - All Use-Cases](image)

In addition to supporting the asset owners with outsourcing options, this tool can be useful for service companies by allowing them to identify customer requirements and areas of focus. This can be achieved through the evaluation of the sensitivity of the key attributes towards the final preference rating, and the focusing of efforts to improve performance in areas that provide the highest leverage.
References


Appendix 1: AHP Calculation Methodology

Constructing Hierarchies

The construction of hierarchies refers to the decomposition of complex decisions into main criteria and homogenous clusters (Saaty, 2001). To build a functional hierarchy of a complex problem, as is required for decision making, each level of the hierarchy occupies a single level. The top level is the focus or goal of the problem. This is the only element at the top level and is used to describe the overall objective of the process. In the question being examined the overall goal can be described as the provision of optimal asset management for the facility. To determine what constitutes this overall goal the next step would be to develop the main criteria that are important to the decision maker in respect to asset management. These main criteria then make up the second tier of the hierarchy and normally are limited to a reasonable number, Saaty recommends between five and nine (Saaty, 2001 p31). If the main criteria are in themselves complex, they too can be decomposed into their constituent elements at the next layer of the hierarchy. At the lowest level of the hierarchy are placed the alternatives or choices. The items at this level are compared with each other in relation to the lowest levels of the hierarchy.

A simple hierarchy as shown in Appendix Figure 1 demonstrates the relationship between the levels of a decision hierarchy. Under the goal are three main criteria. Each criteria has two sub-criteria.

Establishing Priorities

In Saaty’s AHP model the pairwise comparisons are performed by making judgments against the next higher level in the hierarchy using a scale of absolute numbers from one to nine. Saaty defined this scale (Saaty, 1986, 1994, 2001) as being adequate for creating analysis against reasonably homogenous comparisons while staying within a single order of magnitude. The fundamental scale developed by Saaty for this purpose is given in Appendix Figure 2 and gives a relatively clear guideline for making judgment decisions between two criteria.
### Table: Importance Intensity Definitions and Explanations

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective/criteria</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience and judgment slightly favour one activity over another</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td>Experience and judgment strongly favour one activity over another</td>
</tr>
<tr>
<td>7</td>
<td>Very strong or demonstrated importance</td>
<td>An activity is favoured very strongly over another; its dominance is demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favouring one activity over another is the highest possible order of affirmation</td>
</tr>
</tbody>
</table>

| 2,4,6,8       | For compromise between previous values | To allow an interpolation between numerical judgements when there are no words to describe the difference |
| Reciprocals of the above | If aspect A has one of the above non-zero numbers assigned to it when compared with B, then B will have the reciprocal when compared with A | A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit |

#### Appendix Figure 2: The Fundamental Scale for Pairwise Comparisons (Saaty, 2001 p73)

It is important to note that this scale provides a comparison based on relative values between criterion rather than attempting to replicate mathematically an absolute comparison as is sometimes done using expectant utility theories. One of the reasons for this is the fact that absolute values do not always convey enough information related to the importance of the measurement. For example, a person living in Northern Canada where it is -40°C may wish for a warm vacation in January and might consider the following options: Vancouver with an average high temperature of 5°C, Florida with its average high temperature of 23°C, Honolulu with an average high temperature of 26°C or Queensland with an average high temperature of 32°C. Based purely on measured value the vacationer should choose Queensland as it has the highest temperature. Based on judgments the result may be completely different. The vacationer may rate Vancouver as only marginally better than staying home even though it has the highest differential temperature, but is still cold, and rate Queensland as only moderately better than home because they would feel it is too hot, but would judge Miami and Honolulu both similarly better than other choices. This example demonstrates that while absolute measurements are important their value can only be assessed based on the value judgment individuals assign to these measurements.

According to Saaty (2001, p72) when making pairwise comparisons a matrix is the preferred form as it allows for obtaining additional information from comparing all possible comparisons and provides for the development of priorities by establishing dominance between aspects. A matrix also provides for testing of consistencies and sensitivity of the overall priorities that can result from changes in judgment.

To build a matrix it is necessary to start at the top of the hierarchy and make a comparison between each of the criteria as it relates to the goal/target using the
fundamental scale as shown in Appendix Figure 3. In this example C1 is moderately more important than C2 and very strongly important compared to C3. The criteria C2 is considered moderately important compared to C3.

Appendix Figure 3: Pairwise Comparison using Fundamental Scale

From this pairwise comparison a matrix can be developed showing the numbers that are derived. As each criterion must have an equal value when compared with itself the central diagonal of cells will always contain the number one. The cells in the upper right corner are first filled with the results from the pairwise comparison. That is C1 compared to C2 will by four; C1 to C3 will be eight and so on. The cells located in the lower left side of the will be the reciprocal of its diagonal opposite. For example if C1 compared to C2 is represented by the numeral 4 then it is logical that C2 compared to C1 will be represented by its reciprocal 1/4. In this way the entire matrix is filled as shown in Appendix Figure 4. This matrix will provide the basis for the derivation of priorities.

Appendix Figure 4: Example of Matrix Derived from Pairwise Comparison

The derivation of priorities from the constructed matrix requires some mathematical actions in order to synthesise the judgments. This can be demonstrated in an approximate method by first adding the values in each column then dividing each cell by the total of its column to form a normalised matrix as shown in Appendix Figure 5. The percentage of overall relative preference for each criterion can then be obtained with a normalised priority vector for each row by simply averaging the row. In the example given C1 would have a preferential percentage rating of 72.7% compared to 18.2% for C2 and only 9.1% for C3.
In the example shown the priority vector is identical to the normalised results in each column. This indicates that the comparison is completely consistent. This consistency can be shown mathematically using the following method. If \( C_1 = 4C_2 \) and \( C_1 = 8C_3 \) then \( 4C_2 = 8C_3 \) or \( C_2 = 2C_3 \), which is exactly as indicated in the matrix. However, many human judgments are not perfectly consistent resulting in different values. In the previous illustration it could be very possible for a decision maker to have a stronger opinion on one aspect of the evaluation, rating \( C_2 \) strongly important relative to \( C_3 \) so as to give it a rating of 5 rather than its previous 2. This judgment would be grounded by the experience of the decision maker and would be valid, but it would change the level of priority vectors in a significant way as shown in Appendix Figure 6. In most cases this level of inconsistency is not a major issue and satisfactory results can be obtained using this simple normalisation methodology for square matrices up to three by three as shown. However, for larger choice matrices with four or more criteria or those with a moderate level of inconsistency this method will not produce priorities that are sufficiently accurate for modelling (Teknomo, 2006).

To calculate results from inconsistent matrices with a more exact method Saaty recommends a more complex method to determine the eigenvector of the matrix to provide the priority (Saaty, 2001, p77). The eigenvector is described in linear algebra as a non-zero vector that, when transformed, result in a scalar multiple of itself. The scalar is then called the eigenvalue associated with the eigenvector. When used by AHP the eigenvector represents an accurate representation of the preferential priorities of the criteria. Though it is possible to calculate the eigenvalue exactly a simpler method to find a very close approximation is suggested by Saaty (2001, p79) wherein the whole matrix is raised to a sufficient power to ensure that virtually all combinations of dominance are determined\(^{30}\). In the development of a working model for use in this paper the author has found that in general the raising of matrices to their fourth or fifth

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\(^{30}\) Dominance between each criterion includes the direct link between them, in the example given \( C_1 \) can be compared directly to \( C_2 \) but its dominance can also be derived by comparing \( C_1 \) to \( C_3 \) then \( C_3 \) to \( C_2 \).
power produced results that are directly comparable with commercially available software such as Expert Choice®. 31

Appendix Figure 6: Example of Non-consistent Matrix

By using the power method to derive an eigenvector priority for the sample matrix shown in Appendix Figure 7 demonstrates a preferential priority that is slightly different than was determined using a simple normalisation method. The model developed for the evaluation described in this paper uses this eigenvalue priority for establishing all dominances within the AHP.

Appendix Figure 7: Example of Non-consistent Matrix with Principle Eigenvalues

Consistency

Even though Saaty does not insist on strict transitivity he does acknowledge without a high degree of consistency decisions based on judgments may appear to be random

31 Comparison of results from the model used in this paper and from a trial version of Expert Choice® are provided in Appendix 3.
and therefore not reliable. There is then a need to maintain enough consistency among
the objects to a level that allows the model to maintain coherence. His solution was to
develop a method to measure the amount of inconsistency that exists through the
calculation of what he termed the Consistency Index (CI) (Saaty, 1986, 1994, 2001). He
proposed that in any consistent matrix the Principle Eigenvalue ($\lambda_{max}$) will always be
equal to or greater than the number size of the matrix (n) and that a CI could be derived
using the following formula.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

To determine the value of $\lambda_{max}$ from a matrix one must first calculate the priority vector as
shown previously. The principle eigen value for each criteria is then multiplied by the
matrix column total of the corresponding criteria. The sum of these values will be the
Principle Eigenvalue ($\lambda_{max}$). For the matrix given as an example in Appendix Figure 7
$\lambda_{max}$ can be derived as follows.

$$\lambda_{max} = (1.375 \times 0.6986) + (5.200 \times 0.2370) + (14.000 \times 0.0643) = 3.094$$

Using this value for $\lambda_{max}$ the CI for the matrix can then be determined.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

$$CI = \frac{3.094 - 3}{3 - 1}$$

$$CI = 0.047$$

In a perfectly consistent matrix the CI would be equal to zero so this result shows
some level of inconsistency but the question remaining is how much is this inconsistent
and does this level make any material difference. To address this question Saaty
proposed that the results from this calculation could be compared against a scale of
results obtained from many randomly generated matrices of various sizes. Saaty and
Mariano each using a sample size of 500 random matrices (Wind and Saaty, 1980)
developed the Random Consistency Index (RI) that provides an average CI for different
matrices of different sizes as shown in Table 3 giving the basis for comparison. This
comparison termed the Consistency Ratio (CR) is defined as the CI of the matrix divided
by the RI for the matrix size expressed in percentage.

<table>
<thead>
<tr>
<th>n</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0</td>
<td>0</td>
<td>0.58</td>
<td>0.9</td>
<td>1.12</td>
<td>1.24</td>
<td>1.34</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
</tr>
</tbody>
</table>

**Appendix Figure 8: Random Consistency Index (RI) (Saaty, 1986, 1994, 2001 and 2008)**

Saaty proposed that a good consistency would be one where the resulting CR would be
a maximum of 10%. If the CR is above this value the judgments should be re-examined
and adjusted. From our example from Appendix Figure 7 the CR is calculated as 8.10%

---

32 In a consistent three by three matrix $\lambda_{max} = 3$ and therefore the CI would be equal to zero
$CI = 3-3/3-2 = 0$
(0.047/0.58) demonstrating that even though there is inconstancy in the judgments it is within the acceptable limits within the AHP model.

**Consolidating the AHP Model**

To determine the overall preference of alternatives relative to the main goal or focus it is necessary to synthesize the results of all of the pairwise comparisons. This process involves performing pairwise comparisons at each level of the hierarchy and using the higher level priority vector results to act as an adjusting weighting for the next lower level. Using the same results shown from Appendix Figure 7 the level two criteria with evaluations done against five alternatives for each criteria could produce the results shown in Appendix Figure 9. In this table the adjusted weight for criteria C1-C3 is represented by their derived priority. The composite weighting for each alternative is derived from summing the adjusted weights of its priority related to each criterion.

\[
CW_{AI} = (0.2449 \times 0.6986) + (0.4143 \times 0.2370) + (0.3295 \times 0.0643)
\]

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>Composite Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted Weight</td>
<td>0.6986</td>
<td>0.2370</td>
<td>0.0643</td>
<td>1.0000</td>
</tr>
<tr>
<td>A1 Alternative 1</td>
<td>0.2449</td>
<td>0.4143</td>
<td>0.3295</td>
<td>0.2905</td>
</tr>
<tr>
<td>A2 Alternative 2</td>
<td>0.0649</td>
<td>0.1350</td>
<td>0.1037</td>
<td>0.0840</td>
</tr>
<tr>
<td>A3 Alternative 3</td>
<td>0.1297</td>
<td>0.1350</td>
<td>0.1854</td>
<td>0.1348</td>
</tr>
<tr>
<td>A4 Alternative 4</td>
<td>0.1225</td>
<td>0.0743</td>
<td>0.0518</td>
<td>0.1065</td>
</tr>
<tr>
<td>A5 Alternative 5</td>
<td>0.4380</td>
<td>0.2414</td>
<td>0.3269</td>
<td>0.3845</td>
</tr>
</tbody>
</table>

**Appendix Figure 9: Overall Composite Weight of Alternatives**

The resultant composite weighting represents the preferential value of each alternative related to the level above the criteria in the hierarchy that in this simple case would be against the overall goal or focus. In this example alternative 5 has the highest ranking at 38.45% making it the preferred choice.

After completing the composite weighting for the entire hierarchy and determining the preference it is possible to calculate the overall consistency. This can be done by summing the weighted consistency index (CI) and dividing this by a weighted random consistency index (RI). The weighting for the second level criteria will always be one as the goal is at a higher level and the next level lower will use the priority weighting of the criteria. For our example this can be calculated as follows:

\[
CR = \frac{\sum w_i CI_i}{\sum w_i RI_i} = \frac{(0.047 \times 1) + (0.0033 \times 0.6986) + (0.0043 \times 0.2370) + (0.0033 \times 0.0643)}{(0.58 \times 1) + (1.12 \times 0.6986) + (1.12 \times 0.2370) + (1.12 \times 0.0643)} \approx 0.0505 = 0.0297 = 2.97\%
\]
Appendix 2: Detailed Calculation Use-Case One

The following pages give the detailed calculation from the AHP for this use case, which was used to derive the results given in, Section Five. The example begins with a hierarchal overview showing all synthesised results. Subsequent pages provide the pairwise comparison and derived matrices for the criteria, sub-criteria, and alternatives in that order.

Use-cases two and three results are not included with this report but are available on request from the author.

Complete Hierarchy Results

[Diagram of hierarchy results]
### Criteria Pairwise Comparison

<table>
<thead>
<tr>
<th>Criteria</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>Total</th>
<th>Strength</th>
<th>Weakness</th>
<th>Consistency Index</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifecycle Costs</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>37</td>
<td>Poor</td>
<td>Strong</td>
<td>0.3811</td>
<td></td>
</tr>
<tr>
<td>RAM Influence</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td>27</td>
<td>Poor</td>
<td>Strong</td>
<td>0.3811</td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td>2</td>
<td>3</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td>27</td>
<td>Poor</td>
<td>Strong</td>
<td>0.3811</td>
<td></td>
</tr>
<tr>
<td>EHS Performance</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>Overhead</td>
<td>Full</td>
<td>0.9423</td>
<td></td>
</tr>
</tbody>
</table>

#### Criteria Pairwise Matrix

<table>
<thead>
<tr>
<th></th>
<th>Lifecycle Costs</th>
<th>RAM Influence</th>
<th>Quality</th>
<th>EHS Performance</th>
<th>Overhead/F&amp;A Cost</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifecycle Costs</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>RAM Influence</td>
<td>7/3</td>
<td>1</td>
<td>6</td>
<td>1/2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td>1/5</td>
<td>1</td>
<td>1/5</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>EHS Performance</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Overhead/F&amp;A Cost</td>
<td>1/7</td>
<td>1/5</td>
<td>1</td>
<td>1/6</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

### Results

- **Consistency Index**: 0.3811 (Consistent)
- **Shepard's Random Consistency Index**: 0.0457 (Consistent)

---

*William (Bill) Mercer*  
*Page 85*
### Sub-Criteria Pairwise Comparison

#### Criteria: OPEX

<table>
<thead>
<tr>
<th>Sub-Criteria</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset Value Retention</td>
<td>1.3</td>
<td>1</td>
<td>3/3</td>
<td>1.1 OPEX</td>
<td>1.2 OPEX</td>
</tr>
<tr>
<td>Risk Costs</td>
<td>1.4</td>
<td>2</td>
<td>1.2 CAPEX</td>
<td>1.1 CAPEX</td>
<td>1.1 OPEX</td>
</tr>
<tr>
<td>Risk Costs</td>
<td>1.4</td>
<td>1</td>
<td>1.2 CAPEX</td>
<td>1.1 CAPEX</td>
<td>1.1 OPEX</td>
</tr>
</tbody>
</table>

#### Consistency Index: 2.26% OK

#### Comments
- Large utility companies are seldom capital-constrained, therefore operating expenses are an issue.
- Asset-value retention related to protect investments. Most assets are long-term for utility plants.
- Utilities have capability to develop portfolio risk management capabilities, therefore individual plant risks are minimized.

#### Criteria: Equipment Expertise

<table>
<thead>
<tr>
<th>Sub-Criteria</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAM Expertise</td>
<td>2.2</td>
<td>3</td>
<td>2.1 Equipment Expertise</td>
<td>2.1 Equipment Expertise</td>
<td>2.2 Equipment Expertise</td>
</tr>
<tr>
<td>PM Main Training</td>
<td>2.4</td>
<td>2</td>
<td>2.2 PAM Expertise</td>
<td>2.1 Equipment Expertise</td>
<td>2.3 Fleet Knowledge/Eop</td>
</tr>
<tr>
<td>Plant Staff Training</td>
<td>2.4</td>
<td>1</td>
<td>2.2 PAM Expertise</td>
<td>2.1 Equipment Expertise</td>
<td>2.3 Fleet Knowledge/Eop</td>
</tr>
<tr>
<td>Plant Staff Training</td>
<td>2.4</td>
<td>2</td>
<td>2.2 PAM Expertise</td>
<td>2.1 Equipment Expertise</td>
<td>2.3 Fleet Knowledge/Eop</td>
</tr>
</tbody>
</table>

#### Consistency Index: 6.30% OK

#### Comments
- Specific skills related to individual units important, utilities tend to have a mixed fleet with many different types of machines and OEM suppliers.
- Fixed knowledge regarding the large diversified fleet of a utility allows collection and consolidation of information for problem solving and improvements.
- Predefined maintenance skills and training systems, are normally well-developed in utilities already.

#### Criteria: Legal Compliance

<table>
<thead>
<tr>
<th>Sub-Criteria</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO9000 Certification</td>
<td>3.2</td>
<td>9</td>
<td>3.1 Legal Compliance</td>
<td>3.1 Legal Compliance</td>
<td>3.2 ISO9000 Certification</td>
</tr>
<tr>
<td>ISO9000 Certification</td>
<td>3.2</td>
<td>9</td>
<td>3.1 Legal Compliance</td>
<td>3.1 Legal Compliance</td>
<td>3.2 ISO9000 Certification</td>
</tr>
<tr>
<td>Systems and Tools</td>
<td>3.3</td>
<td>5</td>
<td>3.2 ISO9000 Certification</td>
<td>3.2 ISO9000 Certification</td>
<td>3.3 Systems and Tools</td>
</tr>
<tr>
<td>Systems and Tools</td>
<td>3.3</td>
<td>6</td>
<td>3.2 ISO9000 Certification</td>
<td>3.2 ISO9000 Certification</td>
<td>3.3 Systems and Tools</td>
</tr>
<tr>
<td>Plant &amp; Stock Control</td>
<td>3.4</td>
<td>3</td>
<td>3.1 Legal Compliance</td>
<td>3.1 Legal Compliance</td>
<td>3.3 Systems and Tools</td>
</tr>
<tr>
<td>Plant &amp; Stock Control</td>
<td>3.4</td>
<td>3/3</td>
<td>3.1 Legal Compliance</td>
<td>3.1 Legal Compliance</td>
<td>3.3 Systems and Tools</td>
</tr>
</tbody>
</table>

#### Consistency Index: 4.37% OK

#### Comments
- Retaining legal status within an operating jurisdiction is critical to a utility's ability to maintain competitive advantage, also called "big bang" industries with non-compliance at one plant may face additional scrutiny of others.
- Quality systems are well developed and maintained as a method to ensure consistency across a broad fleet.
- Maintenance systems and stock control are vital in order to keep control of all assets on a consistent basis and to optimise maintenance programs.
- ISO certification not considered critical because there is no requirement from customers to achieve external recognition and internal systems are adequate.
- Certification may be pursued only to verify internal systems.
## Evaluation of the Outsourcing Decision for O&M Services

### Sub-Criteria Matrices

#### Group 1

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<tr>
<th>Group 1</th>
<th>OFEX</th>
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<th>Risk Costs</th>
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### Comments

- Both existing performance and a sound system are considered more important than achieving certification. Reputation and compensation ratings dependant on actual incident records more than external certification.
- Utilities normally have well developed system safety concepts and require all new plants to follow risk assessment and risk management practices.

- Utility based companies regard their core competencies to be related to asset management activities that might also allow for their internal resources in this area to be construed as an creating opportunity costs.
- Transaction costs are high due to the corporate structure, many layers are involved with purchasing, review, legal, risk review, and management oversight creating significant costs per transaction.
- Costs of cooperation are not considered as high in the sense of alliance relationships are common.
- Internal overheads are also high due to the bureaucratic nature of the organization, but are considered part of the business and therefore not appropriated a high importance.
## Evaluation of the Outsourcing Decision for O&M Services

<table>
<thead>
<tr>
<th>Group 2</th>
<th>Equipment Expertise</th>
<th>PAM Expertise</th>
<th>Plant Knowledge/Expert</th>
<th>Plant Staff Training</th>
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**Note:** The table above presents the evaluation of the outsourcing decision for O&M services, considering various factors and their corresponding weights and priorities. The consistency check is also provided to ensure the reliability of the evaluation process.
## Evaluation of the Outsourcing Decision for O&M Services

### Table 1: Comparative Analysis of O&M Services

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**William (Bill) Mercer**

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### Alternatives Pairwise Comparison

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<tr>
<td>Internally</td>
<td>1/3</td>
</tr>
<tr>
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</tr>
<tr>
<td>Opt/Maint</td>
<td>1/3</td>
</tr>
<tr>
<td>Opt/Maint + Condly/Mang</td>
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</tr>
<tr>
<td>Opt/Maint, Condly + Op Sup</td>
<td>1/3</td>
</tr>
<tr>
<td>Opt/Maint</td>
<td>1/3</td>
</tr>
<tr>
<td>Opt/Maint + Condly/Mang</td>
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<tr>
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<td>Opt/Maint + Condly/Mang</td>
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### Comments

- Outsourcing cheaper maintenance and configuration management. 
- Supplier has greater ability to use economies of scale (larger similar fleet). 
- Operational support provides an augmentation to the existing engineering departments. 
- Precision of all maintenance is more attractive because firms normally have internal systems and can make higher costs in a plant due to having a separate supplier for half of the function. 
- Can still be considered cost effective than internal supply since internal services are not contractually related and structures.

- Service provided for major maintenance reduces capital costs through the conversion of capital spares requirements into operating costs associated with the O&M firms. 
- Full maintenance services do not add significantly to capital cost optimization and may not be needed to improve maintainability and benefits the supplier more than the owner.
Evaluation of the Outsourcing Decision for O&M Services

### 2.1 Equipment Repair

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### 2.3 O&M Expertise

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### 2.4 O&M Management

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### Evaluation of the Outsourcing Decision for O&M Services

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#### Comments

- As with PAM, best knowledge is achieved through the combination of the customer's knowledge, together with that of the supplier bringing in the new machine/software. This favors operational support contractors.
- Assuming that the customer and supplier each manage a sufficiently sized O&M team and that all O&M work is done in house, supplier training and feedback from daily operations does not impact the supplier's knowledge.

- Utility-based companies require development of the system and training of staff as a highly important activity and therefore must have a strong focus on training.

- The supplier must have the ability to ensure compliance with legal standards and therefore assurance systems will be upgraded since the supplier is generally independent and freely regulated.

- Full O&M transfer creates a similar level of accountability through accountability transfer to the supplier.

Consistency Index: 1.5% 01
## Evaluation of the Outsourcing Decision for O&M Services

### 1.2 Design & Cost Estimation

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Categories</th>
<th>Decision</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Internal Supply</td>
<td>1</td>
<td>A utility-based company might have specific need for external verification of its key systems to meet regulatory requirements. However, suppliers being will often be required to demonstrate competence through ISO certification.</td>
</tr>
<tr>
<td>A2</td>
<td>O&amp;M Service</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>O&amp;M Service + Conty Maint</td>
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<tr>
<td>A4</td>
<td>O&amp;M Service + Conty Maint + Op Sup</td>
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### 2.1 Systems & Maintenance

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<th>Decision</th>
<th>Notes</th>
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<tbody>
<tr>
<td>A1</td>
<td>Internal Supply</td>
<td>1</td>
<td>Quality systems need a large number of components that are very well developed and require constant repair and maintenance. In many cases, the systems are of high reliability and maintain a high standard.</td>
</tr>
<tr>
<td>A2</td>
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</tr>
<tr>
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### 3.1 Human Resources

<table>
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<tr>
<td>A1</td>
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<td>As with other systems, and to ensure the management of maintenance and stock control will be considered crucial both for the owner and the service provider.</td>
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<tr>
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<td>O&amp;M Service + Conty Maint</td>
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<tr>
<td>A4</td>
<td>O&amp;M Service + Conty Maint + Op Sup</td>
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## Evaluation of the Outsourcing Decision for O&M Services

### Table 1: Opportunities to Improve Facility Management Performance

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<th>Internal Supply</th>
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<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
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</tbody>
</table>

**Comment:** Utilize ISO/IEC 9000 quality standards; ISO/IEC 14000 Environmental and OHSAS 18000 Health and Safety Standards are much more important to the owner. Compliance in these standards will demonstrate to external stakeholders the company's commitment to its corporate objectives. Suppliers providing O&M will not meet OHS certification in order to demonstrate its competence in providing service at a high standard. This differing standard between the owner and supplier for outage situations may reduce the consistency of the procedures. This makes long-term, or sometimes, non-economic.

### Table 2: EMS Policy History

<table>
<thead>
<tr>
<th>Requirement</th>
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<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
<th>Choice</th>
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<td>1</td>
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<td>1</td>
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</tbody>
</table>

**Comment:** Many companies consistently have very high standards for EMS and therefore good performance history. Suppliers of O&M O&M service normally rely on high levels of EMS compliance as a differentiation. Major maintenance suppliers may have lower levels of EMS performance due to the lower level and temporary nature of some of the work under contract.

### Table 3: Maintenance Risk

<table>
<thead>
<tr>
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<th>A3</th>
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<th>Choice</th>
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</table>

**Comment:** Many companies consistently have very high standards for EMS and therefore good performance history. There will be any configuration where they maintain safety system control. When there is a division between the maintenance team and the operations team then there is the risk of having confusion between the different systems and risk management lead. Therefore, reducing the performance level. Suppliers of O&M may have their own systems at a similar level as the owner's organization.
### Evaluation of the Outsourcing Decision for O&M Services

#### Table 1: Outsourcing Cost Comparison

<table>
<thead>
<tr>
<th>Option</th>
<th>Initial Supply</th>
<th>O&amp;M Maint + Coord</th>
<th>O&amp;M Maint + Coord + Op</th>
<th>O&amp;M Maint + Coord + Op + Sop</th>
</tr>
</thead>
<tbody>
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</table>

**Consensus:**
- As utility companies have a critical engineering component there is very little opportunity to outsourcing full service. Some jobs can be outsourced by bringing in expertise for specific maintenance and repair management and operational support.

#### Table 2: Transaction Costs Comparison

<table>
<thead>
<tr>
<th>Option</th>
<th>Initial Supply</th>
<th>O&amp;M Maint + Coord</th>
<th>O&amp;M Maint + Coord + Op</th>
<th>O&amp;M Maint + Coord + Op + Sop</th>
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<tbody>
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<td>15</td>
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</tbody>
</table>

**Consensus:**
- Transactional costs with supply support are quite high in utility companies because of the business nature and complexity of the system. It is often discounted through overhead handling and general allocation of resources limiting perceived costs for internal supply services.

#### Table 3: Corporation Costs Comparison

<table>
<thead>
<tr>
<th>Option</th>
<th>Initial Supply</th>
<th>O&amp;M Maint + Coord</th>
<th>O&amp;M Maint + Coord + Op</th>
<th>O&amp;M Maint + Coord + Op + Sop</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>A3</td>
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<td>A4</td>
<td>0</td>
<td>5</td>
<td>15</td>
<td>0</td>
</tr>
</tbody>
</table>

**Consensus:**
- The costs involved with contracts such as the provision of major maintenance and service support are relatively small. There will likely be no additional personnel needed at the plant to manage the arrangement and any cost additional to the internal operation contract management.
- Larger contracts with daily management of maintenance and operational work requires more direct contact at the plant as well as additional personnel from both parties. Often additional "supervisory" positions are used at the plant to oversee the supplier.
Evaluation of the Outsourcing Decision for O&M Services

Alternatives Matrices

Section 1: Lifecycle Costs

<table>
<thead>
<tr>
<th>OPEX</th>
<th>Internal Supply</th>
<th>OS Maj Maint + Config Mang</th>
<th>OS All Maint + Op Sup</th>
<th>OS All O&amp;M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>1</td>
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<td>OS Maj Maint + Config Mang</td>
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<tr>
<td></td>
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<td>OS Maj Maint + Config Mang</td>
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<td>OS All Maint + Op Sup</td>
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<td>OS All O&amp;M</td>
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Consistency Check: 1.199871603, 0.562022779, 0.104854, 0.996919718

Approx. Eigenvalue: 4.5855, CI: 0.0176, CR: 0.12, Consistent:

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Consistency Check: 1.199871603, 0.562022779, 0.104854, 0.996919718

Approx. Eigenvalue: 5.0967, CI: 0.0176, CR: 0.12, Consistent:

As a result, the company has identified a clear advantage in terms of overhead cost reduction.
Evaluation of the Outsourcing Decision for O&M Services

### Asset Value Retention

<table>
<thead>
<tr>
<th></th>
<th>Internal Supply</th>
<th>GS Mgmt Maint + Confg Maint</th>
<th>GS Mgmt Maint, Confg Maint, Op Sup</th>
<th>GS All Maint + Op Sup</th>
<th>GS All O&amp;M</th>
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<tbody>
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### Asset Value Retention

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<th>GS Mgmt Maint, Confg Maint, Op Sup</th>
<th>GS All Maint + Op Sup</th>
<th>GS All O&amp;M</th>
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<th>Approx. Eigenvalue</th>
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### Consistency Check

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<th>GS Mgmt Maint, Confg Maint, Op Sup</th>
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### Risk Costs

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## Evaluation of the Outsourcing Decision for O&M Services

### PAM Expertise

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| Consistency Check   | 0.9660          | 0.9660                      | 0.9660                              | 0.9660     | 0.9660                    |       |     |     |       |            |

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| Consistency Check   | 0.9660          | 0.9660                      | 0.9660                              | 0.9660     | 0.9660                    |       |     |     |       | Consistent |
## Evaluation of the Outsourcing Decision for O&M Services

### Table 1: EHS Performance

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## Evaluation of the Outsourcing Decision for O&M Services

### Hazard / Risk Magic

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### Section 5: Overhead / DA Cost

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### Consistency Check

- **Overhead / DA Cost**: Consistent (CI = 0.000, CR = 0.000)
- **Transaction Costs**: Consistent (CI = 0.000, CR = 0.000)

---

William (Bill) Mercer  Page 101
## Evaluation of the Outsourcing Decision for O&M Services

### Cooperation Costs

<table>
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### Cooperation Costs

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### Internal Overheads

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<th>Internal Supply</th>
<th>OS Maj Maint + Contg Mng</th>
<th>OS Maj Maint + Contg + Op Sup</th>
<th>OS All Maint + Op Sup</th>
<th>OS All O&amp;M</th>
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### Internal Overheads

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</table>

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Appendix 3: Comparison of Excel® and Expert Choice® Software Model Results

To test the accuracy of the excel model used in this report a trial version of the commercially available Expert Choice® software was used. The software was fed with the identical structure and pairwise comparisons as were used in the evaluation of the Use-Case One example. The results of this trial are presented below in screen shots from the software, which are compared to the consolidated results from the self developed spreadsheet model. The results demonstrate that the spreadsheet model provides identical results to the commercial software with allowances for rounding differences. There is a slight difference in consistency rating, likely also do to rounding differences across the entire model.

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<tr>
<th>Criteria Rating</th>
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<th>Expert Choice</th>
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<td>RAM Influence</td>
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<tr>
<td>Quality</td>
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<tr>
<td>EHS Performance</td>
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<td>0.322</td>
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<tr>
<td>Overhead /TA Cost</td>
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<table>
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<tr>
<th>Sub-Criteria Ratings</th>
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<tbody>
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<td>OPEX</td>
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<td>Risk Costs</td>
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<td>Plant Staff Training</td>
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## Evaluation of the Outsourcing Decision for O&M Services

### Quality

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### EHS Performance

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### Overhead /TA Cost

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### Overhead

<table>
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<tbody>
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### Expert Choice

- **Summary**: Synthesis with respect to:
  - Goal: Optimum Asset Management
  - Overall Inconsistency = 0.02

- **Options**:
  - Internal Supply
  - Outsource Major Maint & Config Eng
  - Outsource Major Maint, Config Eng + Op Support
  - Outsource All Maint and Operations
  - Outsource All Maint + Op Support

---

*William (Bill) Mercer*  
*Page 104*
## Evaluation of the Outsourcing Decision for O&M Services

<table>
<thead>
<tr>
<th></th>
<th></th>
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<td>0.0533</td>
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### Overall Consistency of Hierarchy

0.014