STRATEGIC ASSET MANAGEMENT FOR PHYSICAL INFRASTRUCTURE: RUN, REPAIR, REFURBISH, REPLACE

By

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Abstract

Physical infrastructure assets are more than the sum of their components or the services they deliver. They are capital intensive to build or replace and are essential for economic development. Eventually the question of aging physical infrastructure assets becomes central to an asset manager and strategies evolve for ensuring continued effective operations and reliability of service. Asset managers responsible for physical assets are interested in making effective decisions about relevant capital or operational investments. These strategic decisions usually involve competing projects in an environment of finite human resources and capital. This project looks at theories of asset management relating to physical infrastructure and presents a strategic decision support process as a model for comparing and ranking strategic alternatives. The model presented enables the asset manager to compare and optimize strategic choices, evaluate financial implications over the long-term and consider corporate and operational risks in decision-making prior to funding commitments.

Keywords: Asset Management; Decision Support; Physical Infrastructure; Risk; Life-cycle Cost; Utilities, Discounted Cash Flow; Reliability; Enterprise Information Management; Net Present Value; Metachoice

Executive Summary

Physical infrastructure across North America and large parts of the industrialized world are over 30 years old. There is a growing awareness of the importance of these assets since they require significant capital investments and are essential for maintaining quality of life and security of modern society. This situation is also true in British Columbia and especially so for the British Columbia Transmission Corporation (BCTC) which was used as the test case in considering the central issue of this paper. However, the process presented is flexible and easily modifiable for any industry or physical asset other than BCTC or electric transmission lines.

The electric transmission system in British Columbia has an average age of 40 years, consists of about 100,000 distinct assets spread out over 18,000km of rough terrain. The book value of these assets is $11 billion with replacement costs over $100 billion. Given the critical nature of these assets and the regulated requirement for reliability and availability, asset managers in BCTC have to practice effective asset management.

The central issue here revolves around defining what an effective asset management decision should consider. Quite often asset managers focus on doing things right or more efficiently. In this report however, the focus is on doing the right thing or being effective in order to assure asset reliability going forward. Asset managers in BCTC, as with other firms that manage or own physical infrastructure, struggle with making defensible decisions related to running / maintaining, refurbishment or replacement of assets. There is some skill required in maintaining an economic balance between maintenance and replacement. The overall goal is to pursue the lowest life-cycle cost of an asset without negatively affecting the required level of performance. Aging assets have an increased average marginal cost largely due to increased requirements for maintenance dollars. Experience shows that there is not a clear approach for asset managers to use in evaluating opportunities for reducing these life-cycle maintenance costs. The challenge here is principally deciding what is worth doing and when to do it.

Asset management theory increasingly focuses on delivering a centralized approach to planning and investment management. Asset managers expect to make informed decisions across entire asset networks and consider strategic alternatives not only on their own merit but also

against the entire system. There is an appetite for cross-departmental collaboration even in rigidly hierarchical or functional organizations. A repeatable and logical framework is required to support asset management decisions for aged assets. This framework should consider the tangible monetized costs associated with alternatives but also include the intangible and none monetized aspects. An integration of maintenance and replacement planning with system growth requirements taking into account human and capital resource availability is a fundamental to the approach taken. The key considerations of the decision support methodology are:

- Corporate values and risk tolerance
- Asset condition assessment, failure rates and performance trend data
- Historical financial data, amortized replacement costs and discount rates
- Maintenance expense trending, reliability costs and options costs

This report examines general asset management theories and investigates best practices for asset investment as published in national and international standards, conference proceedings and so on.

The model presented in this report enables asset managers to have an objectively subjective and defensible approach to making investment decisions and requesting funding. The process also enables funding approvers or regulators to review planning assumptions and test sensitivity of proposals to any changes in discount rates, project timing, corporate risk or priorities.

In real terms, the Transmission Lines Asset Management Group in BCTC is successfully using the decision support methodology described to develop business cases for asset investment. At the time of writing, the author was a member of this group and transitioning to BC Hydro Power Authority. By order of the provincial government, BC Hydro has merged with BCTC as of July 1st 2010. Initial feedback is that the asset management function of the new BC Hydro will be an integrated model as advocated in this work with all the asset management and planning groups combined into a single corporate division. The decision support method introduced is very timely and is due for presentation to the larger organization in order to achieve buy in as a tool for planning investments.

The proposed decision support approach ensures that a physical infrastructure system continues to have operating capabilities required by stakeholders, enhanced return on asset investments and keep on providing a net social value to the wider public.

the biggest choice of all...

for the strength patience, provision and perseverance it had to have been the Son – I am indeed grateful and thankful.

for the proud smiles, for 'Sir Rod' who believed in doing the right thing at the right time always, for 'Miss Ayo' who makes sure it is always with grace and empathy.

for the proud smiles, for 'Smallz' who has unshakable faith in me and completes me, for 'Tatu' and 'Ziah' who tore up my papers and made me laugh in the midst of it all...

this is for you all...the biggest choice of all is the only real option!

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This work was started at a time of significant professional and personal change in my life and I would never have been able to complete the project without the support of my family. Not least, I would like to thank my wife, Yabome who was always in my corner with patience and forbearance whilst I spent countless hours on this project and often neglected the ‘do-list’. Her absolute belief that I could complete this project regardless of what else was going on was scarier than the work itself.

I hope this paper will stimulate further discussion and add value to thoughts on strategic asset management.

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1: Introduction

Physical infrastructure assets (PIA)s are the backbone of our industrialized economy in North America that support the effective functioning of the state, business activities and maintenance of our quality of life. For the purpose of this research project, I consider PIAs to be tangible, geographically dispersed assets that require significant capital outlays and labour to build, install and maintain as physical installations. The issues discussed in this paper are relevant for physical infrastructure ranging from transportation and communications networks to water, electricity and fuel production, storage, delivery systems as well as physical institutions such as universities and schools, prisons, sports centres and so on (Pickett, 2000).

1.1 Background

The scale, range and function of physical infrastructures supporting our society are very broad and there are significant differences in how owners operate the various assets. As an example, one could consider that the daily operations required for maintaining the function of a university are quite different from those required to ensure the delivery of water to customers in a defined area. However ensuring the physical assets continue to deliver the required reliability of performance in a safe and cost effective manner goes well beyond an operations oriented function to strategic or long-term asset management.

Asset management is a framework of structured decision-making geared towards the long-term maximization of value from assets under consideration given limited budgets and resources (Short, Feinstein, & Morris, 2006). The goal of maximizing value faces budget and resource pressures and increased output demands from the asset users. This happens while the assets themselves are aging rapidly.

Maintaining current operational reliability is becoming a significant issue for owners and asset managers. The issue of aging infrastructure across North America and much of the industrialized world has implications for the economic development of the public and even of nations. If owners chose to mitigate the aging trends through systematically refreshing assets as they near end of life, then there will be significant requirements for future investments in the asset bases of organizations. While this might have its merits under certain circumstances, the strategy might not always present the optimum choice. A strategy of run-to-failure is similarly not the optimum since at failure the solution is complete replacement. Clearly, the issues are not as straightforward as wait and see or throw money at the problem – it might go away.

1.1.1 Infrastructure Condition

In 2003, a Statistics Canada study looked at the four major asset classes comprising 80% of all federally, provincially and municipally owned PIAs. This study considered roads and highways, sewer systems, wastewater treatment facilities and bridges and found that the assets were generally over 50% of their designed useful or service lives (Gaudreault & Lemire, 2006). While the 2003 study and a similar work completed in 2008 noted that significant investments in new infrastructure had resulted in stabilizing these numbers and resulting in a younger stock of assets. There was no evidence that the scale of these additions were producing better performing asset classes (Gagnon, Gaudreault, & Overton, 2008). In the United States, a study of PIAs by the American Society of civil Engineers (ASCE) produced an infrastructure report card in 2005, which graded the Nations' infrastructure as being in poor shape. The report card projected a requirement for PIA investments of USD$ 1.6 trillion over the next 5 years. This investment is the projected requirement to ensure the aging trend is halted and stabilized (Henry et al., 2005). In addition, the US Department of Energy (DOE) estimates that while the electric power grid today is over 99% reliable, aging assets and outages cost stakeholders up to $100 billion a year. The DOE also estimates that there have been over 40% more outages affecting customers in recent times compared to the early 1990's (Department of Energy, 2008). It is patently obvious therefore that the asset base is aging and prudent asset management organizations have to develop strategies for mitigating this trend.

1.1.2 Asset Investment Focus

Building or installing major new PIAs usually gets significant support from organizations' leadership and federal, provincial or municipal governments. However, studies indicate that investing in these new PIAs does not dramatically reduce the aging of an asset class relative to its designed service life (Gaudreault & Lemire, 2006). As an example, the British Columbia Transmission Corporation (BCTC), which is responsible for operating and maintaining the Provincial electricity transmission grid, is currently investing in several capital projects. These projects will add approximately 4% of additional PIAs to the existing 18,000km of transmission circuits. Considering that the average age of BCTCs current capital stock is about 40 years, the new investments support the increasing demand for electrical power in British Columbia (BC) but they do not address the requirements for maintaining the

96% of aging PIAs. Given that similar numbers apply to other organizations and classes of assets, it is reasonable to understand that the asset management challenges faced in delivering the maximum net social value from PIAs are similar in scope.

1.2 Objectives

Asset managers involved in making decisions for maximization of value from PIAs have to consider monetary and non-monetary drivers in order to develop an economic balance between maintenance and replacement of assets. It is a typical goal in asset management practice to pursue the lowest life-cycle cost of an asset without negatively affecting the required level of performance while balancing the conflicting needs of all customers or users of the asset as well as stakeholders within the owners' organization.

A key objective of this project is to present a consistent and systematic business process for PIA owners making key strategic decisions targeted at aging assets. BCTC, as a utility with aging PIAs spread across the entire province of British Columbia is the focus of this project. The book value of the company's assets is $11 billion with a current estimated replacement value of over $100 billion. In addition, BCTC's capital stock is largely a linear asset consisting of transmission lines and infrastructure suspended over the ground on steel, wood and timber structures for the most part or buried underground. This system is similar to the PIAs of the oil and gas industry, water and sewage assets or road and communications networks. There are all industries with very similar issues, policy frameworks, and reliability and safety expectations. Focusing on data and systems specific to BCTC for this project, the overall objectives are:

a. To evaluate and review current asset and reliability management best practices as related to the central project question of ‘Refurbish versus Maintain?’

b. To review relevant cost of capital and financial metrics in investment analysis

c. To consider the relationships between an organizations’ strategy, risk tolerance and policy environment

d. To review and analyse data and information management requirements for supporting strategic decision-making

e. To review the concepts of asset life-cycle and impacts on relevant performance metrics

f. To review and adapt project options analysis techniques and integrate the most relevant with risk concepts

g. To demonstrate a rigorous approach and flexible process for achieving a repeatable evaluation of potential capital investments across multiple business units

h. This project did not include building new software tools - where necessary existing process and tools available in BCTC and the asset management community are adapted and built on.

1.3 Methodology

In order to achieve the objectives of this project, it was necessary to review the existing body of knowledge about asset management practice. Firstly, I carried out a literature review of the leading practitioners and standards for global infrastructure asset management. The books and journals reviewed were useful in benchmarking the best practices and current thinking from around the world. Secondly, the author as a member of several utility and asset management organizations was able to tap into relevant conference proceedings and reports. This exercise was very instrumental in determining that the central questions of the project – what to do about aging assets is of concern beyond British Columbia. The net effect of the literature reviews overall was to demonstrate even more strongly that a process or methodology was required by asset managers involved in making strategic choices. Informal interviews were the third research method used in this project. The informal interviews involved discussing the model with asset managers in BCTC and soliciting feedback on the structure of the risk matrices and the weightings. The overall intention was to investigate as best as possible the methods used by asset managers in their day-to-day activities of making business decisions.

As the decision support model developed, it became clear that it would be helpful to provide the theoretical background for readers. It was felt that this would enable the reader to better challenge assumptions and further customize the scoring matrices to suit their industry or circumstance. As a result, chapter 2 walks the reader through the basics of asset management to set the stage for the considerations involved in managing PIAs. Chapter 3 then introduces the analysis and decision support tools that are in common use by asset managers and discussed their benefits and some limitations. Chapter 4 then brings the reader back to what actually goes on beyond the theory. This section takes a lot from the informal interviews as well as the authors experience as a technical lead and asset manager for over a decade

In chapter 5, I present the criteria, considerations and proposed process for making a strategic choice. This chapter provides a simple framework with an insight into how to apply the scoring matrices presented. The scoring matrices were a critical component of this project and built on the feedback of program engineers at BCTC. This feedback was the result of earlier work done in developing an options analysis tool for the asset management group.

Chapter 6 rounds out the project by again presenting the reader with an overview of the project, some limitations of the study and makes conclusions and recommendations targeted at the asset manager.

2: Asset Management Fundamentals

The theme of asset management is to provide the best value at the lowest cost. Asset managers carry out this mandate while maintaining the quality of service delivery and performance to all stakeholders. An expectation of acceptable returns to stakeholders is also a fundamental basis of investment in an asset base. These returns might be tangible such as rents and profit in the case of financial assets or investor owned PIAs, but the intangible and long-term social benefits are equally important.

2.1 Asset Management Considerations

Organizations with PIAs have in recent year's undergone significant changes. These changes are in the organizational processes for acquiring new assets and obtaining resources for maintaining existing ones. For electric utilities like BCTC, regulatory and commercial pressures especially over the past decade closely match changes in ownership structure and competitive models. Government or State owned / sponsored firms, such as crown corporations are facing increased regulatory oversight with mandates to reduce expenditures. This constraint is in place with an expectation that organizations will maintain the optimum system performance, reliability and safety.

On the other hand, private firms owning or managing infrastructure assets have to ensure that they generate a return for their shareholders. In addition to shareholder wealth maximization, an asset manager also ensures corporate social responsibility, among other organizational values - such as staff development. However, the commercial pressures of rent maximization could lead to higher marginal costs and lower marginal benefits to consumers. This tension between social benefits and free market efficiency could lead to market failures and governments typically step in to regulate the market.

While the utility operations are themselves natural monopolies in terms of the service of providing electrons or water, the transmission infrastructure could approximate to a non-rivalrous but excludable public good. As public goods, albeit not pure public goods therefore, water, power and gas transmission infrastructure could have characteristics of non- rivalry and non-excludability similar to roads and other critical PIAs. Weimer and Vining's (2011) discussion on market failures points out that if a good is not a private good then it can be considered a public good. This argument also uses the example of a particular level of military defence to demonstrate a concept of non-rivalrous supply that applies to the bulk electric transmission system in BC. The discussion is relevant since it helps one understand the rationale behind variable pricing intended to drive efficiency of consumption. This complication is central to the discussion on discounted cash flows where we discount costs but hold benefits as constant for all strategic options considered. The resulting simplification is central to the development of our decision support process. Furthermore, there is an expectation that revenues from PIAs should not increase as a means of achieving higher rents. A key policy role of regulators and governments in the management of PIAs as a public good is therefore to control prices and assure adequate supply for all consumers (Richards & Vining, 2001). Asset managers have to seek regulatory permission in order to generate higher revenues or request subsidies to offset losses from investments. These losses for the transmission system or PIA are the result of from pricing policies that consider the service provided (electric distribution in this case) as a natural monopoly and seeks to force pricing that tracks the economically efficient level (Weimer & Vining, 2011). These investments are usually justified for approved additions to the installed PIA base. The additional revenue required to fund PIA additions produces a marginal cost to consumers of the public good in the form of rate or tax increases.

However, as assets expected to have long useful service lives, planners spread marginal costs out over the population of potential users. These marginal costs are intergenerational since they cover the entire extended amortization period – usually over 50 years. The consensus is that the marginal benefits over time exceed these marginal costs. Here again; the tendency of average costs for a firm's service to decline over time is more typical of a natural monopoly but in the context of this paper we are considering the PIA and not the service of the business. In fact, this whole work requires an understanding of the reality that as PIAs age; average costs do in fact tend to rise. It is this rise in costs that one seeks to trend and use as an input in making an effective strategic decision on asset investments.

Regulators require increased quality of data and analysis to justify funding requests rather than expert opinion or experience based assertions. This poses a problem for asset managers who have to attempt to use incomplete or sometimes non-existent data to build business cases. Clearly alternative and creative project evaluation methods are required. There is also a need to provide an adequate explanation to regulators and asset owners about the PIAs operating environment and performance uncertainties. The effect of this education and communication would be to inform stakeholders about the cost of generating all the possible data sets. The intent is to weight this cost against the risks to the asset and any increase in effectiveness.

While the public policy implications of managing PIAs are not a focus of this paper, there is a relationship between the critical nature of PIAs and market failure. The requirement for an optimum access to a PIA means that there is a premium on price and stability of supply. This requirement accepts that the actual gas, electricity, or goods transported ion the transmission network or highway is itself rivalrous while as mentioned earlier the firms' operations are natural monopolies. Nonetheless, regulators evaluate estimates of the costs of providing the PIAs service and approve rate structures to provide an acceptable return on asset investments. The requirement for organizations to provide access to PIAs at or below specified rates or marginal costs over time provides incentives for efficiency in use of available resources (Richards & Vining, 2001). This consideration for capped expenditures presents a basis for analysing the impacts of asset management strategy. In this environment, customers' willingness-to-pay is less of a factor than reliability and risk management. Because of this 'reliability- centric' philosophy, the analysis required involves not only using tangible data but also on using intangible data. This intangible data includes, stakeholder considerations because of asset failure, probability of component failure and probability of extreme natural events such as windstorms, floods etc.

Richards and Vining's (2001) discourse on the required efficiencies for optimal use of resources are further expanded on by Komonen et al. (2006) Their study includes the need for dynamic and continual life-cycle management, optimal capacity development, higher overall equipment effectiveness, higher reliability and lower maintenance costs for PIAs. These efficiencies are a key driver in developing an asset management framework based on the business objectives of an organization. Any reasonable framework would also consider the technological characteristics and uncertainty of the industry (Komonen, et al., 2006).

2.2 Asset Management Definition

Asset management is the set of actions in a centralized decision-making process relating to the operations of an asset base. This concept is essential in a networked business for the maximization of benefits and effective delivery of services (Meijden et al., 2006). The British Standards Institute, indicates that the required activities have to be systematic and coordinated and have to consider risks, performance and expenditures over the entire asset life-cycle (Institute of Asset Management & British Standards Institution, 2008). A key theme across these definitions is widely acknowledged to be that of life-cycle management and risk mitigation (Association of Local Government Engineering New Zealand Inc (INGENIUM) & Institute of Public Works Engineering of Australia (IPWEA), 2002). Based on work done by the British Standards Institute as well as work by Meijden (2006), for Cigré - the International Council on Large Electric Systems; the key goals of asset management are therefore to:

- Optimize performance and investment over asset life
- Ensure PIAs provide reliable and high quality service
- Ensure safety and reduce PIA impacts on environment
- Coordinate business decisions over entire asset network
- Focus on strategic actions to drive operational excellence
- Implement risk management in technical and business decisions
- Drive effective asset data acquisition and analysis with technology
- Provide detailed justifications and ensure an audit trail for decisions
- Harmonize technical requests with business and governance needs
- Demonstrate compliance with legal, regulatory, statutory mandates

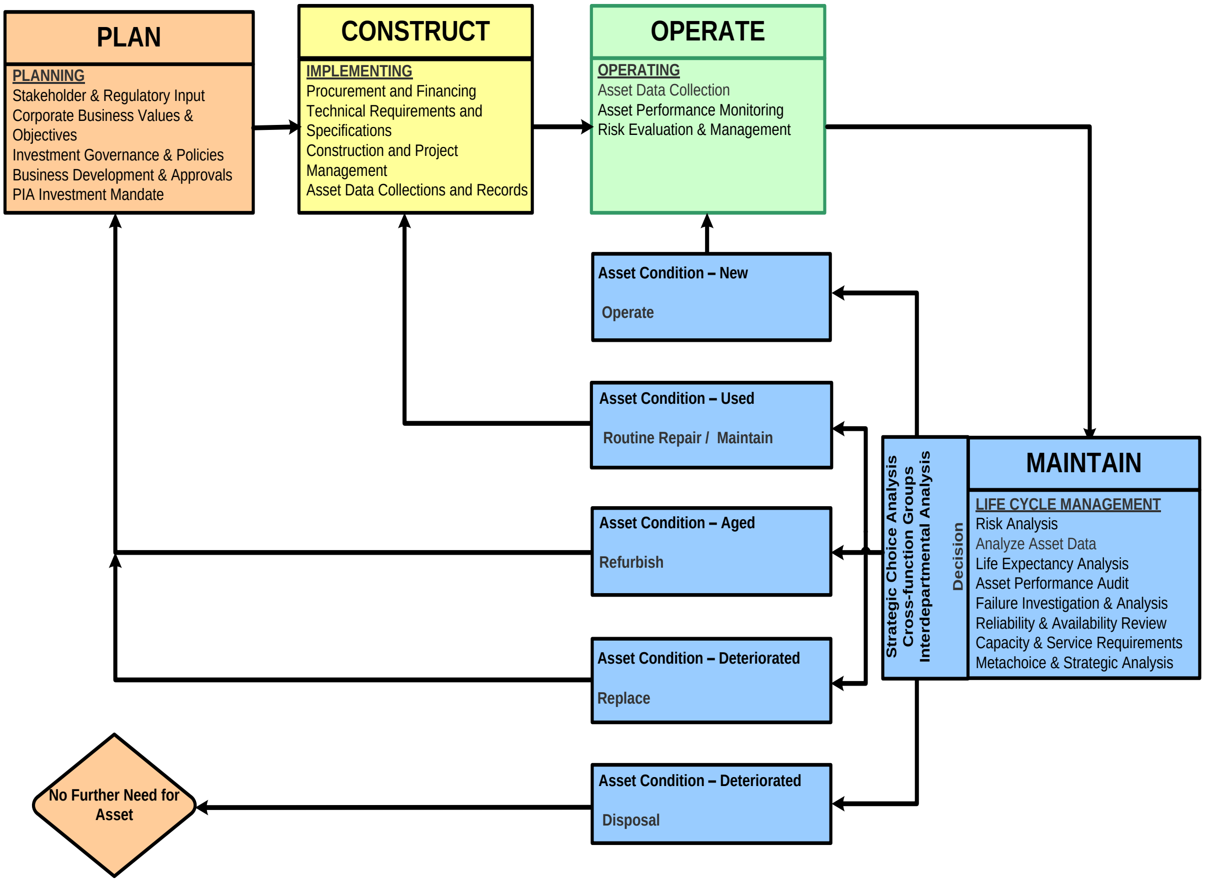

Figure 2-1: Integrated Asset Management Approach

The figure shows the considerations and decision points relating to asset condition and their impact on the relevant asset management stages. Source: Author

The overall impact of the integrated approach displayed in figure 2-1, is that managing assets then cuts across several functional and business groups in an organization. Asset management theory and research point to this integrated approach as best practice. The reality however, is that large organizations and PIA owners tend to consider classes of assets based on functional responsibility and departmental groupings or silos.

2.3 Asset Management Process

Any successful plan has the fundamental elements of what, why, how and when. Clearly, in terms of asset management, developing or implementing an integrated plan requires significant coordination across asset systems and the organizations departments. This systemic approach requires a broad process view that considers policy, strategy, linkages between groups and business considerations.

2.3.1 Asset Management Process – Best Practice

The process view of asset management is the enabling interface between the technical and economic focus inherent in an organization. Cigré points out that in developing an effective asset management process, managers have to understand and consider a dichotomy of worldviews.

- Technical experts look for the cheapest total solution across the entire network that employs the latest and best technology
- Financial experts look for the cheapest incremental solution to drive short term cost minimization and capital deferral

A suitable process links strategy and business values with the business drivers and key performance indicators (KPIs) which are used to monitor business performance (Meijden, et al., 2006).

For BCTC, business drivers include external pressures such as government policy favouring distributed generation of 'clean' energy (Government, 2007), customer expectations of minimized rates and aging infrastructure. In addition, BCTC like most business corporations has internal values. These values fundamentally cover stakeholder relationships, service quality and operational safety and drive the development of executive and corporate strategy.

Furthermore, the key measure of success in asset management of PIAs focuses on the relevant KPIs for an organization. These KPIs are generally mandated or developed from the corporate business values – for example, BCTC has KPIs relating to reliability targets, environmental incidents, safety and time lost targets as well as delivery of programs and projects to planned schedules and cost objectives.

The Institute of Asset Management and the British Standards Institution propose that a best asset management practice accounts for business factors and delivers on KPIs (2008). This practice would involve the following elements:

- Planning - The asset management policy of the organization, regulations, strategy and objectives drive this activity.
- Doing - This action is based on asset management enablers and controls - includes resourcing, communication, risk and change management.
- Checking - This activity reviews asset health by verifying performance and asset condition improvements, audits and investigating reliability impact data.
- Acting - This activity involves management review of the effectiveness of asset management processes, implementation of past actions, asset performance and KPIs.

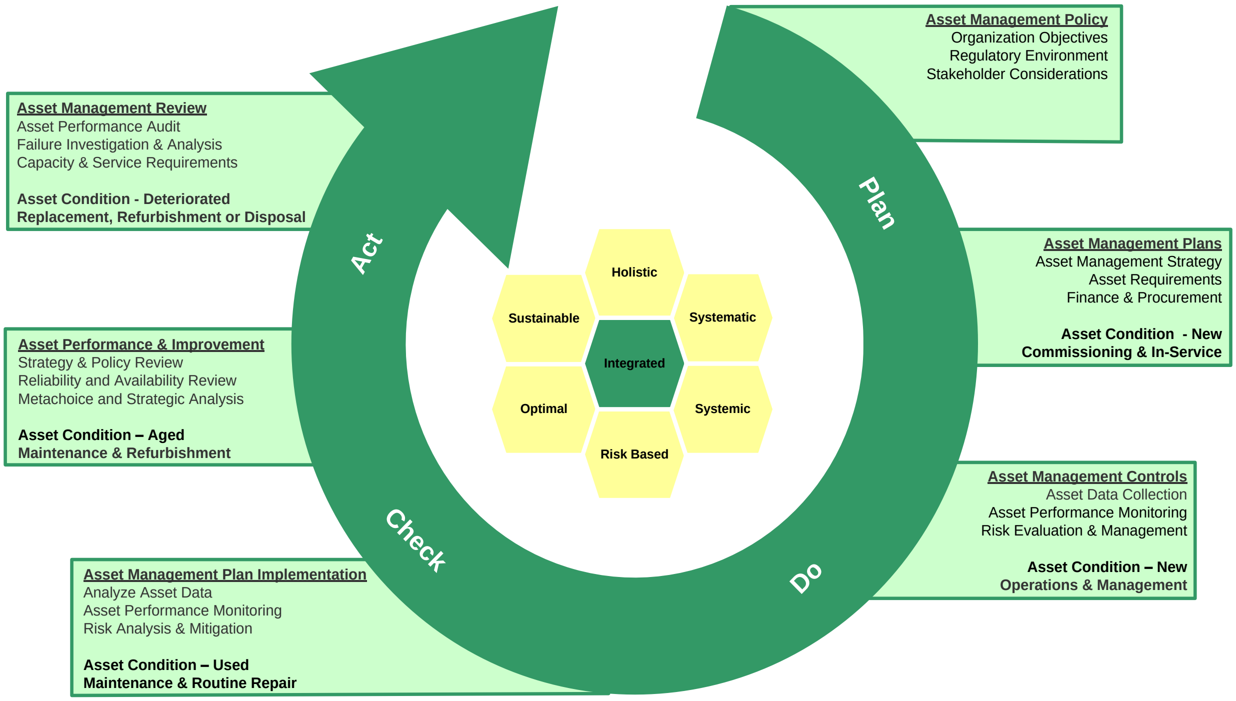

Figure 2-2: Cyclical Asset Management Process and Requirements

> *The figure shows the interrelation between the elements of an asset management process and what constitutes a best practice. Adapted from the Institute of Asset Management (2008)*

The asset management process as described in Figure 2-2 is cyclical and organizations will go through the cycle several times over the life of an asset. The specific actions that are employed in the process might vary across industries and asset types, but the concept is essentially sound. A PIA owner has to align the key processes with strategy, values and policy across the entire asset life-cycle (Meijden, et al., 2006). As a best practice, asset mangers consider the trade-off between functional performance, financial metrics and societal impacts. This philosophy goes beyond simple life-cycle cost and risk management.

Studies by Ault et al (2004) have shown that application of a consistent asset management model or process improves service quality Their work also demonstrates that this action achieves a reduction of long-term operational and capital costs.

BCTC's asset management process for the most part tracks this best practice and asset managers generally follow a process designed to deliver investment efficiency as shown in the figure below:

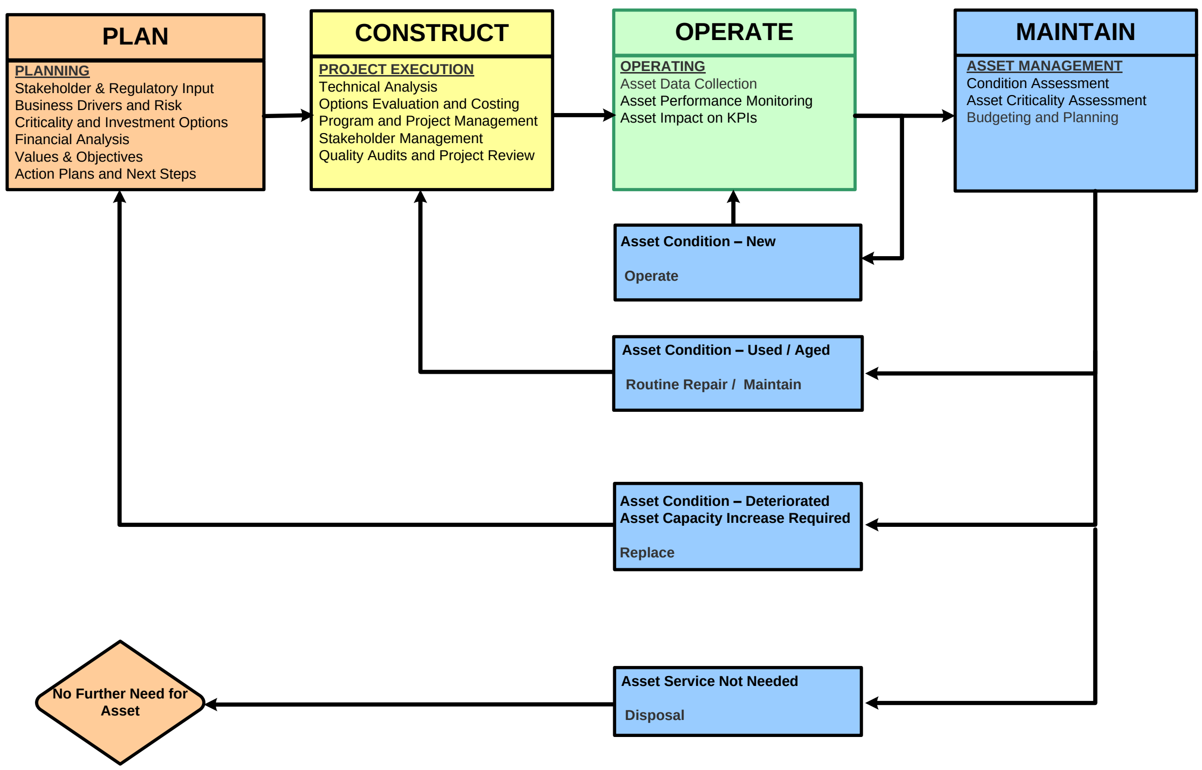

Figure 2-3: BCTC's General Asset Management Process

The figure shows the organizations' functional groupings and integrated actions in the asset life cycle. Source: Author

2.3.2 Asset Management Process – Specific Actions

The general process shown in Figure 2.2, builds on the strategic objectives and values of the firm as well as the nature of electric utility PIAs – that of high value linear assets distributed over a wide geographic area. BCTS's asset management process covers specific actions such as planning, project execution, result verification and monitoring. The planning actions involve reviewing business drivers and KPIs and asset data to determine reliability risks. A key part of this planning involves developing technical alternatives for mitigating defined risks. BCTC also has a focus on project and program management related tasks, which generally involve audits as well as schedule and scope management. Each fiscal year, BCTC reviews asset performance and condition to determine the impact of project investments on corporate KPIs.

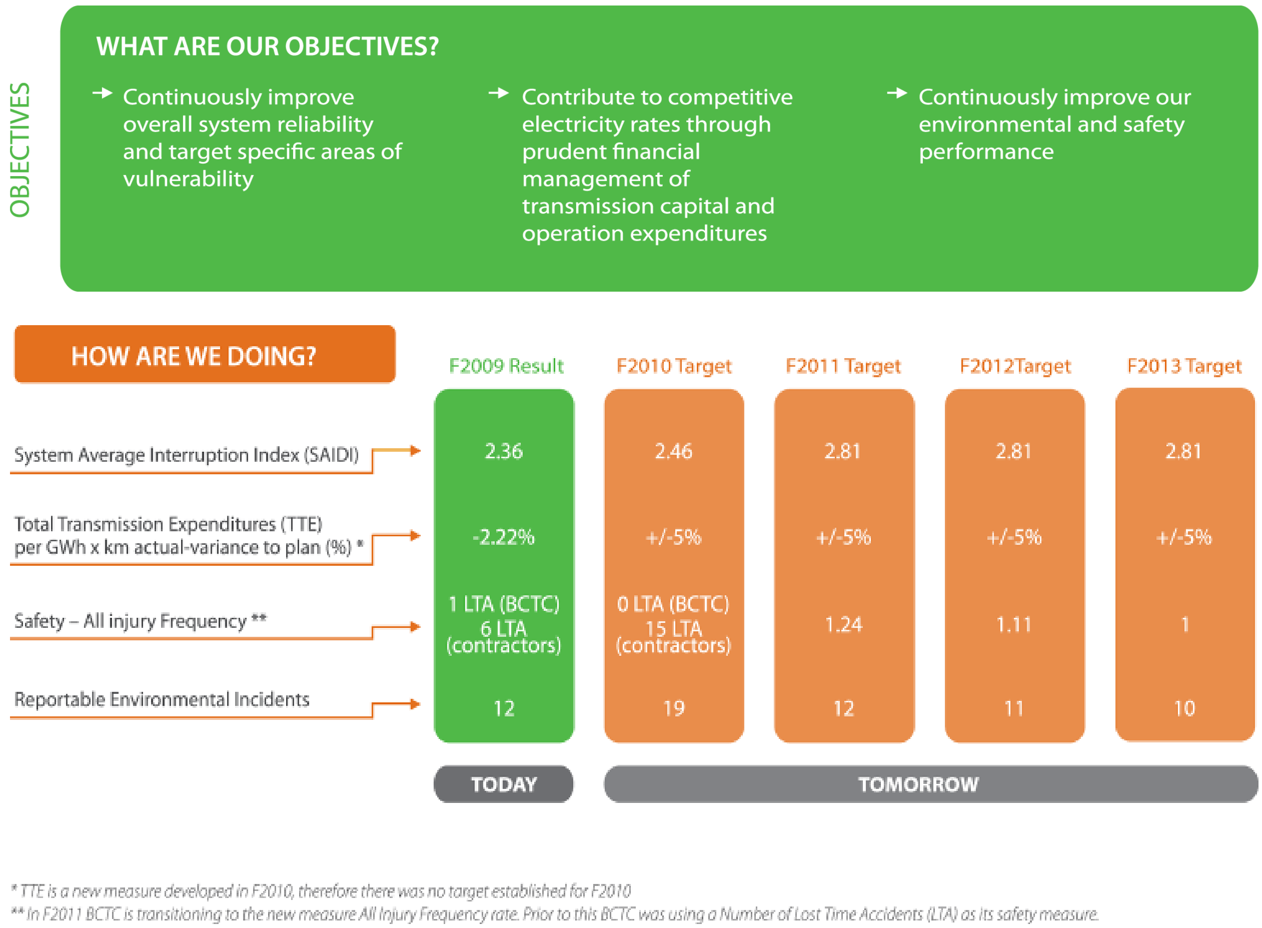

Figure 2-4: BCTC's KPIs showing 2008 and 2009 Performance and Future Targets.

Source: BCTC Corporate Planning

BCTC's asset management process is relatively mature in terms of project delivery. Trends over the past several years as shown in Figure 2.4, indicate that BCTC has been relatively successful in meeting its KPI goals and achieving investment performance according to plan. There has been increasing levels of engagement with stakeholders as well as collaboration with other firms across the industry in North America and beyond. Given that the PIAs are aging and there have been no major investments in the installed base for over 30 years, it is remarkable that system reliability is consistent with no added direct cost to consumer rates in British Columbia.

Nonetheless, there is a limit to the efficiencies achievable solely by process improvements. Clearly, the quality of the outputs from a process depends on the quality of the inputs and not the robustness of the process alone.(Association of Local Government Engineering New Zealand Inc (INGENIUM) & Institute of Public Works Engineering of Australia (IPWEA), 2002). Asset managers have to understand the limitations on effective decision-making posed by lack of quality data. This relates to information on asset condition, stakeholder impacts, regulatory requirements and financial risk.

2.4 Asset Management Data

The asset management process laid out so far has focused on the importance of a prudent planning phase. We have also considered the importance of a measured approach to delivering and monitoring planned activities over the entire life cycle of a PIA. It is obvious that reliable, useful and timely data is available to the decision maker (Ouertani, Parlikad, & McFarlane, 2008). This is true not only for the asset manager but also for the regulator or stakeholders. Informed decisions, policy and regulations are dependant on knowledge of the facts and a thorough understanding of the source of data and potential errors.

2.4.1 Asset Management Data - Requirements

The data and information required in order to optimize decisions include design specifications, asset age and condition. This data relates to design, environmental and service conditions, historical performance, reliability trends, maintenance cost trends, capacity, utilization, cost of replacement, location and so on. The asset manager has to interpret the data and use expert knowledge to derive useful information about risk and potential KPI impacts.

A thorough knowledge of PIA ageing and deterioration rates is required (Meijden, et al., 2006).

There are naturally wide dispersions of information requirements for making different decisions. These decisions typically depend on the endogenous drivers such as strategy and risk tolerance as well as the exogenous factors. Among the relevant exogenous factors affecting an organization are mandatory reliability standards, regulation, unforeseen events and safety among others. This essentially means that for different classes or types of PIA there are a variety of data sets that could be required. Because the interpretation of data depends on the intent, expertise and training of the user, data capture, storage, retrieval and analysis tools have to be flexible and adapt to user requirements. This naturally poses a challenge for PIA owners in deciding what systems they require and what levels of investment are justified

Aging PIAs are also driving grid modernization initiatives for owners. The information technology age has also demonstrated the possibilities for developing smarter PIAs that are able to communicate with owners. Smart PIAs enable lower costs in direct condition monitoring and assessment. This could provide opportunities for more targeted maintenance, refurbish or replacement decisions.

PIA owners have similarities in their requirements for consistent, timely and accurate data on asset location, condition and capacity. Nonetheless, asset characteristics across organizations and even within the same firm are unique and require custom solutions. Asset managers have to realize that clearly defined requirements drive information management strategy. In order to ensure consistency of systems, mature organizations develop enterprise information management (EIM) systems.

For electric, gas and water utilities as well as highways, the PIAs are linear assets with nodes. These nodes could be control centres, generating stations, pumping plants, support structures, valves or bridges, hardware or equipment. These distinct nodes form a networked system linked together by connectors. The connectors could be electric conductors and wires, pipelines or roads.

In effectively managing the assets, an owner needs real time information and trend data on the performance of the network as well as the nodes and connectors. Managers also require data on the capacity of the network and potential effects to the system from a node or connectors' lowered reliability. Relevant information regarding the socio-economic impact of a service interruption due to damage, weather, upgrade works etc is crucial to making informed, holistic and strategic decisions.

For PIAs traditionally considered non-linear such as seaports, airports, hospitals and so on, owners require data on how performance tracks with design expectations and life expectancy of the asset. There is generally no consideration of disparate nodes and connectors. However given that even though these PIAs are point assets, they generally form part of a network in a region or a country's health care, transportation or economic system. In this sense, they are linear with the information systems between them the connectors. In addition, these single location PIAs have several subsystems comprised of equipment and structures that linked operationally to perform the assets' function or deliver the intended service. As a result, data is also required on the performance of the 'network', capacity and trends.

There are obviously differences in the granularity of data required for making decisions across various asset classes and industries. However, the following general classes of data are commonly required in a PIA database:

- Asset Design and Construction data

  This data includes design specifications, component construction costs and parts lists as well as installation dates and any warranty information. The data benchmarks the costs and technical aspects of the asset as new.

- Asset Condition Data

  This data includes all inspection results and condition assessments resulting from field investigations by competent personnel. It is a vital input to the decision process as it triggers an asset management review and leads to a strategic decision.

- Asset Operational Data

  This data set includes asset performance records focusing on assets critical to the overall network. This data is useful in asset service life estimates and involves test data, technical, and business studies.

In BCTC, data relating to the assets service environment is also included with those in the list above. This is because transmission plant like roads and other linear assets traverse aggressive terrain and unsterilized environments. Asset life under these conditions generally varies significantly for the same asset type and quality of construction in a different location. These service environment impacts affect the frequency and quality of condition inspections and increase the overall volume of PIA related data managed by an owner or asset manager.

2.4.2 Asset Management Data –Technology

The interface between operational data and condition data is becoming closer. Real time management of increased volumes of high quality data will definitely put pressures on existing information management systems. This presents a challenge in developing an EIM system (Parekh, Zhou, McNair, & Robinson, 2007).

Pressures on PIA owners to increase efficiency and effectiveness, is also a consideration driving the need for interactive and flexible data systems. These data systems are therefore critical assets whose usefulness depends on an owners' ability to synthesize useful asset information from them. It is not only important what data you collect as an asset manager, but also how you collect and act upon it.

Whether it is a spreadsheet or an advanced custom information capture and analysis program, effective, repeatable and consistent asset management requires a single data view. This enables users to make decisions across the network, identify inconsistencies as well as validate and remove obsolete datasets (Institute of Asset Management & British Standards Institution, 2008). Cigré makes the point that data collection, handling and subsequent input into an organizations' information system is usually a non-strategic task. In most organizations, there is some disconnect between data management and delivery of the business function or service to stakeholders. The reality however is that this is a critical stage given that it supports asset investment decisions (Meijden, et al., 2006). Poor quality data as mentioned earlier could lead to costly and avoidable errors of judgement.

Given the prevalence of information and communication technology in business today, every asset owner with PIAs is effectively managing a network that delivers service to users.

Management of PIAs should consider this interesting linear characteristic of even non-linear point assets. This concept drives the selection of EIM systems as well as data analysis and decision support tools.

3: Asset Management Tools

Effectively managing an asset base requires decisions based on a holistic approach. This approach looks at the cradle to grave life-cycle cost of an asset (Meijden, et al., 2006). A limitation however, is that the asset manager could consider the asset as an isolated node or system. There is a need to recognize that the asset is part of a network and that total cost of ownership (TCO) is a more relevant guide to effectiveness.

The selection of tools for supporting asset management decisions depends largely on the asset type, the situation and the key asset performance metrics. Regardless of the PIA or organization, data collection, classification and analysis are key to investment optimization and resourcing. The general idea is that these are the essential steps involved in the planning and review required for the decision process and investment execution.

Although we have so far focused on the similarities between PIAs regardless of industry, there are nonetheless significant differences. These differences result from the technical considerations that drive the performance of the asset material, and impacts aging and service lives.

The technical tools available even in the same industry vary based on preference, cost and training requirements. Standards and rules govern the practices of technical staff and are typically applicable across any organization in a jurisdiction. This generally produces similar results regardless of the sophistication or simplicity of the tool used in the analysis. In practical terms, the skill of the user is more important than the complexity of the tool. A brief overview of some planning and execution tools follows in the next few sections.

3.1 Data Collection and Classification

Field personnel can collect data by hand into inspections sheets with subsequent manual filing for review by subject matter experts. This is somewhat time-consuming, requires high staff levels and is prone to data input errors. More often nowadays, manual capture of PIA field condition data by field crew is by using handheld devices (PDAs, site computers etc). At the higher end of this spectrum, geographic information (GIS) systems based on high definition satellite imagery are proving useful. GIS captures high volumes of quality data at lower overall cost than the manual methods. GIS also enables layering of service environment and related information with PIA location data. This technology is very useful and can provide a platform for analysis of risk from a variety of sources. New survey techniques such as light data and ranging (LiDaR) provide detailed as-built asset information to enable scenario analysis for PIAs.

The shear volume of information being captured for organizations requires some very capable and custom solutions for data repository (McRae, 1998). Most PIA owners currently store data largely on in-house hosted servers rather than third party solutions. However, as a guide the choice of data storage should take into account the overall information technology strategy of the firm. This includes an evaluation of existing information systems tools and strategy so that field data can be seamlessly integrated into a one asset view model (Association of Local Government Engineering New Zealand Inc (INGENIUM) & Institute of

Public Works Engineering of Australia (IPWEA), 2002; Institute of Asset Management & British Standards Institution, 2008).

Predefined rules covering the type of asset drive classification of collected data. This is useful for assisting portfolio managers determine direct responsibility for data collection and quality auditing. For example, elements of a road data capture could be road pavement, bridge, signage and safety structures etc. While this might be a small detail, the volumes of data that are collected can sometimes become very large and classification is a means of creating searchable indexes in an asset database.

In recent times, there are myriads of asset management software and logistics service providers that provide commercial–off-the-shelf (COTS) solutions for data capture to companies. Some providers are also capable of delivering customized asset data capture solutions. These solutions include full service options like fieldwork, post processing and classification. Depending on the situation, the type of PIA and the level of specialization required, market solutions such as these could be useful for increasing efficiency. PIA managers could look at optimizing the quality and timing of system data capture. One way to do this would be to use the bargaining power of a large customer to drive efficiency levels approaching that of a free market.

While BCTC has access to in house resources for data capture and classification, there is an increasing trend to outsource this function. The requirements for quality, speed and efficiency are obviously significant and asset managers realize the potential benefits. The large pool of service providers available across Canada and the US means that the potential for market inefficiencies or failures is low. This strategy allows most asset owners to focus on their core strength, which is asset management and not logistics. Obviously, organizations going down this path have to analyze the impacts to their business – is the data to be captured sensitive, can you deploy internal forces on more core function work, will supplier bargaining power become a strategic threat and so on.

Regardless of the route taken by an asset manager, data capture and classification is an essential first step in understanding the state of an asset base or a PIA of interest.

3.2 Data Analysis and Condition Assessment

Environmental conditions, usage, mechanical and electrical stresses among others drive the aging process of a PIA. The aging process results in a gradual weakening of the assets ability to withstand the design stresses. This state can lead to pre-mature failures, costly remediation and injury. Condition assessment criteria provide a quick and easy means for field personnel to determine whether an asset is in good shape or not. Subject matter technical experts develop the criteria based on the original asset designs and specifications as well as the industry body of knowledge. Field personnel collecting data by hand into inspections sheets or PDAs can provide their assessment of condition. These recorded observations together with pictures and measurements are useful for further review by subject matter experts. Here again there is a risk of data quality issues since subjectivity, training, experience and preferences would tend to skew the data between one inspector and the next. Where inspectors are well trained, sufficiently knowledgeable about the assets and understand how the data is used, there is a lower risk of poor quality or incomplete data.

Given the BCTC experience broadly shared with PIA owners across North America, the first line of analysis comes right from the data capture itself. Experienced crews use predefined condition assessment criteria to tag the severity of a field observation. For example, BCTC's criteria currently range from condition 'A' (new or good as new) through to condition 'E' (failed and requiring immediate replacement).

Analysis of field data generally involves combining a PIA condition assessment with service delivery data and historical performance trends. This analysis provides a view of the risks and implications of the state of a PIA. A determination of condition can drive initiatives targeted at achieving social efficiency and organizational goals. The overall aim of the analysis is typically to model business risks, performance expectations and impacts on reliability. As a result, informed decision-making based on cost assignments to projected consequences is achievable.

3.3 Design and Fabrication

For PIA owners and managers, there is usually an abundance of subject matter experts. These experts generally have the motivation, knowledge, training and experience to provide input into the design and fabrication process. Jurisdictional and international standards such as the Canadian Standards Association (CSA) and the International Organization for Standardization (ISO), as well as professional liability govern the application of reasonable and competent practice for design and fabrication. Typically, asset managers require several options developed prior to approval. This is an essential requirement for performing an economic analysis in addition to the technical considerations that went into the options.

The best approaches go beyond the traditional role of the technical expert, and move beyond "if we build it they will come" to one where maximizing net social benefit is considered. The specific tools required by asset managers is an interface between the technical software and the cost estimating software of a firm. An asset manager requires information on cost and scheduling impacts that could change the value or timing of expected social benefits. This information could also indicate increases in marginal costs beyond the business needs. Ideally, the asset management view of the proposed solutions should enable an accounting for soft costs in the decision process. Quantifying soft costs is debatably subjective and somewhat contentious, so there is generally a quantitative assessment across all options. An effective tool or asset management process would identify the sources of potential soft costs (and benefits) and quantify those across an organization.

In order to support future management decisions, it is crucial that an asset manager has tools that capture or archive asset data. This data relates to what asset or asset component was developed or built, and describes the techniques and materials for consideration in determining asset life expectancy.

3.3.1 Construction and Maintenance

Following up from the earlier description of the tools and considerations for design or fabrication, construction and maintenance activities have the same philosophy. There is an expectation of professional competence and attention to standards and regulations. For an asset manager, the tools required generally relate to managing the work, scheduling, auditing quality, safety and environmental impacts etc. Established project review and change management processes are useful tools in ensuring delivery of stakeholder approved plans.

Here again, it is essential that all activities, changes and lessons learned are archived and kept accessible as part of the overall management toolkit. The intent is that asset management decisions relating to future projects will effectively leverage this stored information.

3.3.2 Work Management and Resourcing

Work management and resourcing is an essential element for any asset manager in delivering value to customers. This activity includes methods to improve schedule and cost performance. Measures that could lead to this efficiency also increase labour productivity, reduce wastage and plant / equipment downtimes. Standard practices based on the Project management institutes 'Project Management Body of Knowledge' (PMBOK) are the de-facto global guide to delivering value in a project.

Similarly, as for the previous process elements discussed above, the lessons learned and data captured are invaluable in making future decisions. As mentioned under the data collection element earlier, modern asset management frameworks are based on a one system view of assets and related information (Association of Local Government Engineering New Zealand Inc (INGENIUM) & Institute of Public Works Engineering of Australia (IPWEA), 2002; Institute of Asset Management & British Standards Institution, 2008). This focus supports the adoption of Enterprise Asset Management (EAM) systems. EAM software is available as COTS or custom solutions and these deliver scope, schedule and cost management controls.

To conclude, it is important that a decision maker understands that the quality of decisions relating to management of PIAs depends on the quality of the data inputs and historical trends and failure impacts.

In terms of the decision support tools however, there are similarities in the standard applications for analysis. The overall goal is to achieve repeatable and reliable decisions.

3.4 Discounted Cash Flow

Asset Managers of PIAs consider the expected lives of assets usually over several decades and amortize costs over these periods. Discounting of initial capital expenditures and subsequent investments over the entire life of the asset depends on the weighted average cost of capital (WACC) and inflation rate. The discounted cash flow (DCF) of a project is very important in developing business cases since it demonstrates what the net impact of a proposed investment is at any given time. This net impact reflects the time based expectation of investment recovery / repayment over time. This time value of money also affects the rates consumers will pay over time as investment recoveries over longer periods have lower impacts on today. In effect major investments in PIAs seldom require immediate major rate or tax increases, but consumer obligations are ‘stretched’ over the asset life-cycle.

For PIAs where a determination of benefits is clear such as toll roads, the annual flows of recurring rents net on ongoing maintenance. Managers evaluate the net impact due to these cash inflows against operational expenses and the present value of the capital investment. This determines whether the net present value (NPV) is positive or not compared to other alternatives.

Alternatively, where there is no clear means of estimating annual direct benefits resulting from investment in a PIA, then NPV considers the net of investments today against future life-cycle related investments. The result is negative NPVs. You can then evaluate project ideas based on the option with the least impact on the asset owner and users. That is the least negative NPV project wins. The concept of a negative NPV can be somewhat confusing if one looks at this from a traditional perspective. From BCTC’s perspective however, the issue is not that the NPV is negative but rather that the benefits for each alternative are probably similar over the long term. This assumption considers BCTC practice and the fact that planning estimates for a 'run' or 'refurbish' or 'maintain' decision would all seek to achieve reliability and continued benefits. If there were any question about this or an expectation that one option would lead to higher benefits through an increase in capacity or otherwise, then this option would be favoured. As a result, we assume that these benefits are not relevant to the decision process for the most part and are not included in the analysis and equated to zero. Costs are discounted and as cash outflows are negative so the expression 'present value of costs' is probably more appropriate than NPV. We shall however continue to use NPV in this document since it is more common and the concept is the same – sans the zero benefit assumed. In organizations where the benefits do not follow this pattern then financial analysis will include these values and the concept or decision support methodology is not materially affected.

In such an environment, for BCTC, the expected benefits are increased capacity, reliability and system network effects rather than direct dollars.

The WACC is useful in discounted cash flow analysis to develop a social discount rate (SDR) that approximates to a societies' opportunity cost of foregone consumption and foregone returns from an investment. Work being done currently by Boardman, Moore and Vining (2010) proposes that consumption based discounting may be a more pragmatic means of determining the SDR. While this paper does not go into the intricacies of this topic, the reader has to be aware that Boardman paper asserts that the current estimates of SDR used in Canada are higher than needed. The reason proposed for this is that the weighted social average cost of capital (WSOC) method used in SDR calculations overestimates marginal private sector ROI and does not account for the consumption rate of interest (CRI). In the current versions of the decision support process discussed later in chapter 5, the discounting is based on the somewhat less conservative estimates based on the WACC method.

The key point about the SDR is that low SDRs favour projects with the highest total benefits. By extension low discount rates support alternatives with the lowest cost impacts regardless of when they occur (Dale, Wiele, & Iwaarden, 2007). The importance of the choice of SDR is important since low rates approximate the SDR factor in the PV calculations to unity. This means that projects with low but consistent yearly investment requirements would be favoured over those with minimal or no yearly costs and a major expense further down the planning cycle. Similarly, a higher SDR would favour projects with major additional investments further out over projects with minimal and consistent yearly requirements. This could present a problem for projects where the yearly investment is less a factor than the social and environmental impacts of making those investments in the field.

Moore (2001) indicates that there are several options for a SDR, which could have impacts on the outcome of a DCF analysis. Market rates, real growth rates and the shadow price of capital are among the variables a PIA owner should consider. This consideration should weigh the source of the funds and whether intergenerational effects are relevant (Dale, et al., 2007).

Moore's discussion also includes some insights into the implications of determining what benefits or costs could be allocated to the investment or to expenses (Dale, et al., 2007). There is also concern about determining what key assumptions require consideration and validation. For a complete financial picture however, operational and maintenance expenses are quite relevant to the DCF analysis. Over the asset life cycle, asset managers should therefore discount operational cash flows since they could be significant compared to the original investment.

For a PIA owner, the costs of doing business are not only the tangible cash outlays estimated by discounting but also the intangible factors such as social and environmental considerations. While the intangible costs are important for private sector investments, they are somewhat more important for non-private assets as well. This is because PIAs as defined have social benefit maximization as the key business driver rather than rent maximization. As a result, the discounted cash flow is not in itself a sufficient measure to determine the course of action for a planned public project. A framework taking other financial and social considerations is required. This would provide a more complete evaluation of the opportunity cost of investments in PIAs.

3.5 Root-Cause Analysis

Root-cause analysis (RCA) is generally useful as a tool for operations. RCA enables effective response to a system failure event or supports the preparation of a proactive strategy to a projected asset performance failure.

While not intuitively a decision support tool, asset managers could use this methodology to support decisions during planning of PIA investments. The iterative RCA approach considers that the true nature of an asset performance affecting reliability, safety etc might not be immediately apparent. RCA, challenges asset managers to evaluate whether observed symptoms (lowered performance, reduced reliability etc) indicate a deeper systemic consideration requiring increased investments, monitoring, and maintenance. In terms of planning and decision support, the forward-looking elements of the RCA method provides essential inputs into the data analysis and condition assessment stages of the planning process. An understanding of the base drivers that have affected (in the case of a failure) or could affect (in the case of aging assets) asset performance is obviously critical in considering whether a temporary fix, regular maintenance, refurbishment or replacement is appropriate.

There are various techniques used in RCA but for PIAs, the typical consideration is failure-based analysis and forensic engineering. These methods look at the technical causes of failures and potential losses in asset service reliability. Generally, an asset manager has to define the problem and collect design and construction or installation data on the asset. It is also essential to collect detailed and timely failure related evidence. The intent is to identify the underlying cause of a defined problem and potential corrective actions that will support an organizations strategy and make business sense. A significant part of this process is documentation and instituting systems for continuous monitoring of the state of the asset or efficacy of an implemented solution.

The actual tools used in the RCA vary depending on the type of asset to be analysed, the quality and quantity of available data and the sophistication of the analyst. With the exception of a failure mode and effects analysis (FMEA) used by forensic engineers for major infrastructure failures, the various tree analyses (causal factor, current and fault) and other statistical inference techniques are not very appropriate for RCA supporting business cases. The volume of transactions (defined as projects under review, planning or execution), scale of most PIA networks and lack of resources dedicated to this activity mean that there is a requirement for simpler techniques. The Ishikawa method is straightforward and can easily be adapted for use by asset managers. Using the Ishikawa or fishbone technique and asset manager can identify the root cause of a problem aggregated down to its most basic components (Dale, et al., 2007). The fishbone technique is useful in preparing business cases and considering options because it can demonstrate relationships between causal effects and walk the user through arriving at plausible consequences.

3.6 Failure Probability (mean time between failures)

Insights into how likely it is for an asset to fail and how much time can the owner expect between failure events is termed the mean time between failures (MTBF). This is an essential tool in developing business cases and making asset management decisions. The concept of a long-term steady state replacement rate is a well-known life-cycle concept that equates the expected life of an asset to the installed base of the asset. This concept assumes a linear replacement regime of the installed base over the estimated life (Roldan, Chien, & Lee, 2008). Asset managers have to be careful in using this type of measure since the calculation does not factor the impact of maintenance activities and the variation in service conditions across a PIA base.

Effectively estimating life-cycle performance and reliability risks requires calculation of MTBF for a PIA and this requires significant asset related data concerning an organizations PIAs. It is also important that analysts consider relevant industry data on historic performance in other jurisdictions. These data sets enable an asset manager to correlate asset reliability with technical specifications, age, service environment, usage and so on. Naturally, a key part of this analysis is defining what constitutes a failure for an asset. Failures can range from a network failure to a component failure and have corresponding system impacts. According to the Institute of Electric Electronic Engineers (IEEE), reliability refers to the ability of a system to perform its functions as designed and availability refers to the degree to which a component or a system is operational and accessible when required for use (Institute of Electrical and Electronics Engineers (IEEE), 1987)

Generally, availability of a PIA depends on the reliability of the assets and the restoration time when there is a failure (Torell & Avelar, 2004). MTBF is inversely proportional to reliability and so the lower the MTBF, the higher the reliability of the asset. In addition, where contingency planning for restoration in the event of a failure is adequate, availability could be quite high as well.

$$\text{Reliability} = e^{-\frac{time}{MTBF}} \tag{1}$$

MTBF is useful to an asset manager is for providing a clearer understanding of trend data and determining where the gaps in data collection for a PIA exist. The service life of an asset does not relate directly to MTBF since failure rates could be a function of poor maintenance and service condition. However, increasing MTBF trends could result in a lowered service life of a PIA or increased restoration expenses to ensure consistent availability. This provides the asset manager with another key decision input for evaluating maintain, refurbish or replace decisions.

For BCTC and most electric utilities, a key measure of reliability that based on MTBF is the ‘SAIFI’ and ‘SAIDI’ indices. SAIFI or System Average Interruption Frequency index is the average frequency of sustained customer interruptions across a defined area. In calculating SAIFI, the total number of customer interruptions per customer across the total number of customers served is considered. A more useful measure, SAIDI - System Average Interruption Duration index, calculates the customer minutes or hours of interruption and provides and indication of how long on average customer interruption results from a failure.

3.7 Life-Cycle Cost Analysis

Understanding the costs of a program project or project alternative is very important to effective asset management. An asset manager needs to be fully aware of all the costs that are associated with investment decisions. The importance of this is that the costs could provide insights as to long-term operational issues for a PIA. Historically, investment optimization favours the lowest bidder or the lowest up front costs of a project. Experience has shown that this is a very risky approach as minimal costs today could translate into prohibitively high maintenance and replacement expense in future (Fabrycky & Blanchard, 1991).

In carrying out a life-cycle cost analysis (LCA), all cost data is important – construction, asset direct costs, post commissioning and service costs for maintenance, training and operation. In most cases, historical performance data might not be available to guide predictions of future operating costs. Nonetheless, experience with components of the new asset and requirements for resources to operate certain types of equipment, could drive the assumptions required for analysis. For example, manual systems compared to automated systems and vice - versa. The goal of an LCA is to balance initial capital costs with future cost obligations and achieve the lowest overall cost when those future costs are discounted to the present (Ostendorp, 2009). This calculation provides an asset manager with a picture of the total cost of ownership of a PIA.

Since LCA analyzes competing options, service life and MTBF also play a part in estimating future costs for operating, maintaining and potentially replacing the asset in future (Yanev et al., 2000). Discounting of expenses and costs uses a social discount rate appropriate for the industry and the asset type. The process of calculating total ownership costs identifies all aspects associated with business, technical, stakeholder requirements, and their interaction with designs, materials, resources and schedules.

LCA is a powerful tool that brings together elements of several other tools such as DCF, MTBF and CBA. The analysis considers monetizing as many aspects of operating the PIA as possible. A shortcoming though is that it does not focus on direct economic benefits accruing because of the investment. The LCA is an iterative process since the analyst only considers up front capital costs for a PIA after evaluating the present value of all related future costs. The intention is to avoid bias in selecting the option with the lowest initial cost. Therefore for an alternative with an acceptable future cash outlay for operations and maintenance, value engineering may be performed to further evaluate the design or alternative and consider any opportunities for optimization (Ostendorp, 2009).

Christensen, Sparks and Kostuk (2004) support subjecting LCA models to sensitivity analysis in order to derive important insights regarding the results and option rankings. They however caution that this perturbation should occur within some consistent measure of upper and lower bounds at a set confidence interval – usually set by relevant experts to 95%. The argument is that this will avoid random variations in models and the interpretation of results while providing some flexibility across a range of variables (Christensen, et al., 2004). The work done by Christensen et al.(2004) also cautions asset managers that sensitivity analysis could fail to identify a dominant alternative among options. They go on further to point out that if the models are perturbed independently then a sense of the ‘big picture’ or interrelationships between key variables could be lost. Here again it is prudent to carry out a risk analysis (Fabrycky & Blanchard, 1991), where model variables are assigned probability mass functions and cumulative distributions generated to compare model outcomes. Overall, the LCA methodology when combined with sensitivity analysis and risk is an iterative approach that seeks to get asset managers to reassess the selected variables through feedback.

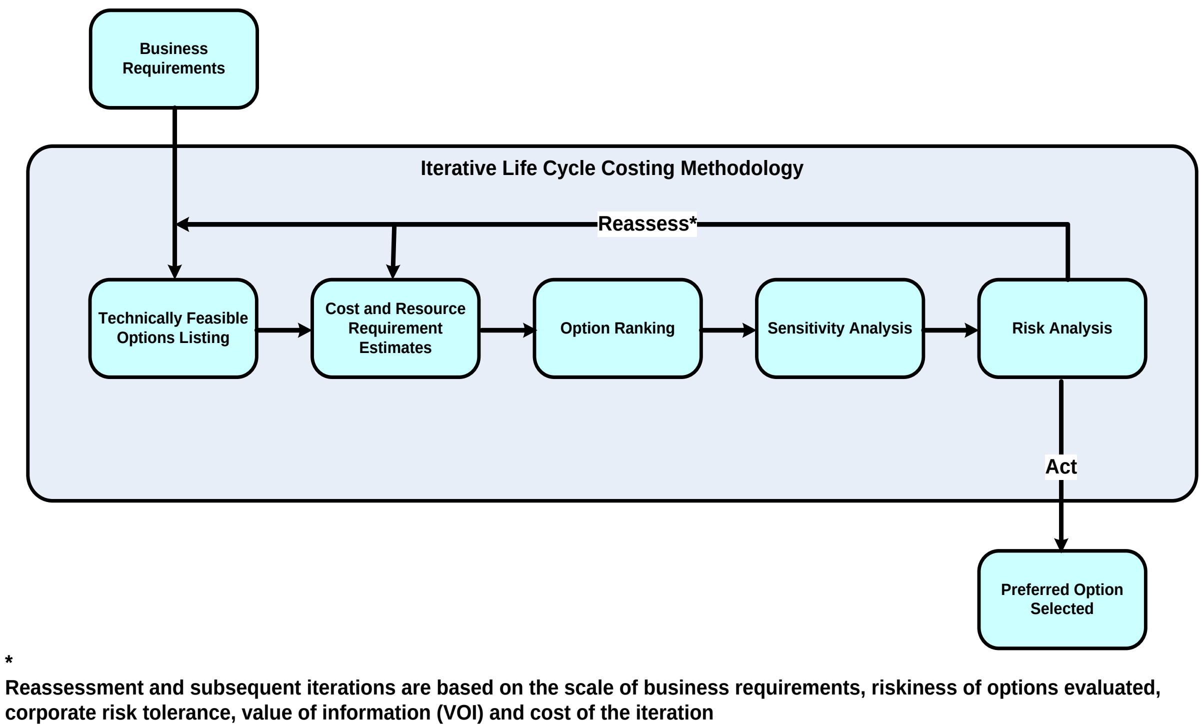

Figure 3-1: An Iterative Approach to Life-cycle Cost Analysis

The figure shows the feedback loop that uses sensitivity analysis and risk to determine the optimum solution. Adapted from Christensen et al (2004) and Fabrycky (1991)

This iteration provides a pragmatic, defensible and flexible means of identifying the best option to meet stakeholder needs. Obviously, for smaller investments in PIA relative to the investment portfolio of an asset owner, judgement as to the required level of rigor is necessary. The requirements for smaller projects may be a simple analysis and not the full-scale sensitivity and risk-based LCA (Fabrycky & Blanchard, 1991).

3.8 Cost-Benefit Analysis

It is essential that analysis leading to a decision follow a rational process that allows for the monetization of as many elements as possible. Cost-benefit analysis (CBA) is a tool that ensures asset managers consider the net result of a decision and encourages the user to evaluate the tangible monetary impact of all inputs and outputs of a project. Benefits define positive factors for quantification, while costs define negative factors for quantification. The net result of summing the positive and negative factors provides results that indicate to the manager whether a project or program has merit over its alternative or alternatives.

In practice though, performing a CBA requires a thorough understanding of the factors that are relevant to a decision. An asset manager not only has to define and monetize the benefits and costs but also has to ensure that discounting happens separately for each year of benefit or cost over the amortized life of the asset. The question of discounting again presents itself where the market rates are not applicable but some level of social discounting is required (Boardman, et al., 2010; Moore, et al., 2001). Valuation of costs and benefits in each year they occur and discounting these values to achieve an NPV should take account of the shadow costs or benefits of an investment. These shadow costs reflect the potential for additional rents or costs if the investment does not have social and organizational constraints. For example in the utility industry, projects benefits are generally compromised and costs increased to allow for alternate PIA project routing due to Aboriginal land issues, environmental policy and so on. Understanding these shadow values is useful in a CBA for demonstrating the impact of accommodating stakeholders and determining what level of bargaining is prudent when making a decision.

Valuation of risk and the consequences of investment alternatives is another fundamental input to a CBA. The riskiness of a PIA investment comes not only from a technical perspective but also from a realization that accommodating social and environmental factors are increasingly important in delivering the project. These social impacts can negatively affect the benefits and increase costs of a PIA investment. For public goods though, the risks are applicable to a large number of persons in the wider society and could have net zero effect. Arrow and Lind argue that the social discount rates applied to costs should be low to reflect this reduced net risk and so too should the benefits gained from a public good. This approach considers that there are seldom instances when a CBA analysis will lead to a perfect Pareto welfare improvement criteria – everyone directly benefits from the investment and any losers are compensated (Arrow & Lind, 1994). In such an environment, it is not very straightforward to define all the benefits, costs and the optimum discount rates. A CBA is therefore nothing more than an effective tool in the decision process and not the means of making the decision itself.

3.9 Risk-Based Analysis

Identifying risks is a significant step in seeking solutions to ensure the reliability of service for a PIA. This activity is contingent upon an asset manager being able to articulate and develop a framework linking corporate objectives, stakeholders and stakeholder requirements with performance criteria (Institute of Asset Management & British Standards Institution, 2008). The concept is basically proposing to asset managers that once the corporate objectives are clear and stakeholder requirements are understood then the risks involving the PIAs can be defined and a risk management cycle laid out (Meijden, et al., 2006).

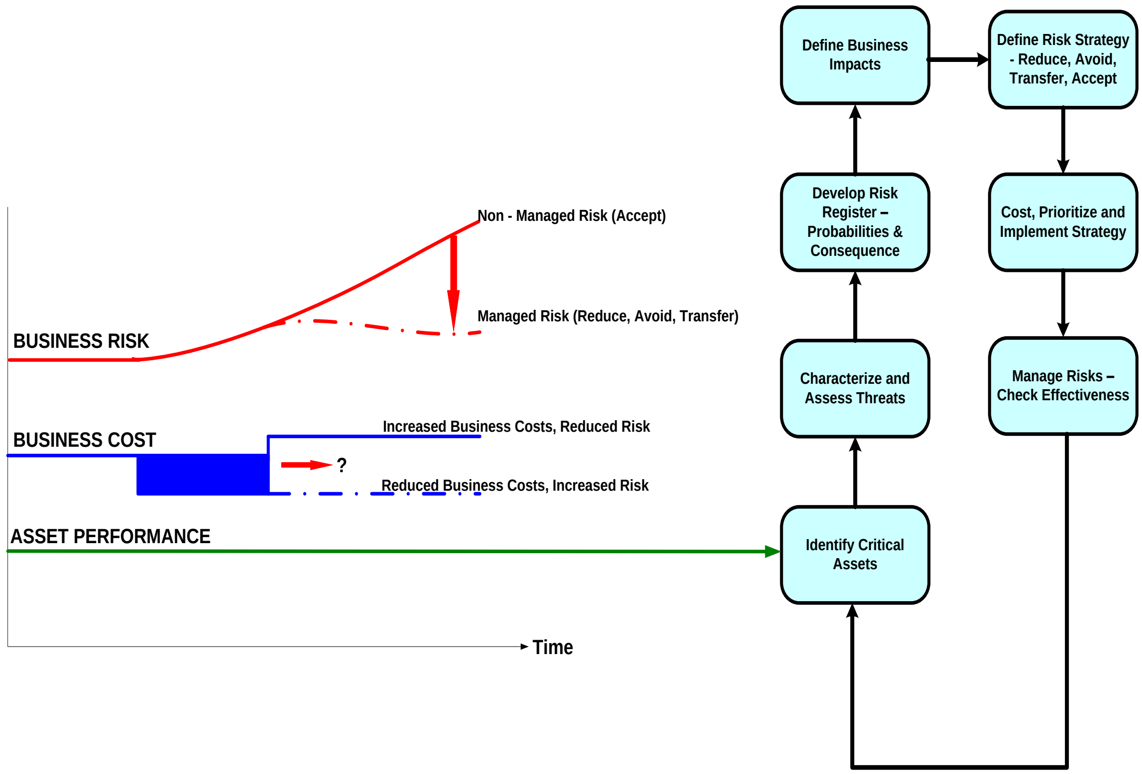

Figure 3-2: Risk Management Cycle

The figure shows the impact on risk profiles relative to asset performance for levels of investment. Adapted from Meijden et al (2006)

As Meijden (2006) points out in his Cigré papers, asset managers should be aware that risk models are specific to the industry, regulatory environment and even the jurisdiction under which an asset owner operates. The risk models developed are merely tools that an asset manager can use to rank risks and investments. Meijden also points out quite rightly that experience is needed in interpreting the result of a risk matrix (Meijden, et al., 2006).

Typically, a coarse logarithmic scale is sufficient for ranking risk consequences. Asset managers mostly gradate this scale from moderate to extreme. In some cases, low to fatal could also be appropriate. In building a risk matrix, it is common for the consequence columns to relate to the organizations business values. Rows generally relate to the probability of occurrence of an event. Horizontal weightings in the matrix usually reflect the internal policies of the PIA owner. Changes in policy can initiate a corresponding change in assigned weightings. It is also important to choose only the key parameters for each business value to ensure the matrix focuses on the critical considerations. For example, where 'Safety' is a business value, it is the norm to focus on impact to lives and the matrix gradates from worker absence to fatalities.

At this stage, the risk consequence matrix so far developed needs to mesh with the probability of occurrence of an incident to define the risk evaluation matrix or risk model. Each cell in the risk model is the product of the risk consequence and its probability of occurrence. This result provides a useful indicator to an asset manager about the relative urgency of a course of action.

The utility of risk analysis depends on the risk tolerance of the decision maker (Canadian Standards Association, 1997). Where owners are relatively risk neutral from a financial sense, such as for investments in PIAs, comparison of alternatives typically proceeds solely based on monetary value. However, for PIA investments involving significant financial, regulatory, stakeholder or technical risk, the probabilistic distribution should probably be developed to address the limitation of sensitivity analysis and expected values (Christensen, et al., 2004).

4: Asset Management Practice

The focus of managing assets is usually getting to a decision. Christensen (2004) argues that, regardless of the level of rigor employed in analysing a business problem, a significant portion of the variables that are selected for inclusion in models or monetization depend on the subjective judgement of experts. This subjectivity infuses the quantitative methods and tools described in the previous section. The indications are that any tool employed will always have a reasonable expectation of bias towards the proclivity of the analyst. The long timelines used in projections also provides an opportunity for error. This occurs because the accuracy of predictions going decades in the future is at best an informed or educated guess. These projections subliminally hold constant any number of performance, environment, usage and resource constraints.

Given the potential impact on results due to tools selected, it therefore becomes essential that the choice of tool or combination of tools becomes the focus of the asset manager.

4.1 Asset Management Analysis

In macro terms, one considers asset managers to be strategic managers since the decisions they routinely make go well beyond the tactical every day operations decisions. Asset management decisions focus on the long-term strategic goal of PIA value maximization over the decades of service expected for the assets. By extension therefore, the issue of strategic choice as addressed by Vining and Meredith (2000) is one that provides one of the biggest challenges for strategic managers. The issue is applicable to PIA asset managers faced with the dilemma of choosing between strategic alternatives, tools or policy in order to analyse a business issue. The action of making a decision involves making a choice based on choices – ‘metachoice’.

Metachoice involves a simple but effective process of factoring goal orientation and willingness to monetize. Metachoice focuses on determining which of four strategic choice methods are applicable for the *ex ante* comparison of decision alternatives. The strategic choice classes proposed by Vining and Meredith (2000) are DCF (including real options variants more suitable for deferred investments or R&D type initiatives), Profitability Analysis, Modified DCF and Multi-goal Analysis. Typically, asset managers have to determine what the relevant strategic goals an investment is seeking to achieve are. An asset manager also has to determine if these goals fall within the organizational strategy and investment policy. They also have to evaluate the monetized variables, those that would require extensive use of resources to monetize or those variables that are not very relevant to the analysis. These considerations are largely at executive policy levels and here again metachoice is involved (Vining & Boardman, 2006). The organizational choice of policies influences the development of strategy and strategic choice of goals and analysis tools. This framework as shown below underscores how essential it is that organizational goals and policy considerations become part of an asset manager’s environment.

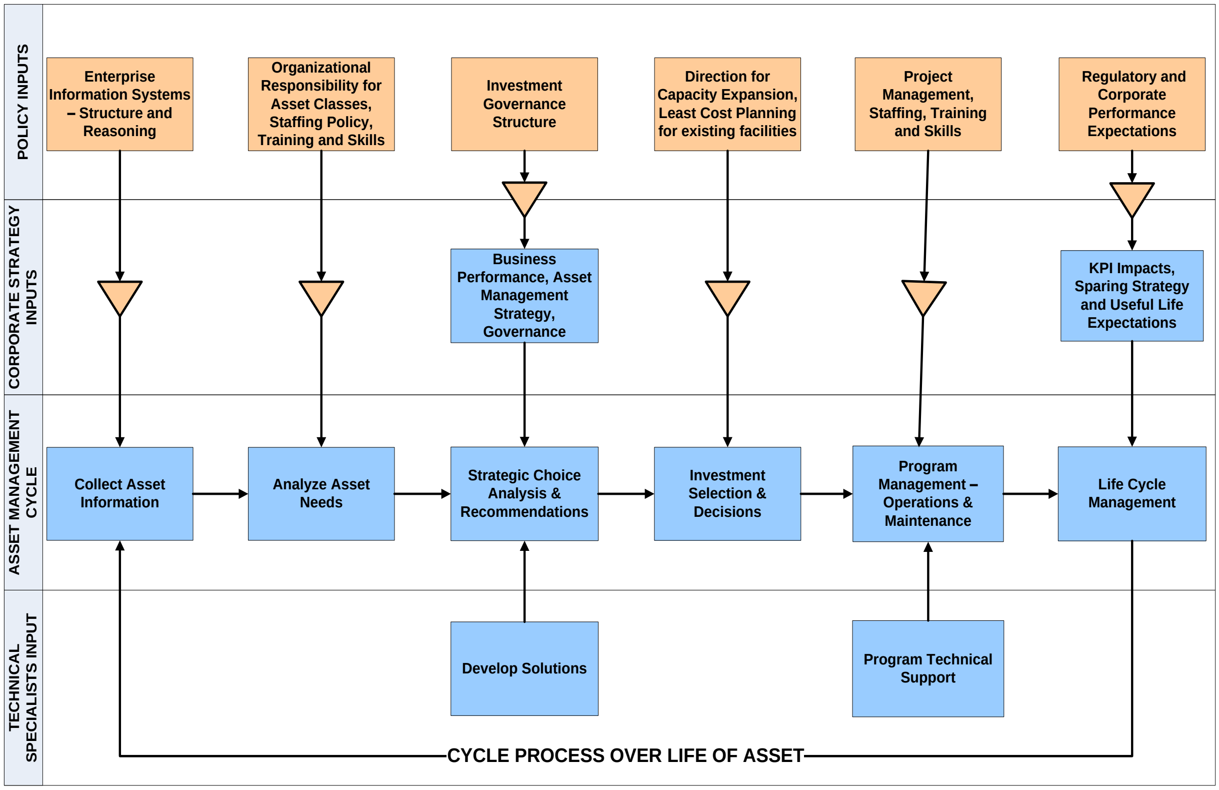

Figure 4-1: Asset Management Cycle

The figure shows policy interaction and strategy implications along the asset management cycle. Source: Author

In performing the analysis required to maintain PIAs, organizations consider not only the tools listed here but also multiple variations of analytical models and methodologies such as reliability centred maintenance (RCM), total productive maintenance (TPM) etc. It is widely recognized among PIA owners that condition monitoring and assessment, data and asset information, work management and resourcing are now basic requirements that computer information systems have enabled. Technology is not a limiting factor for asset managers today and there are rapid advances in condition monitoring tools and reliability management, which are producing ever more sophisticated models (Woodhouse, 2005).

The problem clearly lies not in the analysis but in moving beyond the asset management analysis to making informed decisions – avoiding the proverbial '*analysis paralysis'*. So far, we looked at the impact of aging infrastructure but at this point one should also include the aging workforce as part of the variables for consideration in the analysis of asset management decisions. Retiring workers in organizations have a depth of understanding about the PIAs they manage even though they may not be as comfortable with the newer technology. Newer workers are fully comfortable with the new technology, simulations, and optimization and analysis tools available but may not have the same depth of understanding about the systems they are managing. This is a dilemma that challenges organizational understanding of the actual practical use of the available techniques (Woodhouse, 2005).

As demonstrated in Vining's discussions on metachoice (Vining & Boardman, 2006; Vining & Meredith, 2000), and reiterated by Woodhouse's conclusions (Woodhouse, 2005), the process by which one arrives at a decision is at least as important as the decision itself. Where an asset manager has worked through a business issue with a methodical approach and made strategic choices that reflect the business values and policies, there is some level of confidence and justification in making a decision for or against an investment.

4.2 Asset Management Applied

So far, we have covered the inputs and outputs into an asset management process as well as some of the key analytical methods and tools common in asset management practice. It is interesting to observe that from experience these are for the most part PIA owner organizations largely ignore these methods. The reasons vary from skill and managerial awareness of the possibilities to a conservative and somewhat stoic approach to 'new' methods and ideas. Whatever the reason, it is vital that managers and analysts at least consider or explore the potential improvements on decision-making that these ideas could provide.

4.2.1 Asset Management Practice - Implications

The Institute of asset management prescribes a one asset view, coordinated decision-making process for effective asset management (Institute of Asset Management & British Standards Institution, 2008). However most PIA owner organizations are functional based and not structured to conform to this standard. In BCTC like other utility companies, there is a hierarchical organizational structure organized in competency silos – which are not collaborative in their decision-making. Studies for Cigré by Meijden et al. (2006) indicate that 90% of surveyed organizations have separated their asset management function from their service provider function. The studies indicate that while, 50% have separated their asset owner function from the asset management function (Meijden, et al., 2006), similar to BCTC. Bartlett's study indicates that 81% of respondents feel this separation of function has improved the business performance in terms of operating costs (Bartlett, 2002).

4.2.2 Asset Management Practice - Results

The study data above and personal experiences show that the asset management focus of PIA management companies like BCTC is largely on efficiency rather than effectiveness. Each functional group attempts to deliver its mandate at the least cost to the organization and there is a lack of the 'big picture' view. Reporting of actions and achievement of plans is the key performance indicator and not the effectiveness of the decision process or appropriateness of selected actions.

4.2.3 Asset management Practice - Challenges

While this approach has arguably been successful over the life of most PIAs in North America, the bathtub curve of aging infrastructure indicates the probability of failure is increasing. Given the increasing age of the assets, eventually the volume of investment required for maintaining reliability and availability will skyrocket. The bathtub curve is a probabilistic hazard rate function that quantifies the probability of failure or survival of an asset, regardless of the conventional probability distribution employed (Meijden, et al., 2006). Since installation and commissioning of most PIA assets was over the early part of the last century, avoidance of this bow wave of asset investment requirements will require more coordination across functional groups. Otherwise, it is inevitable that there will be increases to SAIDI and SAIFI.

Another factor is that for public goods, the requirements to prevent market failure and maximize social benefits include regulatory intervention on rates. This intervention puts pressure on asset managers to hold down costs and consequently, managers favour expensing maintenance activities. Expensing maintenance activities and holding down costs means that the funding pools are shallower, and usually set prior to work identification. A tactical approach of just-in-time asset management develops and companies like BCTC have gotten quite skilled at efficiently executing this strategy. In effect there has not been an effective and proactive asset replacement or refurbishment strategy in place and so by default a run-to-failure strategy has resulted (Roldan, et al., 2008) – this is true not only in British Columbia or Canada but across most developed countries as well.

DCF is the method of choice for analyzing investment alternatives in BCTC with qualitative inputs such as reliability and availability supporting the decision process. Risks analysis is part of the project delivery process and not necessarily a consideration from an overall business risk perspective. Where asset managers utilize LCA methods, the efforts are not iterative or include sensitivity and risk analysis. Therefore, the biases of the subject matter experts are possibly more evident than discussed earlier under asset management analysis. In the private sector, the effectiveness of a firm's pursuit of rent maximization drives efficiencies in process and management. Benefits are clear and investment payback estimation has some level of certainty.

Merely, considering how PIA owners or managers like BCTC currently manage their asset base differently from the prescribed treatments in PAS 55 and other works mentioned does not however provide a complete picture. For asset managers to justify investments, they have to demonstrate the investment will have a net positive social benefit. Preferably, this marginal benefit is achievable with no marginal cost to stakeholders. Stakeholders and internal executives often challenge forecasts of residual asset lives. In addition, asset managers expend resources in considering alternate remedies proposed by a public without the full knowledge and of the challenges faced. There is a resulting implicit corporate support system for making do as long as possible without the investment. While the public largely takes a 'not in my back yard' (NIMBY) approach to new investments and upgrades, senior managers can sometimes take the 'not on my shift' (NOMS) approach to increasing operational expenses. Between NIMBY and NOMs, the asset manager is fighting to keep the system running, maintain investment levels and status quo without negatively affecting organizational KPIs like SAIDI. Strategic choice and decision-making start taking a back seat quickly.

Overall, there is no argument about the vital importance of strategic decision-making for effective asset management. Organizational arrangements that have silo'd structures with collective asset ownership can lead to increased professional pride in each sector of a business. The downside is that conflicting priorities between corporate staff, planners, designers and so on could prevent the optimum decision about whether to continue maintaining an asset, refurbish or replace it (Bartlett, 2002). There was a wide variation in responses concerning roles and organizational arrangements from Bartlett's study involving 16 transmission networks with an average length of 14,000km. This points to the fact that strategic asset management is still developing and there is room for improvement across all organizations not just BCTC. From the study results, 88% of respondents agreed that refurbishment / replacement decisions are core management functions, and policy and direction are key components of asset ownership that need to be developed. In addition, 81% of respondents also acknowledged the regulatory environment has a major impact on investment decisions and capital spending.

The major electric transmission utilities across North America, Europe, Scandinavia and the Asia / Pacific region have since 1994 been in partnership with the UMS group which specializes in global energy and utilities consulting to form the International Transmission Operations & Maintenance Study (ITOMS). This benchmarking group seeks to identify the best-in-class asset management performance and practices. ITOMS is very important to electric utilities for sharing experiences and data and several of the performance improvements mentioned in the Bartlett study are a result of this initiative. BCTC has benefited from participation - the current executive attention on making better use of data and collaborating with other organizations to learn best-in-class practices is a direct result of membership in ITOMS (Papadoulis, 2010).

A key insight resulting from collaboration with others has been a move to utilise asset data and business value to establish asset strategy. Another core asset management best practice that BCTC has rolled out so far is an integration of maintenance with replacement planning and growth initiatives for new infrastructure. This integrated strategy involves a cross functional and multidisciplinary planning approach that considers all strategic alternatives and evaluates financial costs and intangible impacts as well. Part of the strategy involves a risk and needs assessment analysis that includes corporate risks as well as project execution risk. Funding and participation in the decision process is from a wide group of internal stakeholders and there is clear executive sponsorship for resolution of the targeted business issues.

While this approach was successful in demonstrating the benefits of integrated planning, it is not very practical for asset managers making daily decisions on individual assets to initiate a wide ranging cross functional group for every planning effort. A reliable, straightforward and repeatable methodology is required that will guide asset management decision-making. Such a method should also adhere to the basic methodologies and philosophies of asset management practice outlined in chapter 2, 3 and 4. Such a process would also provide a means to select the most relevant variables and tools for supporting decision-making and delivering value.

The challenge though is that for practicing asset managers, the theory of the practice is of way less importance than it is to have a simple, intuitive and repeatable methodology. In proposing a process therefore, one has to ensure that we address the relevant theoretical elements, but the key to ensure buy-on from prospective users, is simplicity. This is largely because the asset managers in most PIA organizations are for the most part technical subject matter experts and not financial or business professionals.

5: Decision Support Methodology

Preparation of business cases to secure funding for PIA investments is a crucial role that asset managers play in organizations. As pointed out earlier, in order to optimize investments asset managers have to consider business values of the firm. They also have to make decisions on the choice of tools appropriate for analysis of strategic alternatives. In other words, move beyond formalized strategic choice to consider metachoice.

For BCTC, as with other PIA owners and managers, one of the initial stages in preparation of the business cases is identification and assessment of the potential solutions to address a business need. Classification of business needs according to their breadth gives us single goal needs and multiple goal needs (Vining & Meredith, 2000).

Single goal needs are largely those which can be monetized and for which a single clear result or expectation can be defined. Single goal needs act as a focus for decision-making and include profitability measures such as return on investment, return on assets etc. Corporate social responsibility, safety, ethics and environmental stewardship can also be included as single goal needs provided the asset managers demonstrate their link to the one key overriding organizational goal.

Multiple goal needs on the other hand, are those for which comprehensive monetization is not feasible or practical. There is a realization that over the long term accurate determinations of purely profit maximising goals could be misleading and that it is more important for an analyst to evaluate the factors that could influence profitability over the long term than focus solely on rent generation as an exclusive goal.

For owners of PIAs, it is almost certain that single goal needs are seldom a factor in decision-making. The occurrence of systemic strategic risks warrants a broader appreciation for the intangible endogenous and exogenous factors involved in a firm's business environment. Considering Vining's model (2000) on metachoice, it is clear that most PIA owners requiring an assessment of strategic alternatives should begin by selecting a multi-goal analysis.

The method proposed here scores weighted variables that include both monetized factors and intangible factors. The premise is consistency, repeatability and standardization. This decision support methodology presents an effective procedure to make the inherently subjective process of multi-goal analysis, more objective. The aim is to achieve this through the introduction of a set of ranking attributes based on pre-defined rules for quantifying and scoring the attributes for each strategic alternative.

The key benefit of this process is that functional groups across an organization can make departmental level adjustments to the analysis tool. This flexibility however, will still produce a standardized methodology for supporting asset management decisions by ranking all strategic alternatives. For companies, this demonstrates increasing portfolio maturity with stronger evidence of organization wide strategic analysis to support business decisions.

5.1 Decision Support Process

The decision support process for maintain, refurbish or replace decisions draws from data collection, classification, asset condition assessments and analysis that an asset manager carries out in the planning and review stages. The outcome of a decision process builds on strategic optimization and leads to investment selection for a PIA. In the context of this project, PIA investments driven solely by a need to create a completely new asset to service customer growth demands is not considered especially when there is no impact on existing assets.

5.1.1 Process Overview

Having determined that there is a potential business need based on available data and asset performance reviews, an asset manager then considers the possible strategic alternatives, which could be technical, or business oriented. At this point, there is no solution defined for the issue at hand but rather an awareness of the organizational goals and business values relevant to the situation. Next, a preliminary investigation of possible impacts and risks occurs with assessments for monetization or other value such as increased regulatory oversight or public scrutiny. Evaluation of the proposed alternatives and elimination of outlandish ones then proceeds. The ultimate goal is to perform the multi-goal analysis and weigh the probable alternatives against defined organizational goals. The figure below shows an overview of the decision support process discussed:

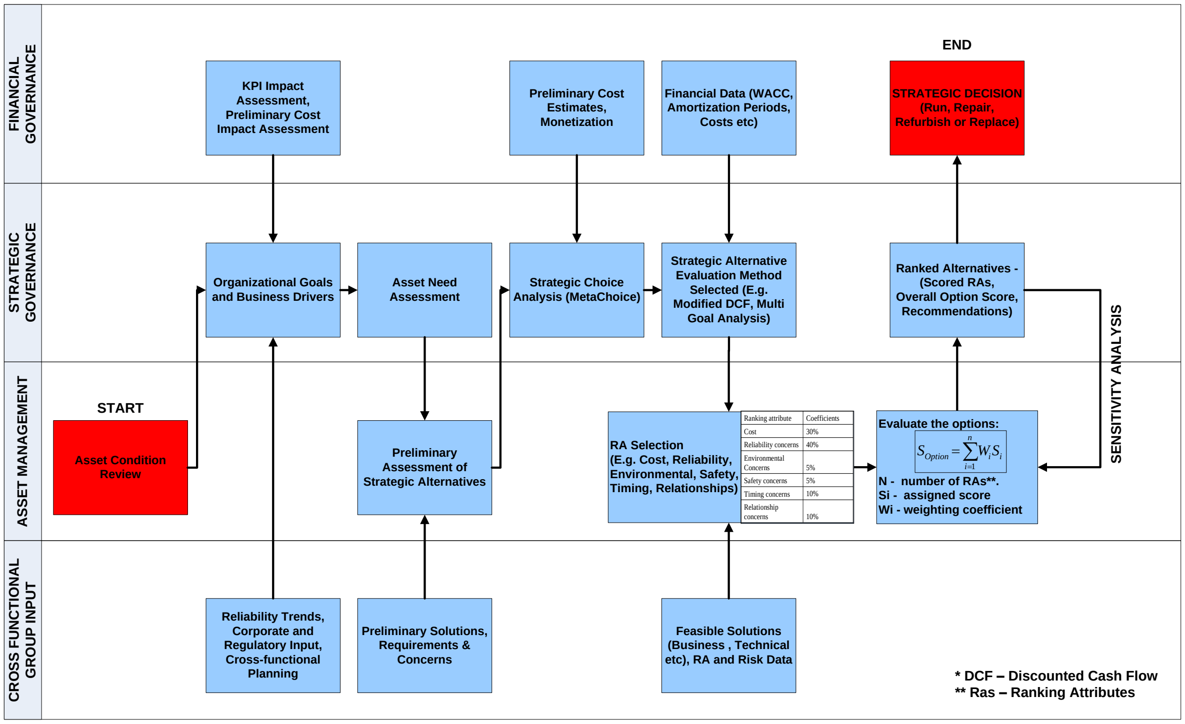

Figure 5-1: Strategic Decision Support Process

The figure shows the requirements, interactions and considerations for governance and organization wide collaboration while making a strategic asset management decision. Adapted from Alaeinovin and Gilpin-Jackson (2009)

Making use of this process requires an understanding of the inputs identified and how the decision support model factors these inputs into its scoring. It is also important to explain the source, quality and importance of the required data on asset condition. We will consider these items in the following sections.

5.2 Decision Support Inputs

The framework shown in Figure 5.1 proposes a multi-goal approach that includes financial, regulatory, asset condition, stakeholder and risk factors. These factors enable realization of the one system, one asset, one view approach proposed by the Institute of Asset Management (2008) since they involve mining data from across the organization.

5.2.1 Decision Support Inputs – Financial

Financial inputs cover all the monetizable factors that are relevant to the decision process. The financial inputs require an accurate evaluation of cash flows relevant to the strategic alternatives. Asset managers should note that these might originate from different sources such as:

- Projected capital investments
- Historical and / or projected maintenance and monitoring expenses
- Potential decommissioning expenses

An asset manager is simply required to enter the real dollar amounts corresponding to each source where available in the year of that cash flow. The decision support tool calculates the discounted cash flow to capture time value of money.

In developing this methodology, it rapidly became clear that in absolute terms, strategic alternatives might not necessarily have the same life cycle and traditional DCF or NPV may not be a rational and accurate method for comparing the real costs of proposed alternatives. Calculating the Equivalent Annual Cash Flow (EACF) for each option solves this problem (Drury, 2004). Calculations of EACF assume that a selected alternative is repeatable at the end of its specified life cycle. This assumption nullifies the variations in life-cycle expectations for options and represents the annual cost required for to sustain the benefits of an option indefinitely.

As mentioned before, it is reasonable to assume that all the strategic alternatives will have the same rent generating potential (given no major game changing capacity increase). Therefore, given the complexity of determining the monetized benefit to the organization from an investment required to sustain asset reliability and availability, managers can neglect these inputs. As a result, the expectation, certainly at BCTC is that analysis will involve negative NPVs. The best alternative based on financial input is therefore the option with the least negative NPV.

5.2.2 Decision Support - Reliability Impacts

Reliability concerns are a key attribute that also affect asset availability. In developing this methodology with BCTC, the corporate risk matrix proved very useful. Asset managers consider this risk-based analysis regardless of the industry. The method as defined earlier, under the risk-based analysis tool in chapter 3.9, involves an understanding of the organizational environment, KPIs and business values. A representative matrix can be developed and used as a basis for defining reliability impacts and scoring them.

Table 5.2.2 (a) – BCTC's Corporate Risk Matrix

Notes: Likelihood and consequence shown as risks with severity classifications defined. (Reprinted with permission from BCTC, July 2010)

Likelihood of occurrence							
90%	(9 in 10) or greater likelihood that event will occur within next year	**5**	**Moderate**	**Moderate**	**High**	**Extreme**	**Extreme**
50%	(1 in 2) or greater likelihood that event will occur within next year	**4**	**Guarded**	**Moderate**	**High**	**Extreme**	**Extreme**
10%	(1 in 10) or greater likelihood that event will occur within next year	**3**	**Guarded**	**Moderate**	**Moderate**	**High**	**Extreme**
1%	(1 in 00) or greater likelihood that event will occur within next year	**2**	**Low**	**Guarded**	**Moderate**	**Moderate**	**High**
<1%	less than (1 in 100) likelihood that event will occur within next year	**1**	**Low**	**Low**	**Guarded**	**Guarded**	**High**
Impact Criteria			**1**	**2**	**3**	**4**	**5**
Safety			First aid injury / illness	Medical aid injury / illness	Lost time injury / temporary disability	Permanent disability	Fatality (ies)
Financial			Impact totalling < $500,000	Impact totalling $500,000 - $1Million	Impact totalling $1Million - $5 Million	Impact totalling $5 Million - $10 Million	Impact totalling ≥ $10 Million
Reliability			One of < 250,000 customer hours lost or < 2GWh energy not served or delivered	One of 250,000 – 1 Million customer hours lost or 2 – 7 GWh energy not served or delivered	One of 1 Million - 3 Million customer hours lost or 7 – 20 GWh energy not served or delivered	One of 3 Million – 7 Million customer hours lost or 20 – 50 GWh energy not served or delivered	One of ≥ 7 Million customer hours lost or ≥ 50 GWh energy not served or delivered
Market Efficiency			Customers and rate payers launch complaints to BCTC	BCTC customers and rate payers lodge complaints to the Government or the Utilities Commission	Government or BCUC enquiry conducted into BCTC practices and policies	Government or BCUC impose strategic or operational changes upon BCTC	Failure to deliver required level of service resulting in loss of license to operate

Relationships	External opposition, resulting in short-term delays or minor modification to work plans	External opposition, affecting ability to implement work plans, Constrained and / or substantive modification to work plans is required	External opposition resulting in increased regulatory oversight; shareholder scrutiny or restricted access to work sites	External opposition resulting in increased regulatory / legislative action, government intervention, loss of corporate mandate, including restricted access to major project sites	External opposition resulting in loss of license to operate and / or imposed corporate restructuring
Organization and People	Negligible impact on service delivery and staff	Impacts the effectiveness or efficiency of some services but would be dealt with internally	Portions of the organization experience unexpected attrition or reduced attraction factors	The ability to achieve the corporate goals is threatened and there is a significant increase in the cost of service	Unexpected loss of multiple critical staff including senior leadership and the ability to deliver critical services
Environment	No reportable environmental incident	Reportable environmental incident with short term mitigation (less than 1 year)	Reportable environmental incident with long term mitigation (over 1 year)	Reportable environmental incident with regulatory fines and mitigation possible	Reportable environmental incident with regulatory prosecution and / or uncertain mitigation

Severity Classifications	
Extreme	Must be managed through a detailed plan by an executive
High	Detailed research and planning by senior management. Executive attention is required
Moderate	Management responsibility must be specified. Manage by specific monitoring or response procedures
Guarded	Manage by routine procedures – regular monitoring is required
Low	Manage by routine procedures

Similar to the corporate risk matrix shown in Table 5.2.2(a), reliability evaluations consider five levels ranging from low, guarded, moderate, high, or extreme. In order to determine the appropriate level, the analyst simply chooses the probability of occurrence of an event affecting reliability and the consequence of that event based on the judgement. This selection is done either in a group, across silos or alone by a knowledgeable asset manager. A reliability risk matrix, relevant to BCTCs' business as shown below is applicable with some modification to any PIA owner or asset manager.

Table 5.2.2 (b) – Reliability Risk Matrix

Notes: The reliability risk matrix shows likelihood, consequences and resulting severity for electric power transmission. Source: Alaeinovin and Gilpin-Jackson (2009)

Likelihood of incidence					
(9 in 10) or greater likelihood that event will occur within next year	**Moderate**	**Moderate**	**High**	**Extreme**	**Extreme**
(1 in 2) or greater likelihood that event will occur within next year	**Guarded**	**Moderate**	**High**	**Extreme**	**Extreme**
(1 in 10) or greater likelihood that event will occur within next year	**Guarded**	**Moderate**	**Moderate**	**High**	**Extreme**
(1 in 00) or greater likelihood that event will occur within next year	**Low**	**Guarded**	**Moderate**	**Moderate**	**High**
less than (1 in 100) likelihood that event will occur within next year	**Low**	**Low**	**Guarded**	**Guarded**	**High**
Impact Criteria	One of less than 250,000 customers hrs lost or less than 2 GWh of energy not served or delivered	One of 250,000 – 1 million customers hrs lost or 2 - 7 GWh of energy not served or delivered	One of 1 – 3 million customers hrs lost or 7 - 20 GWh of energy not served or delivered	One of 3 – 7 million customers hrs lost or 20 - 50 GWh of energy not served or delivered	One of over 7 million customers hrs lost or over 50 GWh of energy not served or delivered

The next step is assignment of a score to the reliability attribute of each strategic alternative. Here again the user simply selects the risk level and pre-determined scores are assigned accordingly. Section 5.3 outlines the scoring of attributes.

5.2.3 Decision Support - Environmental Impacts

Environmental impacts from a strategic option are increasingly important to the business of managing PIAs. The implications of a negative environmental impact arising from the asset operations are so significant that most firms now have this factor as a KPI.

Evaluation of environmental impact essentially follows the same process as outlined for reliability concerns. The corporate risk matrix provides the basis for developing an environmental attribute specific risk matrix. Similarly, evaluations cover five levels ranging from low to extreme. Here again, the analyst simply chooses the probability of occurrence of an event affecting the environment and the consequence of that event based on judgement. This selection is done either in a group, across silos or alone by a knowledgeable asset manager. Determination of the severity of environmental concerns relevant to a strategic alternative requires selection of the probability of having an environmental incident occur as well as selection of the potential impact that such an incident could cause. Selection of these parameters generally happens after consultation with environmental experts and in some cases by using system data from the existing assets. An environmental risk matrix, relevant to BCTCs' business is as shown below.

Table 5.2.3 – Environmental Risk Matrix

Notes: The environmental risk matrix shows likelihood, consequences and resulting risk severity for electric power transmission. Source: Alaeinovin and Gilpin-Jackson (2009)

Likelihood of incidence					
(9 in 10) or greater likelihood that event will occur within next year	**Moderate**	**Moderate**	**High**	**Extreme**	**Extreme**
(1 in 2) or greater likelihood that event will occur within next year	**Guarded**	**Moderate**	**High**	**Extreme**	**Extreme**
(1 in 10) or greater likelihood that event will occur within next year	**Guarded**	**Moderate**	**Moderate**	**High**	**Extreme**
(1 in 00) or greater likelihood that event will occur within next year	**Low**	**Guarded**	**Moderate**	**Moderate**	**High**
less than (1 in 100) likelihood that event will occur within next year	**Low**	**Low**	**Guarded**	**Guarded**	**High**
Impact Criteria	No reportable environment al incident	Reportable environment al incident with short term mitigation (less than 1 year)	Reportable environment al incident with long term mitigation (over 1 year)	Reportable environment al incident with regulatory fines and mitigation possible	Reportable environment al incident with regulatory prosecution and / or uncertain mitigation

The process of assigning scores to the environmental attributes of strategic alternatives is similar to that for the reliability attributes. The user simply selects the risk level with pre-determined scores assigned accordingly as discussed in Section 5.3.

5.2.4 Decision Support - Safety Impacts

Due to the nature of PIAs and the fact that they usually a publicly accessible asset, safety is a core principle and in addition, the nature working in energized environments elevates safety concerns above normal. Safety is a mandatory performance metric by which the regulator measures the effectiveness of BCTC. The matrix shown below is a measure of this metric.

Table 5.2.4 – Safety Risk Matrix

Notes: The safety risk matrix shows likelihood, consequences and resulting risk severity for electric power transmission. Source: Alaeinovin and Gilpin-Jackson (2009)

Likelihood of incidence					
(9 in 10) or greater likelihood that event will occur within next year	**Moderate**	**Moderate**	**High**	**Extreme**	**Extreme**
(1 in 2) or greater likelihood that event will occur within next year	**Guarded**	**Moderate**	**High**	**Extreme**	**Extreme**
(1 in 10) or greater likelihood that event will occur within next year	**Guarded**	**Moderate**	**Moderate**	**High**	**Extreme**
(1 in 00) or greater likelihood that event will occur within next year	**Low**	**Guarded**	**Moderate**	**Moderate**	**High**
less than (1 in 100) likelihood that event will occur within next year	**Low**	**Low**	**Guarded**	**Guarded**	**High**
Impact Criteria	First Aid, Minor Injury or Illness	Medical Aid, Injury or Illness	Lost time injury or temporary disability	Permanent disability	Fatality

Similarly as for reliability and the environment, the user selects the appropriate probability and consequence level on the safety matrix to determine safety impacts of a strategic alternative. Section 5.3 addresses safety attribute scoring together with environment and reliability.

5.2.5 Decision Support - Relationship Impacts

PIA owners generally manage public assets and there is an expectation that as stewards of public property they have to go beyond the normal requirements for purely private firms to be good corporate citizens. Corporate social responsibility (CSR) for BCTC extends beyond simply managing generic public interests. CSR also involves dealing with third party issues, right of way problems or relations with First Nation communities. It is fundamental to categorize these issues when considering strategic alternatives. In the recent past, the regulator has mandated a full risk evaluation especially regarding First Nations concerns. The relevant matrix for relationships is similar to matrices already described for reliability, environment and safety risks.

Section 5.3 discusses scoring of relationships attributes as already mentioned for the other attributes.

Table 5.2.5 – Relationships Risk Matrix

Notes: Relationships risk matrix showing likelihood, consequence and resulting risk severity for consideration of electric power transmission stakeholders. Source: Alaeinovin and Gilpin-Jackson (2009)

Likelihood of incidence					
(9 in 10) or greater likelihood that event will occur within next year	**Moderate**	**Moderate**	**High**	**Extreme**	**Extreme**
(1 in 2) or greater likelihood that event will occur within next year	**Guarded**	**Moderate**	**High**	**Extreme**	**Extreme**
(1 in 10) or greater likelihood that event will occur within next year	**Guarded**	**Moderate**	**Moderate**	**High**	**Extreme**
(1 in 00) or greater likelihood that event will occur within next year	**Low**	**Guarded**	**Moderate**	**Moderate**	**High**
less than (1 in 100) likelihood that event will occur within next year	**Low**	**Low**	**Guarded**	**Guarded**	**High**
Impact Criteria	External opposition, short-term delays, minor modifications to work plans	External opposition, affecting ability to implement work plans, Constrained and / or substantive modifications work plans is required	Increased regulatory oversight; shareholder scrutiny, restricted access to work sites	Increased regulatory / legislative action, government intervention, loss of corporate mandate, restricted access to major project sites	Loss of license to operate, imposed corporate restructuring

5.2.6 Decision Support - Timing Impacts

This risk is a flexible attribute that accounts for the uncertainty inherent in planning and execution of a project. While the strategic analysis does not address the execution stage of the investment, it is germane to the discussion to consider potential influences that might lead to implementation difficulties as planning level risks. Experience shows that the longer the duration and complexity of a project the more chance for failure and missed objectives.

Timing impacts can sometimes be the direct result of business needs for addressing a need or they could be indirect impacts from an options projected procurement, construction and commissioning requirements. In addition, the criticality of a strategic alternative in terms of special work windows, approvals etc might also lead to timing risk impacts. Similar to the financial attribute definition in section 5.2.1, a straight method of quantifying this risk is appropriate. Five time spans correspond to the risk matrix levels used for the reliability, environment, safety and relationships risks. These levels range from quick turnaround, low risk solutions to multi-year major efforts and scored accordingly.

- Less than two months
- Two months to six months
- 6 months to a year
- 1 year to 2 years
- over 2 years

NOTE:

The selection of time intervals reflects the planning windows of BCTC's current regulatory approval process for capital investments.

Naturally, this approach will skew the preferred strategic alternative towards the shorter duration options. The intention behind this thinking is to balance the long terms strategic focus of this methodology with the practical reality of managing the work after an asset manager makes the strategic decision.

5.3 Decision Support Scoring

While the six ranking attributes discussed above are the most relevant for BCTC, a user of this methodology is free to develop new attributes or to modify the ones already mentioned. It is crucial though to apply all the attributes across all the strategic options evenly.

The scoring process happens automatically and the only input required by users is selection of attribute risk level or inputting cost estimates for the financial attributes. The intention of the scoring process is to normalize the various tangible and intangible data and eliminate from the choice platform all options that are not within organizations framework policies.

5.3.1 Monetized Attributes

As a ranking attribute, financial inputs are ranked in the range of [-10, 0] to ensure compatibility with other ranking attributes. Scoring the financial attributes of each alternative involves assigning the lowest score of -10 to the option with the smallest EACF and prorating the other options accordingly

5.3.2 Intangible attributes – non monetized

In order to ensure alternatives that are feasible are considered in the decision-making process, options with low, guarded and moderate reliability concerns are assigned scores that are within the [-10,0] range. Unless there are significant extenuating circumstances, there is no expectation that options with high or extreme reliability concerns should be highly ranked in the process - regardless of what the scores of other attributes of the same option are.

The scoring of reliability, environment, safety and relationships are similar and relevant calculations indicate high and extreme risks should have very low scores of -191 and -2369 respectively assigned.

Using simple linear functions, calculation of scores is as follows:

$$S_{Alternative} = \sum_{i=1}^{n} W_i S_i \qquad (2)$$

Where:

n - Number of the ranking attributes considered and in this analysis

S_i - Score assigned to the i^{th} ranking attribute

W_i - Weighting coefficient of the i^{th} ranking attribute

Equation (2) shows that weighted coefficients play a major role in determination of the results of the ranking process. The weighting and scores assigned to attributes were the result of internal interviews, meetings and discussions with senior engineers and capital managers at BCTC (Alaeinovin & Gilpin-Jackson, 2009). Interestingly, the weighting coefficients for attributes independently recommended by interviewees were very similar.

Depending on the business focus of the user, this methodology is flexible. Where a networked system such as the electric transmission grid is analysed, reliability ranks highly ranked due to the impact loosing any system element may have on service availability for the entire network.

Overall, the coefficients listed in table 5.2.2 (a) below were useful in performing the analysis.

Table 5.3.2 (a) – Ranking Attributes and Recommended Weightings

Notes: Ranking attributes for decision support analysis showing the recommended weighting coefficients developed for BCTC. Alaeinovin and Gilpin-Jackson (2009)

Ranking attribute	Weighting coefficient
Cost	30%
Reliability concerns	40%
Environmental Concerns	5%
Safety concerns	5%
Relationship concerns	10%
Timing concerns	10%
Totals	100%

For the non-matrix attributes such as 'Timing Concerns' selected by BCTC a simpler approach is appropriate for estimating attribute scores. The basic premise of scores between [-10, 0] is again applied but in this case a linear approach is used to divide the scores equally across the possible selections. The resulting scores corresponding to various risk levels for non-matrix risks are:

Table 5.3.2 (b) – Timing Attribute Scores

Notes: The criteria and associated scores for timing risks reflect the riskiness of a project with increasing duration. Alaeinovin and Gilpin-Jackson (2009)

Less than 2 months	0
2 months to 6 months	-2.5
6 months to a year	-5
1 to 2 years	-7.5
Over 2 years	-10

As mentioned earlier, the rational behind assignment of scores ensures that any option with high to extreme risks for at least one of its ranking attributes falls below options without high or extreme concerns for any of their ranking attributes. Options without high or extreme concerns for any of their attributes can have overall scores as low as -10 but not any smaller. To ensure definitive results are achieved, the contribution of the least important attribute (attributes with the lowest weighting coefficients, i.e. 0.05) to the overall score of the option is less than -10 (larger than 10 when considering just the absolute values) i.e.

From tables 5.3.2 (a) and 5.3.2 (b) above:

$$(-10)\times 0.3+(-10)\times 0.6+(-5)\times 0.1=-9.5$$

In other words,

$$(x)(0.05)\geq -9.5 \tag{3}$$

Or $(x)\geq -190$

Where x represents the assigned score.

Therefore, based on Equation (3), the score assignment for high cases is -191.

Similarly, options with extreme risk concerns should rank lower than the options without extreme concerns. The lowest score that options without extreme concerns should have is:

From tables 5.3.2 (a) and 5.3.2 (b) above:

$$(-10)\times 0.3+(-191)\times 0.6+(-7.5)\times 0.1=-118.4$$

To have the least important ranking attribute capable of dragging down an option with extreme concerns, cases with extreme concerns need to be scored in a way that

$$(x)(0.05) \geq -118.4 \tag{4}$$

Or $(x) \geq -2368$

Where x represents the assigned score.

Therefore, based on Equation (4), the score assignment for extreme cases is -2369.

The overall scores for the various levels of assigned risk reflect the organizations aversion for high and extreme risk options. Where analysts use this methodology to analyse options for action then regardless of any benefits associated with the option options, asset managers will not select options with the highest risk. Conversely, when the most risky alternative is of concern, in order to drive the most impact on corporate KPIs, then the options having high and extreme risks will be under consideration first in reverse order.

Again as mentioned previously, the ranking and scoring are selectable based on user organization preferences and risk tolerance.

Table 5.3.2 (c) – Overall Risk Impact Scores

Notes: Scores for risks impacts reflecting the relative bias in extreme risk alternatives compared to low risk options. Source: Author

Low	-1
Guarded	-5
Moderate	-10
High	-191
Extreme	-2369

An asset manager runs the analysis process for all of the options under consideration with evaluation scores assigned before final ranking of the options.

5.4 Key Decision Considerations

Having discussed the use of the decision support tool it is necessary that we look at the various scenarios that an asset manager could be required to analyse using this methodology. The scenarios correspond to the various life cycle stages of an asset or asset base related to the key regions in a typical hazard-rate function curve. The figure below shows the positions of the relevant run, repair, refurbish or replace decisions along the asset life cycle.

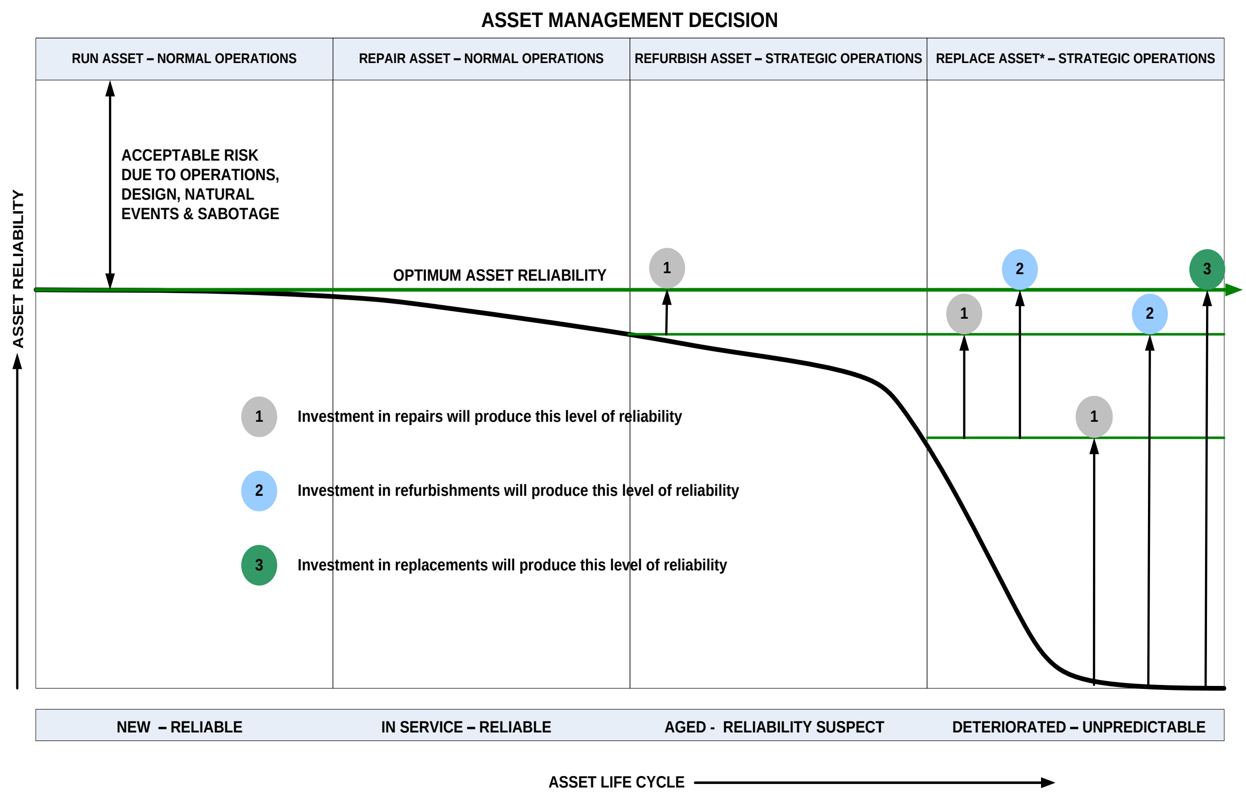

Figure 5-2: Asset Management Decision Alternatives

The figure shows potential investment decisions and strategic alternatives relative to asset life cycle. Source: Author

It is important to understand the relevant decision scenarios so that the metachoice capability of the proposed decision support methodology can be fully exploited. These scenarios are discussed in the following sections.

5.4.1 Maintenance Alternatives

We have established that run-to-failure is not a prudent asset management practice and in service PIAs are expected to be maintained to assure continued quality of service as designed. Given the input from system level data and inspections about asset condition, an asset manager makes discrete choices about the focus for maintenance dollars each year. Since maintenance dollars and resources are finite, some amount of prioritization is required. Maintenance decisions consider life extension of an individual component, mitigate the risk of premature failure and might involve replacement or refurbishment of system components. For the purposes of this discussion, run and repair decisions that are relevant at the early life-cycle stage of the asset are jointly called – maintenance decisions. While Maintenance investments are a normal part of PIA operations, the selection of suitable projects depends on expert judgement and corporate focus.

The relevant decisions each year are:

a. What asset or class of assets should an organization invest in maintaining?

b. For which asset classes should an organization defer maintenance to subsequent years?

Generally for BCTC, assets with a condition rating of ‘D’ or ‘E’ are mandatory projects and the prioritization is left between assets in condition category ‘C’ should be invested in. Evaluation of the strategic alternatives (viable condition C and lower assets) includes all the ranking attributes except cost in order to determine their relevant criticality to the business. Most PIA owners expense maintenance costs and count them against the operational expense (OpEx) of a business. Increases to OpEx can affect the rate base of a public good owner and drive management pressure to cap these investments as mentioned earlier in this paper.

The most critical projects or alternatives are then analysed for cost, budgets and potential for bundling into major maintenance programs that might span several fiscal years.

5.4.2 Refurbishment Alternatives

Refurbishment in asset management largely refers to the overhaul of a significant portion of a network or PIA. While maintenance seeks to extend the life of a component, refurbishment targets life extension of part or the whole of an asset network. Examples are the replacement or renewal of major lengths of a defined road, re-construction of a significant section of a defined transmission line or the complete resurfacing of a bridge deck. The usefulness of a single source of data as advocated by the Institute of asset management (Institute of Asset Management & British Standards Institution, 2008) and detailed in work by Parekh (Parekh, et al., 2007), was used in internal BCTC studies to determine the appropriateness of current capital budgets and garner an overall picture of asset health (Ta, Girard, & Forget, 2009).

Refurbishment generally occurs beyond midpoint of an asset life cycle and is the result of a mid-life management capital strategy. The relevant decisions here again are:

a. What asset or class of assets should an organization invest in refurbishing?
b. For which asset classes should an organization consider continuing maintenance or move directly to replacement?
c. What threshold levels of investment or defects should trigger refurbishments?

Generally, for BCTC, asset demographics and health trend data are invaluable for making these strategic choices. In principle where the condition of a significant portion of an asset is in poor condition, reliability is trending downwards and the number of failures or defects are increasing then a refurbishment may be appropriate. The amortized value of the asset is, discounted and used, to determine the EACF for comparison against maintenance costs. If this value is trending higher than the projected yearly maintenance expenditure on the asset then it is almost certain that a refurbishment is feasible.

Evaluation of the strategic alternatives (generally variations of options to refurbish or maintain) includes all the ranking attributes in order to determine their relevant criticality to the business. Since refurbishments are capital expenses (CapEx), effective planning is essential to avoid any unexpected costs that could factor into the PIA rate base. Increases to CapEx are amortizable over the life of the asset and do not have an initial large impact to stakeholders, however, regulators expect a prudent asset manager to have a longer-term asset view and provide justification for capital investments – the decision support methodology can provide this level of confidence.

5.4.3 Replacement Alternatives

Replacement in asset management typically refers to the overhaul of a network or PIA. A replacement decision can trigger asset rebuilds, upgrades or expansions. This is usually a straightforward decision brought about by asset failure or the requirement for increased service capacity. Examples are the rebuilding due to a reroute or carriageway expansion of an entire stretch of road, re-construction of an existing transmission line or the construction of a new bridge to replace an existing one.

Here again the usefulness of accurate data on future asset performance requirements, historical performance and failures, operational costs and so on is critical for the decision.

Replacement generally occurs at end-of-life of an asset provided the service is still critical. The relevant decisions are – what new asset or class of assets should an organization invest in installing or building? – Is an increase in quality and capacity over the previous asset a requirement for the new asset? – Is it prudent for the asset manager to refurbish or repair the existing asset in order to defer the replacement investment?

Generally, historical costs, asset demographics and health trend data are invaluable for making these strategic choices. In principle where an asset has failed, reliability is trending downwards, original equipment manufacturer (OEM) spare parts support is not available and the number of failures or defects is unacceptable then a replacement may be appropriate. ,

Strategic alternatives are generally variations of replacement options as well as refurbish or maintain alternatives. Their evaluation includes all the ranking attributes in order to determine their relevant criticality to the business. CapEx requirements for replacements target installing the new asset prior to failure of the existing poor condition asset. Regulators expect a prudent asset manager to have an integrated approach to replacements that look beyond the current reliability and availability requirements to projections of future use and technology.

5.5 Interpretation of Results

The decision support methodology introduced provides a means of considering all the relevant factors involved in making strategic choices. On completion of the analysis, an asset manager should receive with clear-cut solutions and recommendations backed up with reliable source data. It is relatively straightforward to make a decision in this case. In some cases, the outcome of the analysis may present some closely ranked alternatives and there is a dilemma of judgement. In the Excel® based User Interface (UI) set up so far as an initial version of the decision support tool, proximity boundaries have been set up which trigger a message – 'further analysis required' when options are sufficiently close together in aggregate scores. The expectation is that this should trigger a sensitivity analysis, revision of assumptions or consideration of further strategic choice alternatives.

Regardless, the asset manager has to keep in mind that the methodology and the resulting decision support tool are only guides and aides for asset management. Given that there are several assumptions required for the analysis that may depend on the bias of the analyst, the method only attempts to provide uniformity of analysis in a relatively subjective process such as decision-making – in other words provide objective subjectivity.

Generally, where several closely ranked alternatives are similar in the majority of key attributes, the areas where they score differently could require additional study and analysis to validate assumptions and inputs. In the final analysis though, the asset manager will have to make the decision.

6: Summary and Conclusions

Traditional business planning efforts are suitable when risks and planning horizons are near term. However, these same methods are not as useful when an asset base starts to age with reliability, and availability of service becoming a concern. The intent of strategic choice for asset managers and owners of PIAs is to increase effectiveness in allocations of capital investment dollars and other resources. The concept assists asset managers with forecasting of future requirements. This forecasting is integral to promoting an overall strategy for the entire asset network that ties in with corporate policy and business values. The next few sections present some closing thoughts on the strategic choice process and asset management.

6.1 Gaps and Requirements

This document focuses on the need for efficiency in strategic decision-making and touches on the importance of physical infrastructure assets to a nation's economy and the well-being of the citizens. I also acknowledge that there are certainly differences in service life, function, costs and governance between spatially stationary point assets - buildings (hospitals, generating dams etc) and linearly dispersed assets (power lines, highways). As a result, asset managers responsible for the different types and classes of PIA require different approaches. However, the concept of PIAs used in this work is a broad generalization that reflects the key similarities between the major classes of assets and provides a means for developing a general process that is flexible and can be tailored so any PIA type. The resulting methodology, factors and scores outlined in this document are a useful start to developing a comprehensive but simple and intuitive tool to support strategic decision-making. Nonetheless, some requirements or shortcomings need addressing in order to improve the practice of strategic asset management for PIA owners and managers.

6.1.1 Policy

Corporate policy sets the tone for asset management strategy and goal selection. An organizations' policy direction, whether set by external forces, the market or the nature of the business itself concerns optimizing an efficient allocation of resources and social benefits (Vining & Boardman, 2006). Recognising that fire fighting skills, operational efficiency and tactical decisions are admirable; an organization's leadership has to ensure a long-term focus for PIA investments and strategy. Public policy usually drives new investments in PIAS, leading to changes in operational practice. These changes in turn are instrumental in determining CapEx and OpEx levels.

Corporate policy and strategy frameworks also help shape attitudes towards data management, organizational structure and resourcing. For the effective asset management of aged PIAs, organizations have to support and sponsor cross-functional planning. An integrated approached to all business aspects can provide significant strategic advantage. Asset manager KPIs should encompass this iterative and integrated approach targeting effective decision-making and not just focus on operational efficiency.

6.1.2 Organization

Regardless the business problem, organization's business or environment, the structure of the organization itself is usually a crucial factor in the effectiveness of any management or executive policy and initiatives. In effectively delivering an asset management service, the big picture view across the entire organization should be the only strategic view that matters. Effective asset managers ensure they consult across business groups for financial analysis, operational planning, human resource and procurement support and so on.

Hierarchical, silos and rigidly functional organizations present a barrier to cross-functional integration and true operational efficiency. There is clearly a need to consider 'silo busting' initiatives that force managers to look beyond their functional groups for support with a business need. Single source data with multiple access points could help do this, but the change has to come from an organizational perspective.

6.1.3 Technology

The key input that triggers the entire decision process is data on the state, location, history (financial, performance and technical) and life expectancy of the PIAs. Inspection, Monitoring & Assessment Data and Trends, provide insights into the overall condition of an asset base, effect of ageing and service capability. Collectively this data makes up an asset health index (AHI) which is unique to each asset class in a PIA base.

A centralized EIM framework is widely considered vital to generating accurate and relevant AHIs for asset classes and a best practice. In most PIA owner organizations such as BCTC, this is not the case and it becomes a challenge to collect, validate, analyze and use data effectively.

Powerful data acquisition and analysis platforms are required. These have to be robust enough to handle the variety of formats for legacy data and accept new geospatial type data. The required systems have to power the back end of the decision support methodology and risk analysis tools and perform complex statistical manipulations on life expectancy. However, the data systems also have to be equipped with simple UIs to promote buy-in by all mangers and analysts.

Currently there are various systems on the market but no single one COTS enterprise system that can perform this function.

6.2 Conclusions

Asset management of PIAs is essential and has a direct impact on the economy of a nation and the welfare of its citizens. The volume of work, extensiveness of PIA networks, high capital requirements and long life cycle of PIAs require owners to be on top of their game concerning operational excellence and long term strategic planning.

The literature reviewed in this work and experience indicates that the body of knowledge for managing the execution of projects is substantial. Leaders across various industries and jurisdictions largely agree on the general principles of what constitute best practice for asset management. However, when one considers the disparate methods, tools and philosophies that are available concerning strategic decision-making it is tough to make a choice. A metachoice framework is required just to select the potential solution or tool. In practice, one realizes that with the possible exception of the Institute for Asset Management, there is no real standardized approach or best practice for strategic asset management. A ‘best of breed' approach prevails where business issues are analysed using best-fit solutions without much thought to consistency and repeatability.

On the other hand, the strategic choice model and methodology presented in chapter 5 predicates delivery of a repeatable and consistent process for strategic asset management. The strength of this methodology as laid out in this paper is its simplicity and ease of configuration. The trial excel UI takes no more than a few minutes to set up and run, providing almost instant feedback on the inputs relative to multiple strategic alternatives and options. This feature ensures running a sensitivity analysis is similarly fast and secure.

As with every process, however, there are limitations. The reader should be aware that in order to provide simplicity and speed for asset managers, the adapted risk matrices involve the user making several broad assumptions that could skew the results of an analysis. These assumptions arise from a judgement of probability of an event and its consequence. However, having a group evaluation could reduce this bias through a collaborative completion of the matrices.

Further limitations are that in running the DCF analysis, the user has to complete significant up front work to estimate costs and think about the feasibility or consequences of proposed alternatives. Here again the analysts should consider the impact of using a DCF with discount rates based on WACC. Given that most PIA projects could have intergenerational impacts and do not really crowd out private investment, then time declining investments might be appropriate (Boardman, et al., 2010). This project does not analyze the implications of this and it would be interesting to perform this analysis and determine what would be the results if this concept is applied to past decisions.

In a similar vein, the simplification of PIAs as non rivalrous but excludable public goods is debatable; under most circumstances they could be considered natural monopolies. While I recognize that the exactness of the classification is important for determining the appropriateness of any public policy response to managing the assets, this work does not explore the economic implications of classification on PIA governance. Because of this limitation, the assumption embedded in this document that the regulatory environment is intended to attempt to address market failures differs in only the specifics regarding each asset regardless of whether it is a natural monopoly or a public good. The essential service and functions provided by regulators are largely intended for the same purpose – provide a framework that approximates to Pareto efficiency by mitigating the impacts of market failures. It is arguable that the natural monopoly better defines the market failure associated with some PIAs but that is a discussion outside this work. In the final analysis, especially for BCTC, an open access tariff and distributed electricity generation from private investors does push the monopoly question into unknown territory.

Finally, given the scope of this work, I have not defined a decision point to trigger the refurbish, or replace question. This is an area where it would be interesting to do further work in order to determine what the economic point of efficiency is for an asset class that would match a defined probabilistic failure and life expectancy assessment for PIAs.

PIA owners do not have unlimited resources and asset managers have to demonstrate the choices they make are prudent, defensible, and repeatable and will improve the network. Decisions have to be supported regardless of whether the pressures triggering a strategic alternative are due to outage costs exceeding amortized replacement costs; requirements to maintain certain levels of reliability or asset end of life. Because it is usually the cheaper option in the near term to continue maintaining an asset, a decision support methodology that looks at the overall picture and accounts for all tangible and intangible costs provides a considerable more accurate picture for asset managers;

The methodology discussed in this work seeks to ensure that strategic choice is an integral part of asset investment planning and portfolio management. The approach recommends the use of organizations' corporate policy, goals and objectives (as described by the relevant risk matrices) in combination with financial and cost information to leverage data on asset health and capacity. The intention is that an objectively subjective approach will stimulate asset managers to think about the impacts of all business attributes. If this approach leads to an integrated mindset that enables analysts and managers to start looking at the big picture beyond asset life cycle, then the concept will have proved successful.

References

Alaeinovin, P., & Gilpin-Jackson, A. (2009). Development of a Business Decision Support Tool. Unpublished Internal report. BC Transmission Corporation.

Arrow, K. J., & Lind, R. C. (1994). Risk and Uncertainty: Uncertainty and Investement in Public Investment Decisions. In R. Layard & S. Glaister (Eds.), *Cost Benefit Analysis* (2 edition ed., pp. 160-178). Cambridge.

Association of Local Government Engineering New Zealand Inc (INGENIUM), & Institute of Public Works Engineering of Australia (IPWEA). (2002). *International Infrastructure Management Manual* (Second ed.). Auckland: National Asset Management Steering (NAMS) Group.

Ault, G. W., Meijden, M. A. V. d., Toneguzzo, J. P., & Welch, I. (2004). Asset Management Investment Decision Process. [Technical Brochure]. *CIGRE(International Council on Large Electric Systems) Working Group C1.1, 106*.

Bartlett, S. (2002). Asset Management in a De-regulated Environment. [Study Paper]. *CIGRE(International Council on Large Electric Systems) Study Committee SC23, 303*(Session 2002), 4.

Boardman, A. E., Moore, M. A., & Vining, A. R. (2010). The Social Discount Rate for Canada Based on Future Growth in Consumption. Unpublished White Paper. Canadian Public Policy.

Canadian Standards Association, C. C.-Q. (1997). Risk Management: Guideline for Decision-Makers, *General instruction No. 1*: CAN/CSA.

Christensen, P. N., Sparks, G. A., & Kostuk, K. J. (2004). A Method-Based Survey of Life Cycle Costing Literature Pertinent to Infrastructure Design and Renewal. *Canadian Journal of Civil Engineering, 32*(1), 250-259.

Dale, B. G., Wiele, T. v. d., & Iwaarden, J. v. (2007). *Managing Quality* (5th ed.): Wiley-Blackwell.

Department of Energy. (2008). *Exploring the imperative of revitalizing America's electric infrastructure*. Retrieved from http://www.oe.energy.gov/DOE_SG_Book_Single_Pages.pdf.

Drury, C. (2004). *Cost and Management Accounting* (6th ed.). London: Thomson Learning.

Fabrycky, W. J., & Blanchard, B. S. (1991). *Life Cycle Cost and Economic Analysis*. Englewood Cliffs, NJ: Prentice Hall.

Gagnon, M., Gaudreault, V., & Overton, D. (2008). Age of public infrastructure: A Provincial Perspective. *Statistics Canada, Analysis in brief* (Catalogue No: 11-621-MIE2008067).

Gaudreault, V., & Lemire, P. (2006). *The age of public infrastructure in Canada*. *Statistics Canada, Analysis in brief*(Catalogue no. 11- 621- MIE2006035).

Government, B. C. (2007). *The BC Energy Plan: A Vision for Clean Energy Leadership*. Retrieved from http://energyplan.gov.bc.ca/PDF/BC_Energy_Plan.pdf.

Henry, W. P., Natale, P. J., Walton, C. M., Basham, D. L., Brown, J. A., Bennett, J., et al. (2005). *Report Card for America's Infrastructure*. Reston: American Society of Civil Engineers.

Institute of Asset Management & British Standards Institution. (2008). Asset management: Specification for the optimized management of physical assets, *PAS 55-1:2008*. London: British Standards Institution.

Institute of Electrical and Electronics Engineers (IEEE). (1987). Standard Terms for Reporting and Analyzing Outage Occurrences and Outage States of Electrical Transmission Facilities, *IEEE Std. 859-1987 (R2002)*: IEEE.

Komonen, K., Kortelainen, H., & Räikkonen, M. (2006). An Asset Management Framework to Improve Longer Term Returns on Investments in the Capital Intensive Industries. In J. Mathew, J. Kennedy, L. Ma, A. Tan & D. Anderson (Eds.), *Engineering Asset Management* (Vol. Proceedings of the 1st World Congress on Engineering Asset Management (WCEAM) 11 – 14 July 2006 pp. 418-432). London: Springer

McRae, D. (1998). Asset Management System Ties It Together. *Transmission and Distribution World*. Retrieved from http://tdworld.com/mag/power_asset_management_system_2/index.html

Meijden, M. v. d., Janssen, A., Ford, G., Rijks, E., Allan, D., Balzer, G., et al. (2006). Asset Management of Transmission Systems and Associated Cigre Activities. [Technical Brochure]. *CIGRE(International Council on Large Electric Systems) Working Group C1.1, 309.*

Moore, M. A., Boardman, A. E., & Greenberg, D. H. (2001). The Social Discount Rate in Canada. In A. R. Vining & J. Richards (Eds.), *Building The Future: Issues in Public Infrastructure in Canada* (Vol. Policy Study 34). Winnipeg: CD Howe Institute.

Ostendorp, M. (2009). *Life Cycle Cost Analysis* (No. CEATI Report T083700-3219). Montreal: CEATI International.

Ouertani, M. Z., Parlikad, A. K., & McFarlane, D. (2008). Towards an Approach to Select an Asset Information Management Strategy. *International Journal of Computer Science and Applications, Vol. 5, No. 3b,* 25 - 44.

Papadoulis, J. (2010). International Transmission Operations & Maintenance Study (ITOMS). In B. T. A. Management (Ed.), *Conference Report* (Report to asset management group on the outcome of a corporate sponsored conference ed.). Christchurch, New Zealand.

Parekh, K., Zhou, J., McNair, K., & Robinson, G. (2007). *Utility Enterprise Information Management Strategies*. Paper presented at the Grid Interop Forum 2007. Retrieved from http://www.grid-interop.com/2007/downloads/GI07-Proceedings.pdf

Pickett, J. P. (Ed.) (2000) (Fourth Edition ed.). Boston, MA: Houghton Mifflin Company.

Richards, J., & Vining, A. R. (2001). Thinking about Infrastructure. In A. R. Vining & J. Richards (Eds.), *Building The Future: Issues in Public Infrastructure in Canada* (Vol. Policy Study 34). Winnipeg: CD Howe Institute.

Roldan, Z. S., Chien, S. H., & Lee, R. J. (2008). A Step Ahead of Run-to-Failure. *Transmission and Distribution World*. Retrieved from http://tdworld.com/customer_service/step_ahead_runtofailure_1008/index.html

Short, T., Feinstein, C., & Morris, P. (2006). *Guidelines for Intelligent Asset Replacement:* . Palo Alto, CA: Electric Power Research Institute.

Ta, T., Girard, J. P., & Forget, M. A. (2009). *Strategic Asset Management: Sustain Investment Model*. Paper presented at the EUCI.

Torell, W., & Avelar, V. (2004). Mean Time Between Failure: Explanation and Standards. West Kingston: APEC Media.

Vining, A. R., & Boardman, A. E. (2006). Metachoice in Policy Analysis. *Journal of Comparative Policy Analysis, Volume 8*(1), 77-87.

Vining, A. R., & Meredith, L. (2000). Metachoice for Strategic Analysis. *European management Journal, Volume 18*(6), 605-618.

Weimer, D. L., & Vining, A. R. (2011). *Policy Analysis* (5th ed.): Pearson Education Inc.

Woodhouse, J. (2005). *Decision Support: Technology and people in solving problems and making better Asset Management decisions* Paper presented at the European Refining Technology Conference (ETRC). Retrieved from http://www.macroproject.org/casestudies/ERTC%202005%20Decision%20support%20paper.pdf

Yanev, B. S., Itoh, Y., Kawamura, K., Miyamoto, A., Frangopol, D. M., Peil, U., et al. (2000, August 7-8, 2000). *Life-Cycle Cost Analysis and Design of Civil Infrastructure Systems.* Paper presented at the First US/Japan Workshop on Life-Cycle Cost Analysis and Design of Civil Infrastructure Systems, Honolulu, Hawaii.