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**ASSET MANAGEMENT OF
TRANSMISSION SYSTEMS AND
ASSOCIATED CIGRE
ACTIVITIES**

**Working Group
C1.1**

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ASSET MANAGEMENT OF TRANSMISSION SYSTEMS AND ASSOCIATED CIGRE ACTIVITIES

Working Group C1.1

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† On July 2, 2006, Philip Wester passed away, after a struggle against cancer of over half a year. Philip contributed significantly to the establishment and activities of WG C1.1, as he did to other CIGRE working groups. To the last moments, he was involved as far as his disease allowed him, with the completion of this Technical Brochure.

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TABLE OF CONTENTS

1.	Executive Summary	5
2.	Introduction	6
3.	Asset Management Processes	9
4.	Organizational Relationships	14
5.	Asset management Activities in CIGRE	22
5.1	<i>CIGRE Study Committees</i>	22
5.2	<i>Overview of CIGRE TBs on Asset Management Topics</i>	25
6.	Asset Deterioration	31
6.1	<i>How Equipment Ages</i>	31
6.2	<i>Expected Life and Factors that Affect it</i>	32
6.3	<i>Rate of Ageing</i>	36
7.	Asset Management Decision Methodologies and Strategies	40
7.1	<i>Key Performance Indicators</i>	41
7.2	<i>Asset Health Indices & Reliability Tools</i>	45
7.3	<i>Establishing cost-efficient, long-term plans to mitigate risks for Asset Groups</i>	47
7.4	<i>Other Considerations in Developing Options for Managing Ageing Infrastructure</i>	51
7.5	<i>Development of an Optimized Business Plan</i>	52
7.6	<i>Information Requirements</i>	52
7.7	<i>Run, Repair, Refurbish, Replace Decisions</i>	54
7.8	<i>Diagnostics and Monitoring</i>	64
8.	Conclusions and Recommendations	68
8.1	<i>Conclusions</i>	68
8.2	<i>Recommendations</i>	69
9.	Literature	71
	Appendix 1: Key Reference Papers	73
	Appendix 2: Asset Risk Management Example	90

List of Figures

Figure 2.1	<i>Asset Management Challenge – Can cost be saved by exploiting higher risks? What are reasonable costs for a manageable risk level?</i>	7
Figure 2.2	<i>Asset Management Challenge – What are acceptable Cost/Risk/Performance levels?</i>	9
Figure 4.1	<i>Organizational Relationships</i>	16
Figure 5.1	<i>Summary of CIGRE Group Activities Related to Asset Management sorted by Topic and, at the bottom, for all topics summed up</i>	24
Figure 5.2	<i>Activities of Working Groups, which are involved in the AM segment</i>	25
Figure 6.1	<i>A conceptual illustration of how final end-of-life in the form of equipment failure in-service is a function of progressive ageing and weakening of the equipment combined with random system or environmental stresses which ultimately exceed the equipment's deteriorated strength</i>	34
Figure 6.2	<i>Influences affecting ageing</i>	35
Figure 6.3	<i>The influence of loading history on transformer ageing. These hazard rate curves show the probability of failure at any specific age for generator unit transformers (GSU) and area supply network transformers (Network)</i>	37
Figure 6.4	<i>Asset ageing rates increase if no action is taken to extend life</i>	37
Figure 6.5	<i>States of ageing concept and possible asset management actions</i>	38
Figure 6.6	<i>State-based ageing model [9, 10]</i>	39
Figure 7.1	<i>Projection of investment needs for a population of assets</i>	51
Figure 7.2	<i>Hazard rate function for Hydraulic drives of SF₆ circuit breakers</i>	55
Figure 7.3	<i>Issues influencing asset management decisions</i>	56
Figure 7.4	<i>A Classification of Asset Management Strategies</i>	58.5
	<i>Condition and importance assessment of 110 kV circuit-breakers</i>	59
Figure 7.6	<i>Prioritisation of the service activities of 110 kV circuit-breakers</i>	60
Figure 7.7	<i>Performance Focused Maintenance Processes</i>	62
Figure 7.8	<i>A qualitative PFM framework</i>	63
Figure 7.9	<i>Logic diagram to assess probability of payback for monitoring systems</i>	65
Figure A2.1	<i>Risk Management Cycle</i>	91
Figure A2.2	<i>Example of a Risk Consequence Matrix: Hard Values</i>	93
Figure A2.3	<i>Example of a Risk Consequence Matrix: Soft Values</i>	94
Figure A2.4	<i>Risk Evaluation Matrix</i>	95
Figure A2.5	<i>Example of a Risk Intake Form</i>	97
Figure A2.6	<i>Example of a First Risk Assessment</i>	98
Figure A2.7	<i>Example of the Added Value of a Single Investment Proposal</i>	99
Figure A2.8	<i>Total Added Value of the Proposed Projects</i>	100
Figure A2.9	<i>The real risk size (risk = frequency x consequences) is not equal to the perception of risk by an organization</i>	101
Figure A2.10	<i>EBIT of a Company following Investments along the Lines of "Risk Perception" and "Real Risk Size"</i>	10302
Figure A2.11	<i>Project Classification by means of Frequency and Consequences</i>	103

<i>Figure A2.12</i>	<i>The approximated lognormal function inside consequence category “serious” with median 30 and a 68% confidence interval of [10...90].</i>	<i>105</i>
<i>Figure A2.13</i>	<i>Investment Boundaries for a Lognormal Distributed Risk with Median $Exp(\mu)$ and Standard Deviation σ</i>	<i>106</i>
<i>Figure A2.14</i>	<i>Risk Matrix and Investment Boundaries</i>	<i>107</i>

List of Tables

<i>Table 4.1</i>	<i>Survey Results Generic Asset Management and Service Provider Functions with Potential for Outsourcing</i>	<i>18</i>
<i>Table 7.1</i>	<i>Example of Asset Health Indices for Transformers</i>	<i>46</i>
<i>Table 7.2</i>	<i>Benefits of Performance Focused Maintenance</i>	<i>61</i>
<i>Table A2-1</i>	<i>Upper and lower bounds for 68, 95% and 99.7% confidence limits</i>	<i>104</i>
<i>Table A2-2</i>	<i>Practical rules for "do invest" and "do not invest"</i>	<i>107</i>

1. Executive Summary

Working Group C1.1 “Asset Management of Transmission and Distribution Systems” was initiated in 2002 with an approved scope of work, which included:

1. Investigate asset management decision processes (What decision support techniques, tools and skills are required)
2. Identify organizational issues (What structures are required to manage assets?)
3. Build on the work already done by JTF23.18
4. Investigate work done by Working Groups in other Study Committees in CIGRE
5. Issue a report on the above for discussion during the CIGRE meeting in Paris in 2004
6. Prepare a final report

This CIGRE Brochure is the final report of the Working Group.

The Brochure begins by describing asset management processes and how they relate to the key business drivers, which determine system and equipment performance requirements as a framework for making decisions. Operational and environmental stresses imposed on equipment, the quality with which equipment is maintained and several other factors are integrally linked with asset life and therefore are critical concerns of asset managers. Therefore, asset deterioration and ageing processes are summarized. Organizational structures, responsibilities and the identification of core capabilities and opportunities for efficient outsourcing are reviewed in the next section. Survey results on CIGRE asset management related activities and the relationships between the various groups in CIGRE are described including summaries of relevant Technical Brochures. Asset management decision processes and strategies are described with a detailed example included in an appendix. Lastly the brochure summarizes key findings and conclusions and makes recommendations for further actions (section 8).

2. Introduction

Over the past decade, electric utilities worldwide have undergone a period of significant business and regulatory change that impacts on all aspects and elements of their businesses irrespective of their different forms of vertically integrated regulatory, competitive and ownership models. Most have embraced concepts of competition and commercialisation and some government owned companies have moved towards corporatization and full privatization. Consequently, various strategies have emerged as these organisations strive to improve performance and retain profitability in an environment where competition or regulatory pressure is reducing revenues and the expectations of their customers and the general community is ever increasing. The focus has shifted away from engineering excellence towards commercial performance and the term “Asset Management” has become the new business ideology for these utilities.

This business environment puts increasing pressure on asset managers as they endeavour to balance system performance and cost/risk with constrained budgets and resources. In developing effective business plans for sustaining ageing assets and mitigating risks within this environment, the asset manager needs to use as much information as possible to forecast the many uncertain events. Questions such as the following are typical:

- “What is the residual life of aged populations of equipment?”
- “Are remedial measures available which would extend life, and if so, for what cost and for what benefit in terms of years of life extension?” or
- “If existing maintenance practices and costs are continued, what failure rates can be expected and therefore what investment in spare components will be needed?”

At the CIGRE SC C1 Session in 2004, as well as at earlier occasions, WG C1.1 presented its definition for Asset Management [1, 2]:

The Asset Management of Transmission and Distribution business operating in an electricity market involves the centralisation of key decision making in the network business to maximise long term profits, whilst delivering high service levels, with acceptable and manageable risks.

The following characteristics of Asset Management are stressed in this definition:

- centralisation: to ensure an overview over the whole network and the whole business
- key decisions: focussing on the more strategic decisions rather than all (operational) decisions
- decision making: focussing on more than developing a strategy; it also includes the implementation of the policy
- network business: focussing on the business of the network rather than on the network as an object
- to maximise profits: focussing primarily on the business point of view
- long term profits: focussing on more than short-term cost minimization to maximize short-term profit by stressing management accountability for several decades

- high service levels: focussing on all business values and measures including, safety, the environment and services other than just delivery point performance alone
- with acceptable and manageable risks: focussing on the fact that 100% guarantees are not required; but that the risk level has to be clearly under control in relation to the risk appetite of the stake holders.

Asset management activities and practices attempt to optimally manage assets, and their associated performance, risks and expenditures over their lifecycle for the purpose of achieving the required level or quality of service in the most cost effective manner. If delivery point performance indices need to be improved, changes need to be made which may affect costs and/or risks. If asset managers determine that the condition of aged fleets of equipment is deteriorating and that the business risks associated with continued operations are too high, then increased capital spending and/or investments in refurbishment programs may meet shareholder and regulatory approval. Other challenges faced by asset managers involve achieving the required performance in the most cost effective manner through cost control. This takes on the form of budgetary cost reallocation, cost reductions or cost increases. If cost, risk and performance are constant and stable before a cost reduction is implemented, and if performance is not to be sacrificed, then risk will increase sooner or later as illustrated in Figure 2.1 below [2]. For example on the left of the figure or at the starting point, there is an equilibrium between “business cost” and business and technical risk. At the point where costs are reduced, the risk profile typically increases. The business may choose to maintain this new business set-point. Alternatively they may wish to increase “business costs” and thereby attempt to lower business and technical risk as shown by the dash-dot line.

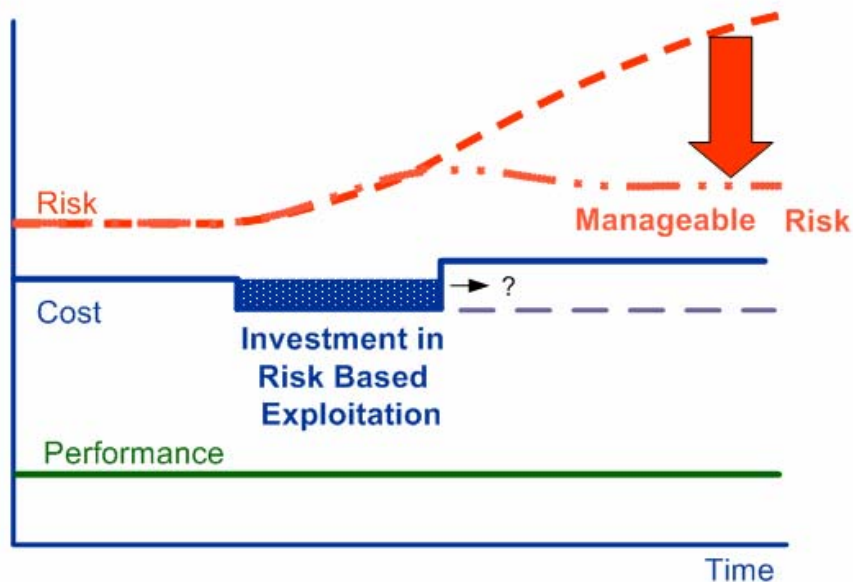


Figure 2.1 *Asset Management Challenge – Can cost be saved by exploiting higher risks? What are reasonable costs for a manageable risk level?*

In advanced regulatory jurisdictions regulators now require evidence (as opposed to assertions) to support asset investment decisions. Therefore, an important element in

the process of optimally managing assets in the most cost effective manner, involves the development of credible business cases for optional asset management strategies.

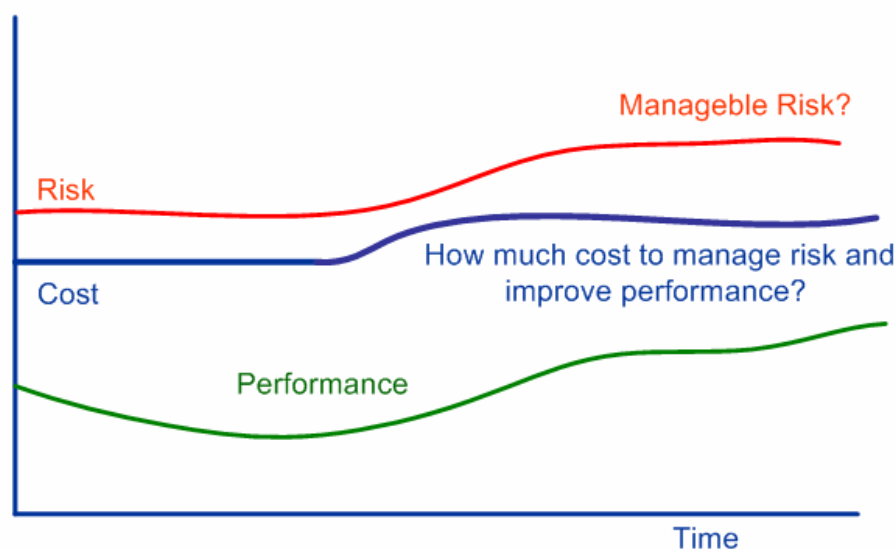


Figure 2.2 *Asset Management Challenge – What are acceptable Cost/Risk/Performance levels?*

Most credible options that may be of interest involve issues, factors and quantities that are uncertain. Therefore, if asset managers are to provide improved business case analysis to support investment decisions, methodologies which model uncertain events and factors using improved data mining and analysis and which formulate the business cases using probabilistic methods to quantify risks, are needed. The term risk is used here in the general sense as the mathematical expectation of a benefit or loss. Therefore, as illustrated in Figure 2.2, the classic asset management issue is how to determine acceptable cost/risk levels when for example there is a need to improve performance measures through additional investment, and possibly some additional business risk.

The purpose of this CIGRE Technical Brochure is to document the work of WG C1.1 (WG C1.1's key references are included in Appendix 1). We begin by describing asset management processes and how they relate to key business drivers which determine system and equipment performance. Organizational structures and responsibilities and the identification of core capabilities and opportunities for efficient outsourcing are reviewed in the next section. CIGRE activities are summarized and the relationships, in particular between the various groups in CIGRE, are described. Environmental and operational stresses imposed on equipment, the quality with which equipment is maintained and several other factors are integrally linked with asset life and therefore are critical concerns of asset managers. Therefore, asset deterioration and ageing processes are described. Asset management decision methodologies and strategies are described, including reference to a detailed example of risk management which is included in Appendix 2. Lastly the brochure summarizes key findings and conclusions and makes recommendations for further studies.

3. Asset Management Processes

Asset management as a term can have a wide range of applications depending on the field or types of assets of interest. CIGRE WG C1.1 is aware of several definitions of Asset Management, each with its own emphasis. For example in the USA, EPRI has defined asset management as it relates to transmission and distribution as:

“a structured, integrated series of processes aligned with business goals and values and designed to maximize societal value by minimizing the life-cycle costs and maximizing the life cycle benefits of power delivery asset ownership, while providing required performance levels and sustaining the system forward” [3].

Asset Management begins with the fundamental premise that all asset management decisions made by utilities should contribute to stakeholder values, as set forth in the organization’s goals and policies. Asset Management applies this premise in decision processes at every level of the organization. The resulting alignment of decisions with criteria and value measures derived from the asset owner’s or senior management’s direction ensures that every asset management decision consistently supports the organization’s strategic objectives and delivers value to stakeholders [3]. Asset management is focused on optimizing the added value of its decisions and is therefore not simply a methodology designed to cut costs.

In response to demand from UK industry for a specification for carrying out Asset Management, a UK Publicly Available Specification (BSI-PAS 55) for asset management processes was published in 2004. BSI-PAS 55 is applicable to any organization where physical assets are key or critical in achieving its business objectives and in achieving effective service delivery. The development of BSI-PAS 55 was through consultation with a large number of organizations and individuals active and proficient in the field of Asset Management. A number of the UK regulators were also involved in the development of PAS 55, and it was also made widely available for public comment. Companies from the UK electricity supply industry and their regulator were active participants in the development.

BSI-PAS 55 identifies the objective of AM as: *‘to ensure (and be able to demonstrate) that the assets deliver the required function and level of performance in a sustainable manner, at an optimum whole-life cost without compromising health, safety, environmental performance, or the organization’s reputation.’* BSI-PAS 55 contains 21 key requirement areas for an Asset Management system. The criterion for including the requirements was that, without them, the Asset Management system would be regarded as deficient. More specifically PAS 55 defines Asset Management as *‘Systematic and co-ordinated activities and practices through which an organization optimally manages its assets, and their associated performance, risks and expenditures over their lifecycle for the purpose of achieving the required level of service in the most cost effective manner’*.

Being at the interface between technical and economic focuses, the asset manager has to balance between two different worlds:

- that of the technical experts, who prefer complete solutions for the whole network and for the long term, thus looking for the cheapest total solution

- that of the financial experts, whose analyses typically support short term cost minimization and capital deferment, thus looking for the cheapest incremental solution.

Communication between these two worlds is one of the key competences of asset managers.

A critical function of asset management is therefore to provide clarity in linking business drivers with business values and related key performance indicators (KPI's) that can be measured to monitor business performance. Business drivers are external influences, (for example shareholder financial expectations, customer pressure to minimize rates, government pressure to favour distributed generation), which push business managers to adapt specific strategies. While business values are developed internally in response to the perceived drivers; but they articulate broader company objectives (for example providing excellent customer service, maintaining good relationships with regulators, providing a safe work environment). KPI's are measurable performance indicators developed out of the business values which can be used to gauge company performance. Examples might include, reliability targets, operating, maintenance and administration costs/customer, number of and severity of personnel injuries, the number of corrections in decisions and activities as forced by the regulator and so on.

Asset Management is dependent upon “quality” information inputs: optimal investment decisions cannot be made without supporting information on asset age, performance, condition, capacity, utilization and cost with the aim of developing life cycle costs for each asset type and their operational groupings [4, 5]. Therefore an Asset Management business needs to collect data that supports the business needs and turn this into the information on which decisions will be based. Converting data into the useful information needed to make decisions is not straightforward. Expert knowledge of ageing and deterioration processes in general and the rates of deterioration are needed to interpret asset data and convert it into information. In other words, differing types of asset management decisions require different types of asset information and the required asset information needs to be developed by analyzing and interpreting the required types of data. The use of information therefore determines what data needs to be collected [6].

A key challenge for an asset manager is making the best use of available data, especially when assigning some level of predictability to the uncertainties at hand. The levels of confidence in quantifications using limited data always pose an interesting challenge and an element of innovative research for an asset manager. The data collection, handling and input into the information systems are tasks that are often seen to be ‘disconnected’ from the delivery of the work on the assets. In reality it is a critical stage as it forms the basis of a large proportion of the asset investment decisions.

Asset management is about aligning key processes across the entire asset lifecycle to higher-level strategies and values. The core competencies lie in the decision-making processes. The key is to optimize tradeoffs across a variety of financial and non-financial metrics, rather than simply attempting to manage lifecycle cost or risk. See Appendix 1 for key literature and Appendix 2 for an example of how to deal with different business values, such as safety and the environment. An Asset Management decision-making framework is guided by performance goals, covers an extended time

horizon, draws from financial analysis as well as engineering, and considers a broad range of assets. AM provides for the economic assessment of tradeoffs between alternative actions and investment strategies from the network- or system-level perspective. At the same time, it allows for the more complete comparative analysis of options for individual projects. [3]

Clearly, the correct storage and diligent analysis of the data is vital to the success of the business and depends on the company having credible data acquisition and storage systems. The systems need to be interconnected to allow retrieval of data from any part of the integrated system. The integration of the data also allows detailed analysis and cross comparison of different elements of the data. It is this ability that facilitates the raw data being turned into the information on which effective investment decisions can be based.

One of the key motivators for extracting value from regulated infrastructure businesses is the accuracy, relevancy and appropriateness of the data relating to assets, load growth, processes and customers that comprise the business. For this reason, Asset Management organizations are normally centralised with data being analysed at their central location, so that the risk of duplication is limited and data is easy to retrieve. A critical process element that an asset manager needs to secure is to ensure open and complete communication between the centralized location and the equipment and subsystem technical experts who provide the valuable information about asset performance which can add credibility to decisions reached by an asset manager. Few companies can claim to possess completely comprehensive and accurate databases. Therefore, good asset management needs to manage the risks associated with incomplete and inaccurate data and disparate systems whilst still facilitating investment decisions that are as effective as possible.

A generic framework for Investment Planning was described in a CIGRE paper produced by WG C1.1 in 2004 [2] which includes several major elements illustrated in Figure 3.1. A copy of this paper is included in Appendix 1.

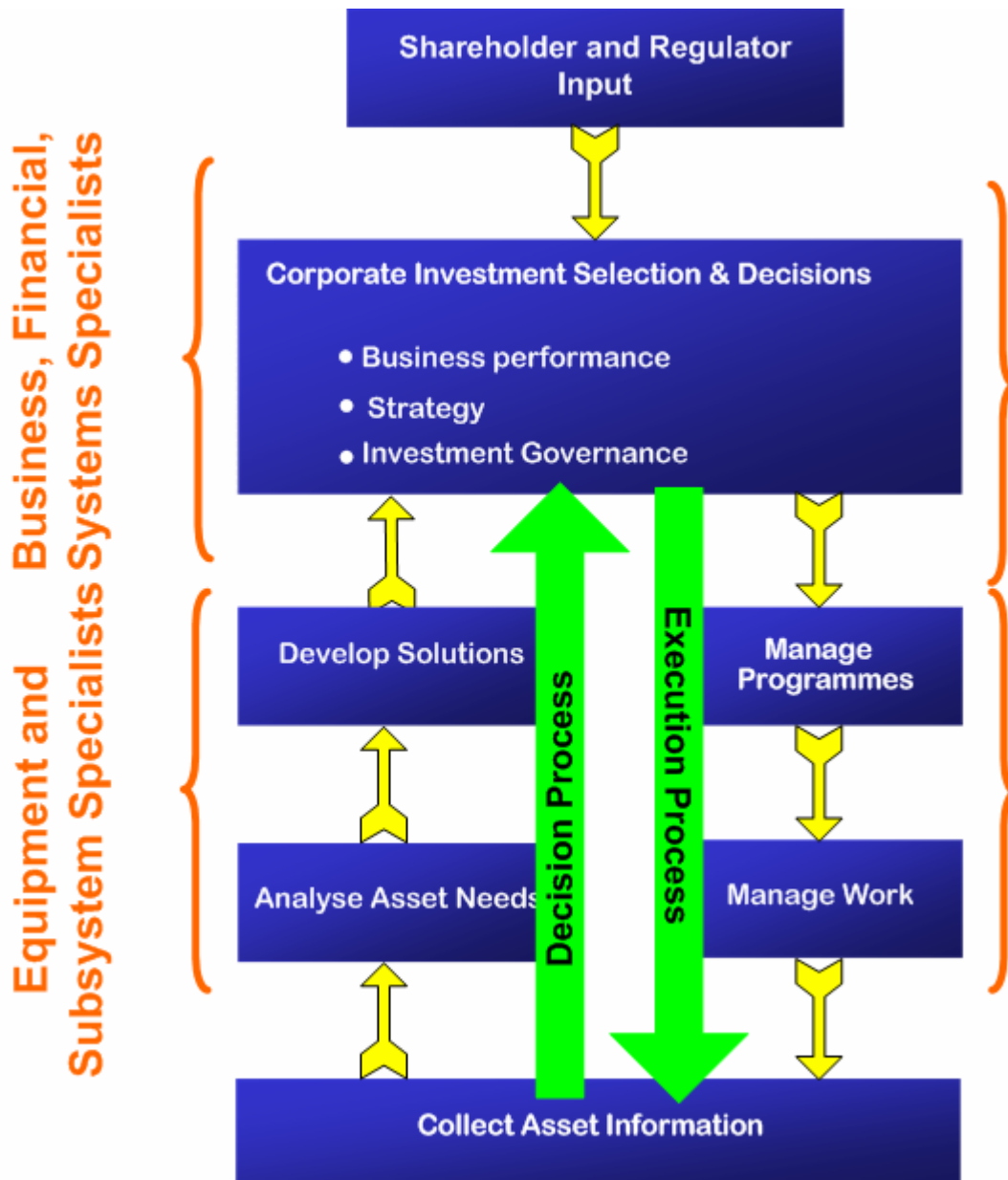


Figure 3.1 A simplified framework for asset investment planning

Although not shown on this figure, materials and diagnostics experts play an important role in developing improved scientific understanding of material properties as they age under stress, diagnostic symptoms and measures of ageing under stress and development of diagnostic tests and measurements. In the CIGRE context, Study Committees in the A and B groups provide valuable expertise in equipment behaviour, condition assessment, maintenance technologies and options for life management, refurbishment, repair or replacement. Study Committee D1 provides valuable expertise in material behaviour, related diagnostic techniques and residual life assessment. Asset management decisions at these levels are primarily based on engineering analysis focused on the near-term needs of a limited number of specific assets. For example, decisions to replace specific circuit breakers which have become unreliable and no longer economic to maintain, or the number of spare transformers that should be budgeted for purchase in the next year.

These decisions are based on near-term equipment condition assessment by equipment experts and involve little or no long-term system planning or long-term analysis. As such, expert engineering opinion, frequently involving the prediction of likely and imminent failure is adequate for budgetary approvals. The amounts of investments are typically similar to historical spending levels, and engineering-based arguments to support such investments have been adequate. However, for utilities facing adverse demographic asset age distributions, implying significant growth of investment caused by projected increasing failure rates and where there will be a significant gap between historical depreciation-based capital spending rates and the replacement value of the failed assets, much improved business case analysis is needed. Therefore, at the system-wide level of investment decision-making, more data and new types of information and analysis are needed. Fortunately, the necessary basic methodologies exist; however they need to be adapted and applied to the types of business case analysis required at this level. Formulation of the necessary business cases will require data and information. Some of the data are readily available in most utilities; however there may be some gaps in the early going for some utilities, depending on the thoroughness with which they have kept records. Such gaps identified through this process will provide useful input to the A and B study committees with respect to the type, and quality of data that are needed for the systems level of asset management decision analysis.

Referring again to Figure 3.1, the focus of equipment and subsystem specialists is typically on collecting data related to asset condition which needs to be interpreted in order to develop usable asset information. Out of this information asset needs are identified and analyzed in order to develop options for addressing these needs. Clearly these tasks in the lower left of the diagram require strong technical knowledge of the equipment, how it functions, the stresses imposed by loads and the environment and most importantly how the equipment ages under the influence of these stresses and loads. These aspects are discussed more completely in Section 6.

4. Organizational Relationships

A predecessor to WG C1.1, CIGRE Task Force 23.18 was established in September 2000 to investigate Asset Management practices, particularly in transmission businesses operating in de-regulated electricity markets. A distinction has been made between the roles of the Asset Owner (accountable for the business strategy, the direction of the network company and the overall financing of the investments), the Asset Manager (accountable for making investment decisions to balance asset/service performance, financial performance and risk) and the Service Provider (accountable for making decisions related to delivering work on time, within budget and in a safe manner in accordance with agreed specifications).

In the CIGRE 2004 Sessions, WG C1.1 published Report C1.106 (see Appendix 1) and highlighted the need for a strong relationship between the Asset Manager and Service Provider roles, as this is the key to the achievement of a successful and lasting results. Effective co-operation is necessary to foster staff motivation on both sides, to reduce needs for organizational complexity, to avoid duplication of technical functions and to encourage an inspiring professional environment, which can retain and attract competent people.

CIGRE Task Force 23.18 surveyed its member organizations to gather information on:

- Benefits of adopting Asset Manager / Service Provider models.
- Roles of Asset Managers, Asset Owners, Service Providers.
- Organizational arrangements.
- Risk management practices.

This survey covered 19 transmission networks with an average transmission line length of 14,000km. The work of this Task force was reported in 2002 [7]. A copy of this paper is included in Appendix 1. Figure 4.1 below summarizes the statistical results from this survey.

The radial scale is the per cent agreement associated that the functions are properly associated with the respective asset management process participants. For example 88% of survey respondents agree that definition of policy and direction is the function of the asset owner.

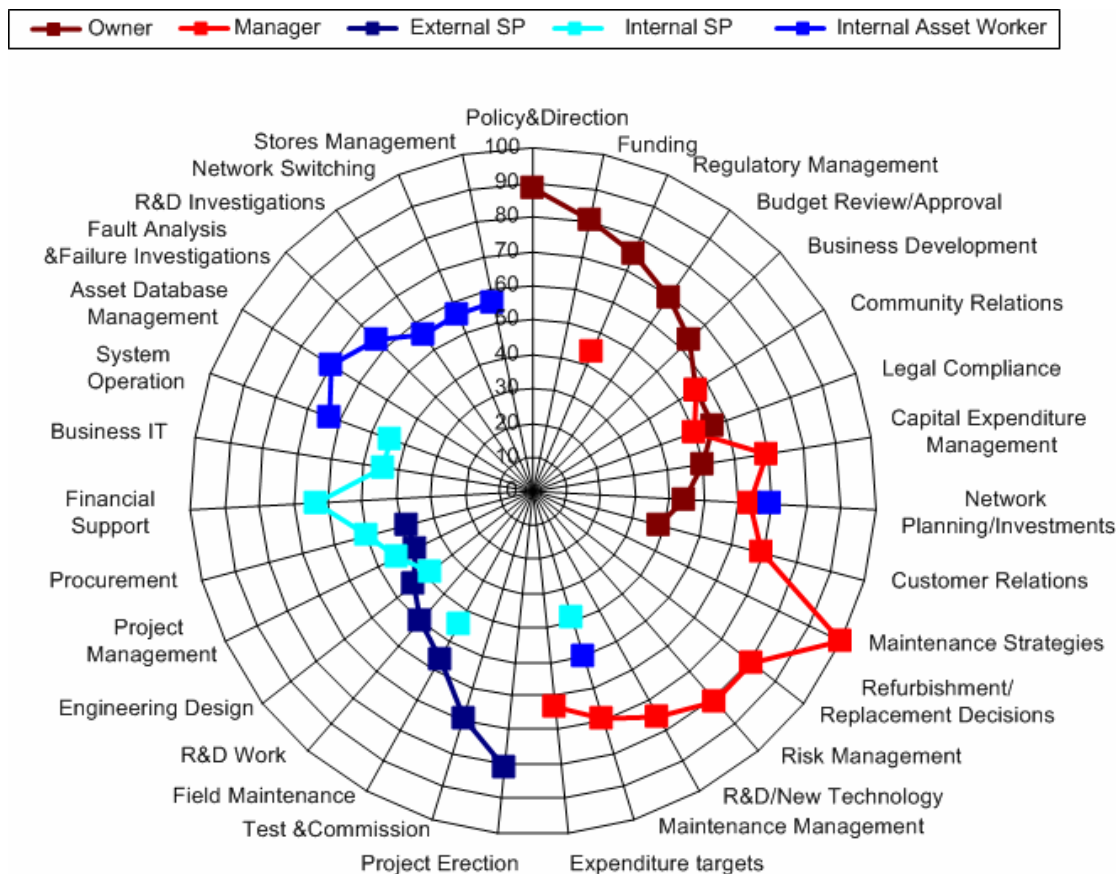


Figure 4.1 Organizational Relationships

Utilities embark on outsourcing initiatives because the market can provide a specific service or product more cost effectively than having the work performed internally and with an adequate degree of quality. Considerations in deciding on an outsourcing strategy include:

- ◆ What are the incremental costs to the utility of establishing a contract management group to carry out tendering, contracting, procurement and monitoring functions associated with having multiple Service Providers?
- ◆ Is it more cost effective for the external Service Provider to complete the service given the tendering, contracting, procurement and monitoring functions, which must be established within the company to do so?
- ◆ Can the utility outsource the work given existing labour agreements?
- ◆ What are the performance measures needed to monitor the effectiveness, efficiency and quality of an external Service Provider?
- ◆ Can the external Service Provider meet performance and other quality assurance requirements specified by the utility?
- ◆ Are external Service Providers required to follow the same processes developed for the internal Service Provider? If not, what are the process requirements?

- ◆ Do the external Service Providers have access to the staff training and other critical resources (labour and materiel) needed to sustain cost effectiveness and quality deliverables, over the contract period?
- ◆ What should be the contract period?
- ◆ What access rights to facilities and systems are required by external Service Provider staff need to perform their work?

As a follow-up to the first survey, CIGRE Working Group C1.1 has conducted another survey of outsourcing practices of utilities to develop an understanding of the rationale for outsourcing some functions whilst retaining some as internal, and to determine the extent of outsourcing experience. Table 4.1 below lists a number of generic Asset Management and Service Provider functions, which can either be performed by expertise available within a company or external to the company. For each of these functions, respondents were asked if the function was performed completely Internal to the company (**I**), completely External to the company (**E**), or a combination of Internal and External (**C**.) service providers are used. Then for services, which are, performed internally (**I**), respondents were asked for the reasons why the Service is not outsourced. The optional answers were, Cost Effective to perform internally (**CE**), the function is considered to be Strategic to the business (**S**), or, the company believes that there is no effective external expertise (**NE**). If there is a plan to outsource these services, it is identified by (**P**). For the services, which are provided externally or in combination, respondents were asked how long the outsourcing practice has been in effect? **1 to 2 years; 3 to 5 years; > 5 years.**

Twelve companies responded to the questions:

Hydro One - Canada
 Duke Energy - USA
 TenneT - Netherlands
 Nuon - Netherlands
 ESB - Ireland
 RTE - France
 Eles - Slovenia
 Powerlink - Australia
 Long Island Power Authority - USA
 Centerpoint Energy Houston - USA
 EnBW-Group - Germany
 RWE Energy Group - Germany

Observations from the results of this survey include:

- 100% of the companies surveyed perform the core AM-activities themselves, while a few perform supporting tasks in combination with external assistance, possibly the collection of information (for instance to develop the Asset Management Plan). This policy is clearly for strategic reasons, albeit that some utilities claim that it is also cost effective to perform the core AM-activities themselves because these competences are generally not available externally. The core AM-activities referenced here are listed in Table 4.1 on page 18, only.
- Service level Agreements are developed internally; mostly for strategic reasons.

- Grid operation is done internally or exceptionally in combination with an external service provider, for strategic reasons as well as cost-effectiveness and no external expertise available.
- The same applies for customer service and contracts.
- Project management is not outsourced, basic engineering is done in combination with an external service provider or by the company itself, while detailed design can also be outsourced. This policy is based on strategic reasons and a matter of cost-effectiveness.
- Cost estimation, tendering and procurement are, for strategic reasons, performed by most companies themselves, sometimes in combination with an external service provider. Two responses reported that tendering and procurement is outsourced.
- Construction work is outsourced or both outsourced and done by internal employees. Most utilities have long lasting experience with outsourced construction work.
- Core maintenance is mainly performed internally, but half of the companies also use external forces. Non-core maintenance is outsourced, although half of the companies use also internal forces.
- Meter management is predominantly performed internally; meter reading, billing and call handling are mostly done internally, but also externally.

Table 4.1 Survey Results Generic Asset Management and Service Provider Functions with Potential for Outsourcing

Generic AM and SP functions	Internal (I)	Combination (C)	External (E)	If Internal – Why?				If Outsourced – For how Long? (Years)		
				CE	S	NE	P	1-2	3-5	>5
Development of Asset Management Plan	11	1	0	5	10	4	0	2	0	0
Development of Asset Strategies for Sustaining Investments	11	0	0	5	10	4	0	2	0	0
Development of Asset Expansion Plans for growth	12	0	0	5	11	2	0	1	0	1
Development of Asset Maintenance Policies	12	0	0	7	10	3	0	1	0	1
Development of Revenue Requirements, Rates and Regulatory Responses	11	0	0	1	10	1	0	0	0	1
Development of Optimized Annual Investment	11	0	0	3	9	2	0	0	0	0
Plan for inclusion in Business Planning (near term investments to manage system growth and ageing)	12	0	0	4	10	1	0	0	0	1
Development of Service Level Agreements with internal and / or external Service providers	11	1	0	6	7	0	0	2	0	1

Generic AM and SP functions	Internal (I)	Combination (C)	External (E)	If Internal – Why?				If Outsourced – For how Long? (Years)		
				CE	S	NE	P	1-2	3-5	>5
Customer Service (Contracts / Agreements)	10	1	0	6	7	1	0	0	1	1
Operations (Switching, Work Protection, Outage Coordination)	10	2	0	7	5	4	0	1	0	2
Engineering	3	9	0	4	4	0	0	3	1	4
Detailed Design	3	5	4	2	3	0	0	3	2	3
Estimating	7	5	0	5	4	2	0	1	1	3
Tendering (for Core Capital and Maintenance Work; Major Capital Equipment Purchases; General Work - Such as road construction, grading, etc)	8	2	3	3	6	2	0	2	1	3
Procurement	7	3	2	3	5	2	0	3	1	2
Project Management	10	1	0	6	5	0	0	1	0	2
Construction	0	7	5	2	1	0	0	3	3	5
Resource Planning and Dispatching	11	0	0	6	5	1	0	1	0	1

Generic AM and SP functions	Internal (I)	Combination (C)	External (E)	If Internal – Why?				If Outsourced – For how Long? (Years)		
				CE	S	NE	P	1-2	3-5	>5
Asset condition data collection	6	5	0	3	3	0	0	1	1	3
Asset condition assessment	10	2	0	2	8	0	0	1	1	0
Core Lines Maintenance	6	4	2	4	4	0	0	1	1	3
Non-Core Lines Maintenance (Right of Way - Vegetation Management)	0	4	8	2	1	0	0	2	3	5
Core Station Maintenance (Power Equipment Maintenance; P&C Maintenance; Ancillary Equipment Maintenance)	6	5	1	4	3	0	1	2	0	4
Non-Core Station Maintenance (Services – such as janitorial services, snow removal, etc.)	0	4	8	2	1	0	0	3	1	7
Meter Management	10	0	1	4	2	2	2	1	0	1
Meter Reading	4	4	2	3	3	0	0	1	2	4

Generic AM and SP functions	Internal (I)	Combination (C)	External (E)	If Internal – Why?				If Outsourced – For how Long? (Years)		
				CE	S	NE	P	1-2	3-5	>5
Billing	7	1	3	5	2	0	0	3	1	1
Call Handling	6	3	2	4	3	0	0	3	1	2

5. Asset Management Activities in CIGRE

5.1 CIGRE Study Committees

Asset management in various forms and aspects is an active subject in all CIGRE Study Committees. Logically, the focus of these activities is different as illustrated in a general sense below:

Life Cycle Management of Equipment (A)

- Understand component ageing & Impact on equipment performance
- How to manage the fleet of assets (transformers, cables, circuit breakers)

Life Cycle Management of Sub-Systems (B)

- Impact of interaction components on sub-system performance

Life Cycle Management & System performance (C)

- Impact interaction of sub-systems on System Stability & Delivery Point Service Quality
- Concepts and principles to manage (refurbish, replace) fleets of assets

Life Cycle Management of Materials (D)

- Understand material ageing as a function of stress and environmental conditions.

To develop a more quantitative perspective on CIGRE activities related to Asset Management a task force in WG C1.1 developed an inventory of Asset Management related topics, prepared a short questionnaire and distributed it to the conveners of Working Groups in other Study Committees. The following paragraphs illustrate the results of this questionnaire and show the extent of the CIGRE interest in Asset Management.

About 30 % of the CIGRE Working Groups (~ 150) answered the questionnaire and specified the actual work regarding existing or planned publications and questionnaires in detail. The Working Groups, which did not respond were assessed by the task force based on documentation of their asset management activities which have been published in their Terms of Reference, Scope or annual reports. The final results based on the different Study Committee Groups A-B-C-D within CIGRE are given in Figure 5.1. The chart shows at the bottom the overall percentage of Group activities related to asset management. Then the overall AM involvements are broken down by topic with the respective group activities shown as a percentage of the total group activities.

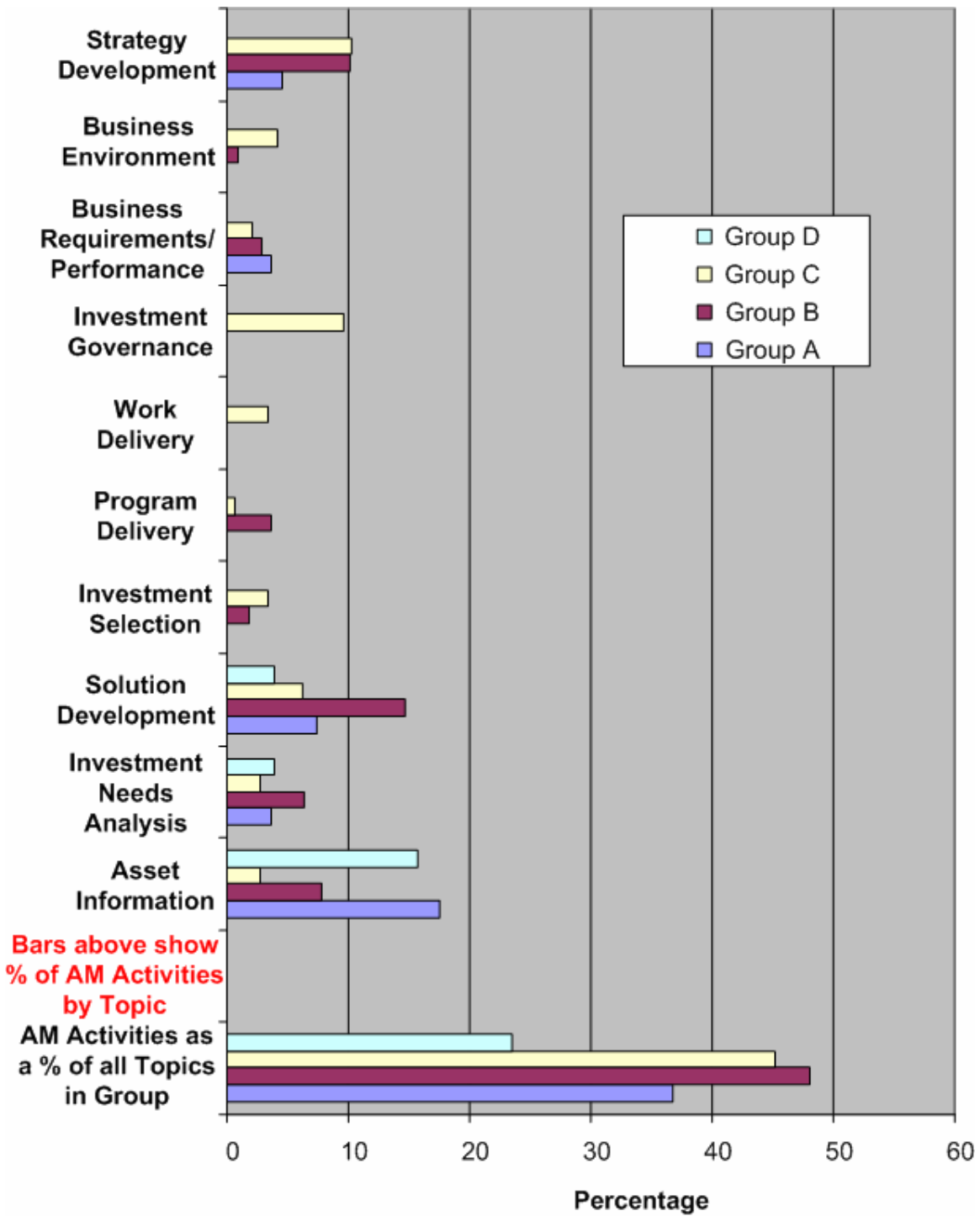


Figure 5.1 Summary of CIGRE Group Activities Related to Asset Management sorted by Topic and, at the bottom, for all topics summed up

In a general sense, this figures illustrate that asset management activities at the A and B Group levels are largely focused on developing and documenting information on specific types of assets (generators, transformers, switchgear etc.) and subsystems (substations, lines etc.), identifying needs and developing options for solution to these needs. Group D is primarily concerned with asset information development in the sense of understanding how materials used in the assets age under stress. In the C group, asset management concerns centre primarily on the development of asset management strategies, investment governance and other business performance issues related to decision analysis and investment justification.

Figure 5.2 represents the different types of asset management activities, which are covered by all Working Groups. The biggest area of work is “solution development” followed by “asset information” and “strategy”.

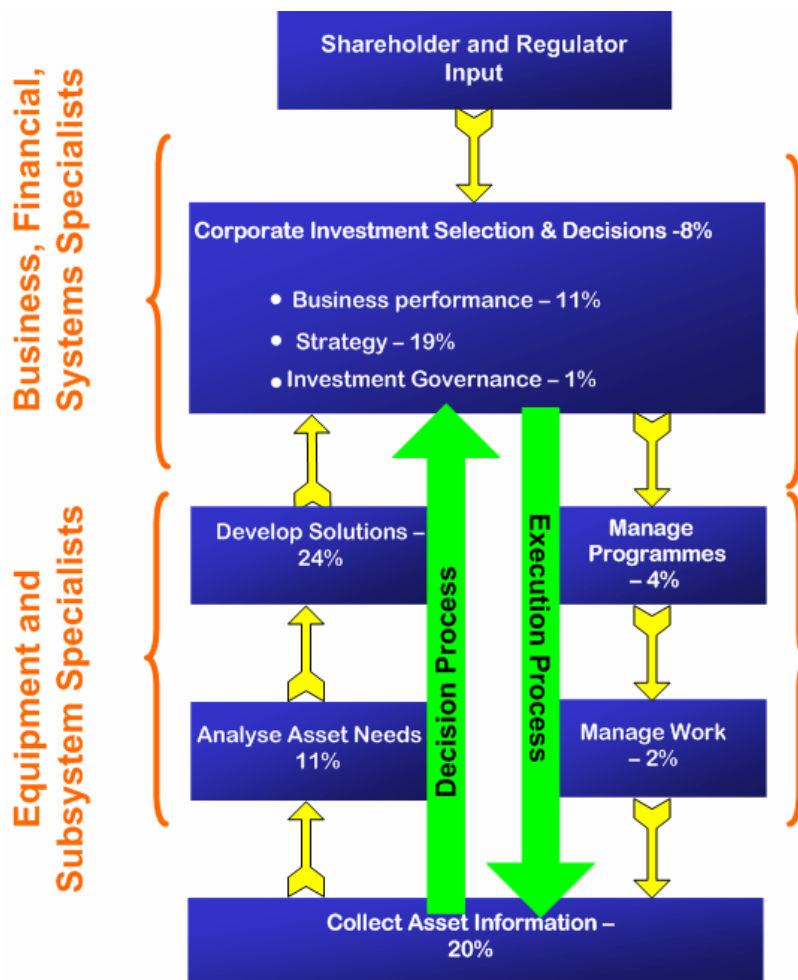


Figure 5.2 Activities of Working Groups, which are involved in the AM segment

Asset management activities are obviously a key factor affecting the choices and priorities of Study Committees and occupy a lot of the CIGRE technical effort. These results indicate that most Working Group activities relate to “Business Performance”, “Asset Information”, “Strategy” and “Solution Development”, whereas there is a lower apparent involvement within CIGRE in the areas of “Investment Governance” and “Program & Work Delivery”.

As AM topics represent a cross section function within CIGRE work it is important to understand and possibly coordinate the different approaches of the Working Groups. The origin of the CIGRE was mainly driven by the solution of technical problems. Today the engineering approach of CIGRE tasks covers not only technical expertise but also economic and environmental aspects, and takes the impact of the organizational and regulatory aspects into consideration as stated in the CIGRE Master Plan. Therefore it is worth-while to closely monitor and coordinate the progress of asset management activities in CIGRE.

Listed below are brief summaries from recent CIGRE Technical Brochures (TB) relevant to the general subject of Asset Management. In Section 6 a deeper study of the content of these Technical Brochures is presented, showing several aspects of Asset Management treated by different Study Committees.

5.2 Overview of CIGRE TB on Asset Management Topics

SCs A2/3-B1/2/3:

- **TB 211 (2002): *General overview on experience feedback methods in the field of electrical equipment.***

The reliability of network components and systems is a major concern for manufacturers of electrical equipment and utilities. Reliability techniques, derived from the aeronautical and nuclear industries have been used in the field of electrical systems and have now reached maturity. Thus CIGRE Committees have considered reliability to be an important characteristic of network components and reliability is still the subject of many discussions and exchanges of experience.

SC A1:

- **TB 002 (1988): *Report on large turbine generator maintenance practices.***

Preventive maintenance of generators is an important contribution to the improvement of their availability. The number and nature of the maintenance tasks as well as the periodicity depend largely upon the machine type, its design and its duty type. These practices are generally agreed between the manufacturer and the user.

SC A2:

- **TB 096 (1995): *Thermal aspects of transformers.***
Contains chapters on : Heat run test procedure; Direct measurement of the hot-spot temperature; A survey of facts and opinions; Lifetime evaluation; Dissolved gas analysis; Analytical determination of winding hot spot factor; Experimental determination of power transformer hot spot factor; Survey of power transformer overload field practices.
- **TB 209 (2002): *The short circuit performance of power transformers.***
Service conditions-questionnaire and conclusions. Design calculations: magnetic field and force calculations; mechanical stress calculations. Design review procedure; description of radial and axial forces; manufacturing issues; references. Monitoring: winding movement detection techniques, standardisation and optimisation techniques, problems of interpretation, winding slackness, on-line monitoring, recommendations, references. Includes: questionnaire, summary of responses, detailed information on failures.
- **TB 227 (2003): *Life management techniques for power transformers.***
Emphasis on common goals and benefits and a vocabulary of commonly used terms. A presentation of general knowledge and theoretical issues: basic failure concepts, condition, classification, recommendations on failure identification. Detailed appendices with examples and checklists, catalogue of defects and faults. A summary of dangerous effect of degradations factors is proposed. Methodologies. Diagnostic and monitoring techniques
- **TB 248 (2004): *Economics of transformer management.***
Guide designed to help transformer and asset managers perform economic evaluations of proposed solutions. A list of key parameters has been established covering technical, operational, economical, environmental and other strategic aspects that arose during the early development of the guide. Some models and flow charts have been included. Intended mainly for transformer managers/asset managers managing high-voltage electric systems. Includes 4 parts: Risk management, Specification & Purchase, Operation & Maintenance, Repair vs. replacement.

SC A3:

- **TB 083 (1994): *Final report of the 2nd international enquiry on HV circuit-breaker failures and defects in service.***
The studies include items such as : Use of diagnostics; Maintenance policy; System reliability study data; Kind of operating mechanism; Comparison of metal enclosed versus non metal enclosed reliability; Impact on testing; SF₆ gas leakages.
- **TB 165 (2000): *Life management of circuit-breakers.***
Current life experience of high and medium voltage circuit-breakers of older and current design; determination and evaluation of residual life expectancy, possibilities and procedures;

risk assessment; possibilities for life extension such as monitoring, maintenance procedures, availability and maintainability; testing; economic impact taking into account additional expenditures of preventive measures, reduction of reliability etc; legal, environmental and strategic aspects; changes in network condition.

- **TB 167 (2000): *User guide for the application of monitoring and diagnostic techniques for switching equipment for rated voltages of 72.5 kV and above.*** Condition monitoring and diagnostic techniques are playing an increasingly important role in the design, life cycle cost evaluation, commissioning, operation, maintenance and end of life determination of substation equipment. Users need guidance on the applicability and implications of the various techniques and how their benefits can be evaluated. The report gives guidelines for the application of monitoring and diagnostic techniques covering all switching technologies and including disconnectors and earthing switches as well as circuit-breakers.

SC B1:

- **TB 279 (2005): *Maintenance for HV cables and accessories.*** This Technical Brochure is based on the report prepared by CIGRE WG B1.04. The attention will be focused on the present utility practices regarding maintenance, the failure modes for the usual cable systems and the related diagnostic methods, and recommendations to utilities for effective and efficient maintenance. One of the main recommendations is that maintenance should be based on a clear strategy and elaborated in a clear maintenance plan. Finally the TB indicates that maintenance trends are moving to so called predictive maintenance.

SC B2:

- **TB 141 (1999): *Refurbishment and upgrading of foundations.*** This report provides an outline of good practice on the refurbishment and upgrading of existing overhead transmission line support foundations. Possible reasons for foundation deterioration are reviewed, which may result from such diverse causes as early-age concrete cracking to damage by frost forces. The critical nature of the inspection and testing strategy are considered, with attention focused on the economics of the inspection/testing regime, the use of alternative strategies and the different levels of foundation inspection together with the actual inspection test methods.
- **TB 147 (1999): *High voltage overhead lines. Environmental concerns, procedures, impacts and mitigations*** Electricity utilities involved in transmission development, maintenance and operation face increasingly severe challenges as a result of heightened environmental awareness, more comprehensive legislation and standards and growing public expectations and concerns. These trends will have a major influence on the approach of companies to the management of both new projects and existing transmission assets.
- **TB 175 (2000): *Management of existing overhead transmission lines.*** Can you answer the following questions: Can you quantitatively justify investments in you O/H transmission system? Can you predict the probability of you next O/H transmission line

failure event? Do you collect the right data when you have a failure event? Do you know the present capability of you OHTL components? Could you manage these data effectively if you did collect them?

- **TB 216 (2002): *Joints on transmission line conductors: field testing and replacement criteria***
Description of the tests currently available to determine the condition of joints in order to establish their quality and ability for a reliable and continuing service, especially when an increase in electrical load is expected (for example, when increasing the operating temperature of a line). It should be noted that this is not exclusive to ACSR joints.
- **TB 230 (2003): *Assessment of existing overhead line supports.***
Results of a questionnaire comparing worldwide information about practices on assessment of all types of existing overhead line supports: inspection techniques, causes and types of defects and management criteria to undertake actions, especially routine maintenance, repair, life extension, refurbishment and upgrading of supports. Includes: self supporting lattice steel structures; guyed lattice steel structures; self supporting hollow steel section structures; steel poles; concrete poles, wood poles.
- **TB 244 (2004): *Conductors for the uprating of overhead lines***
Methods for increasing the thermal rating of existing overhead transmission lines: weather data and load profiles fed into computer programs - real-time monitoring - re-assessment of electrical clearances under an existing line - replacement of existing conductors.
- **TB 265 (2005): *Life Cycle Assessment (LCA) for overhead lines***
This BT presents a broad examination of LCA and LCA methodologies. A summary is given on how LCA developed and how it is classified and outlined in the ISO 14040 series. Included is a full review of work done in Scandinavian countries on LCA. An explanation and comparison is provided on various LCA software packages, and some studies dealing with the overhead line as a system are included. Finally conclusions and recommendations are presented.

SC B3:

- **TB 057 (1990): *Paper-oil insulated measurement transformer.***
The document is a set of papers issued in Electra expected to be complete enough and useful for manufacturers or users of equipment: i.e. General considerations; Design and construction; Checking and monitoring; Failure survey; Endurance - testing - life test; Non standardized stresses and Quality Assurance.
- **TB 088 (1994): *Design and maintenance practice for substation secondary systems.***
The report deals with the main features of substation secondary systems. It includes in its scope relay-based and computer-based equipment. The emphasis in much of the report is on large-scale transmission substations. However, many of the systems discussed are applicable also to sub-transmission and distribution level substations even though they are generally less complex.
- **TB 150 (2000): *Report on the 2nd international survey on high voltage gas insulated substations (GIS) service experience***

Reliability, economic advantage for life cycle cost and physical compactness of HV GIS have resulted in their widespread use over some 30 years. Many Users' approach to its application is still rather unique. GIS technology can however contribute very effectively to increasing the reliability of new substations and to improving the asset life cycle of existing ones. For the user to be able to decide on GIS he needs data on which to judge his investment and maintenance decision. WG 23.02 has created a database to be updated every 5 years with the results being accessible through CIGRE channels.

- **TB 152 (2000): *An international survey of maintenance policies and trends***
General information about the utilities that responded. Quality of information is generally good but it is necessary to bear in mind that due to the nature of the information requested (e.g. replacement costs, type of equipment, age etc) much of the information was estimated. 64 responses were entered into a computerized database. Analysis of the general information obtained. Further details of the construction of the database and calculation of composite size and age factors used in the analysis are also given. The method used for detecting correlation between answers is also given.
- **TB 162 (2000): *Questionnaire concerning aspects on planning - design - operation and maintenance of future substations.***
In Cigré report 23-207 of 1996 "The future substation: a reflective approach" a number of conclusions were made which to a great extent is forming the base for this questionnaire. 49 responses were received: 30 from utilities - 16 from manufacturers and 3 from consultants.
- **TB 201 (2002): *Maintenance outsourcing guidelines***
In CIGRE 2000 Session papers concepts of outsourcing were reviewed including business models, assessing the risk through outsourcing exposure and the development of contractor-owner relationships. These guidelines attempt to review these in a systematic manner. Part I discusses the general issues around the development of a service options strategy, Part 2 focuses on the analysis of outsourcing opportunities, Part 3 considers some more general aspects of outsourcing and Part 4 discusses key performance indicators.

SC B4:

- **TB 130 (1998): *Operational guidelines and monitoring of HVDC systems***
Major advances in technology for controlling HVDC systems has led to greater efficiency in operation and maintenance, as well as providing a reduction in staff. The quality and reliability of an HVDC system is directly dependent on the type of monitoring implemented. Recent developments now allow implementation of computer based information systems with significant improvements in the delivery and presentation of data necessary for supporting the operation.

SC B5:

- **TB 087 (1994): *Maintenance and management of protection systems.***
The growing size and complexity of power systems generate increasing needs for maintenance and management efforts to optimize investment and renewal costs. On the other hand the rapid development of information technology can provide a new approach to reduce life cycle costs. SC34 has considered these aspects from the point of view of protection and control systems.

- **TB 246 (2004): *The automation of new and existing substations: why and how.***
Discusses the impact of modern secondary equipment in substations to utilities. Overall and not individual functions are discussed. It applies to new substations as well as for refurbishment of secondary equipment in existing substations. The purpose is to assist engineers who have not yet had experience with modern secondary equipment. It provides useful information gained by utilities, manufacturers and system integrators

SC CI:

- **TB 176 (2000): *Ageing of the system. Impact on planning.***
In the past the driving force for system modernization has been load growth: equipment was replaced because its rating or characteristics were no longer compatible with the changing requirements due to steady and considerable load growth. Nowadays in the low growth environment that prevails in many countries - many assets are rated sufficiently to fulfil their roles in electricity transmission up to the expiry of their lifetimes.

SC DI:

- **TB 226 (2003): *Knowledge rules for partial discharge diagnosis in service***
A discussion of the possibility of interpretation (knowledge) rules to support PD diagnostic of service aged HV components. Based on systematic experience from this field it evaluates and classifies PD quantities which are found useful for diagnosis monitoring of different HV components, particularly for different insulation systems of HV components like instrument and power transformers, distribution and transmission power cables, GIS, generator stator insulation general characteristics of typical PD quantities are also evaluated.
- **TB 228 (2003): *Service aged insulation. Guidelines on managing the ageing process.***
A new methodology to analyze and manager service aged insulation. In contrast to the usual focus on accelerated ageing in a laboratory this approach starts from scientific observations on aged or failed in-service equipment.

6. Asset Deterioration and Ageing Processes

6.1 *How Equipment Ages*

Power equipment (transformers, circuit breakers, cables, protection and control systems, overhead lines and so on) that forms a power system, ages in service under the full range of operating and environmental stresses to which they are exposed. So-called normal ageing occurs as a result of thermal, chemical, mechanical and electrical stresses. Rapid deterioration also may occur as a result of transient or short-term stresses or transient phenomena on power systems that includes for example, extreme wind loading, short-term overloading, lightning surges, switching surges, temporary over voltages and short-circuits. Ageing under normal service conditions occurs primarily because of mechanical wear out between moving parts and thermal and chemical stresses which relate to oxidation and chemical deterioration of the insulating materials, epoxies, papers and oil. Moisture, oxygen, and build-up of deterioration by-products such as acidity in oil/paper insulation systems in cables, breakers, and transformers accelerate the ageing.

On overhead lines, high loading levels combined with ambient temperatures cause annealing of aluminium conductors resulting in a gradual loss of conductor strength over time. Suspension insulators can be exposed to contamination and moisture which reduces electrical withstand strength. Towers exposed to the elements corrode over time and lose strength. Footings subjected to frost and other environmental stresses, may age and crack exposing reinforcing steel and anchor bolts to atmospheric corrosion.

In gas insulated equipment, partial discharge and arcing between contacts as they open or close, can cause the insulating gas to dissociate into chemically active compounds. These react with any available oxygen or moisture that may be present to form corrosive compounds which attack support spacers and other components. The corrosive attack leads to pitting and metallic corrosion on metals and blistering and tracking of epoxy surfaces. Metallic corrosion and pitting can roughen surfaces leading to increased electric field stresses or damage to electrical connector contact surfaces. Surface deterioration under electrical stress can result in surface tracking and eventual failure through flashover.

Moisture and dissolved gas in transformer oil and insulating paper responds to thermal stress and at very high loading, by coming out of solution at hot spots creating bubbles in the oil between the discs and/or in the paper insulation. Such bubbles are voids, which if they are located in areas of high electrical stress, may facilitate the onset of partial discharges. Partial discharges cause further damage to the paper resulting in conducting tracks in the paper. Insulating tracks in the paper can cause an increase in local electrical stress, which compounds the rate of deterioration. In addition, poor stress grading or damage to conductors may result in discharges in the insulating oil from metal components, connectors, core and so on. Discharges in oil can cause dissociation of the aromatic molecules in the oil and the generation of additional gases.

The insulating paper and other cellulose bracing materials are composed of long polymeric molecules, which are intimately intertwined to create the mechanical strength of the material. The most direct measure of ageing is to measure the degree of

polymerization (DP) in the paper. New paper has a degree of polymerization of 1000. DP decreases as the paper ages and end of life is usually declared when the DP reaches 200. At that level, the paper and bracing materials have significantly reduced mechanical strength and winding displacement in the event of a short circuit through fault is very likely.

6.2 *Expected Life and Factors that affect it*

As discussed above, the materials in power equipment age under normal operating conditions. Apparatus designed for heavy loading, for example auto transformers, are typically specified and designed to operate at full load continuously for 25 years (ANSI/IEEE C57.92-1981). Under lighter loading and with effective maintenance, such transformers can operate reliably for much longer periods of time exceeding 40, 50, and even 70 or more years of service in some cases. The ageing process results in a gradual weakening of the equipment's ability to withstand stresses (particularly to transient or dynamic stresses) and this implies an increasing probability of failure. Probabilistic methods are commonly used to illustrate this conceptually as follows. The strength of a component is represented by the cumulative probability of withstand curves shown on the right in Figure 6.1 below. Over time the withstand curve will move to the left, reflecting reduced strength. The distribution of stresses to which the equipment is exposed is shown to the left of the figure. This curve remains essentially constant over time (assuming minimal system changes), so as the equipment's strength reduces through ageing processes, the stress and strength curves begin to overlap. The increasing overlap reflects an increasing probability that stresses will exceed strength and that failure may occur.

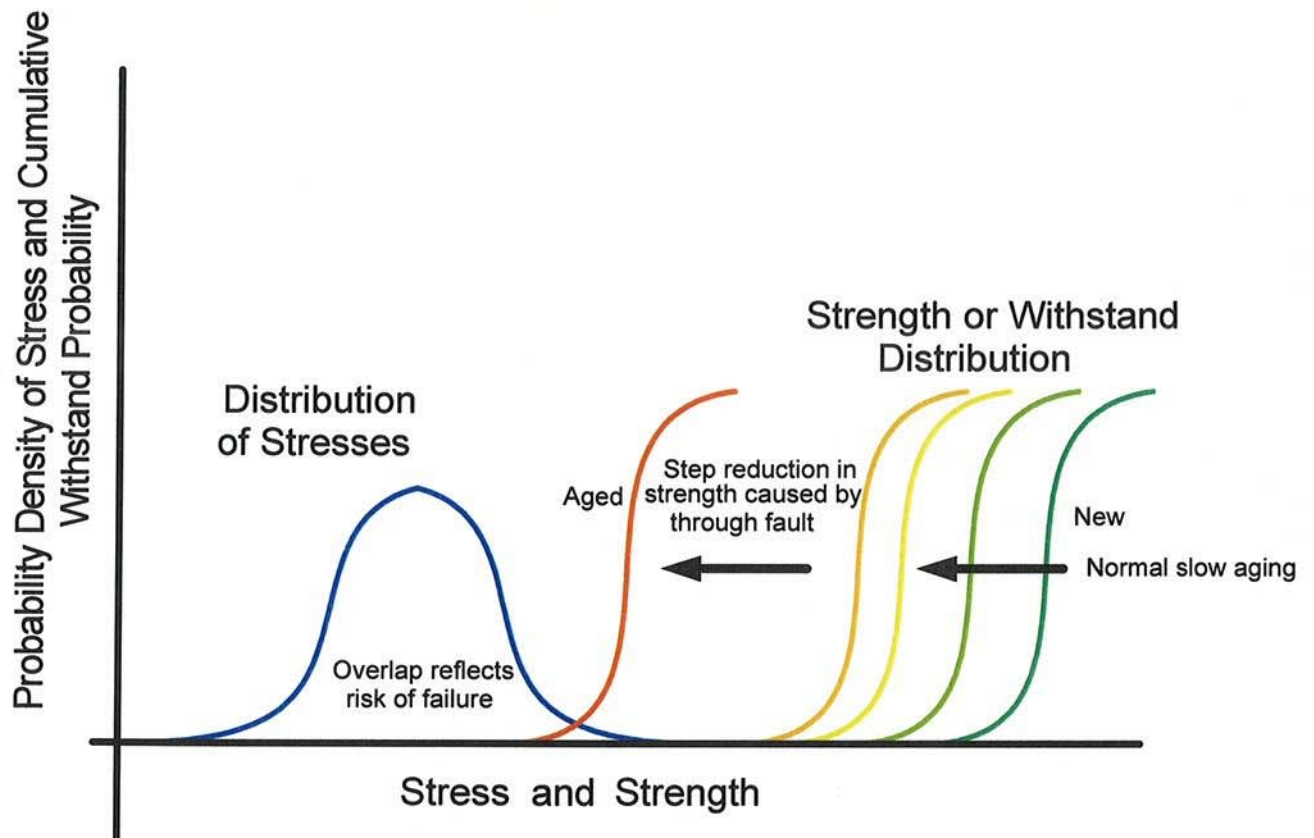


Figure 6.1 *A conceptual illustration of how final end-of-life in the form of equipment failure in-service is a function of progressive ageing and weakening of the equipment combined with random system or environmental stresses which ultimately exceed the equipment's deteriorated strength*

As a result, the eventual failure under “normal ageing” is a statistically determined event. Therefore, remaining life estimation (for example in the “run to failure” asset management strategy) can only be quantitatively expressed on a probability or risk basis.

For transformers, and other apparatus using oil/paper insulation systems, normal ageing is influenced by a number of factors including primarily the type of paper (thermally upgraded or normal), cumulative temperature exposure, moisture, oxygen and the chemical makeup of the transformer oil (for example its acidity). Breakdown of cellulose molecules is caused by high temperature (pyrolysis) and/or the presence of water (hydrolysis). Further, oxidation weakens the bindings between the monomer units, making both hydrolysis and pyrolysis easier. Oxidation may take place both if conditions are too acidic or too basic. For normal oil/paper systems moisture, acidity in the oil and oxygen has significant influence on the rate of ageing as measured by the degree of polymerization (DP). Thermally upgraded papers have significantly superior performance even when relatively moist. DP and mechanical strength reduce gradually,

and events such as through faults stress transformer windings for example. Significant winding displacements lead to step reductions in withstand strength leading to accelerated local ageing. Fairly accurate remaining life estimation could be done based on an end-of-life criterion of DP less than 200, if data like that above were available for transformers under a realistic range of operating conditions and if it were possible and practical to obtain direct measures of the paper DP. Unfortunately, such data are not available and getting direct DP measurements is invasive and therefore risky. As a result, utilities rely on DGA and other indirect measures to assess oil/paper insulation condition. This points out the ongoing challenge for Study Committee D (WG D1) relating to materials and other A Working Groups relating to specific equipment types. In view of the importance of gaining improved quantitative understanding of ageing of materials and components under stress for asset condition assessment and decision making, continuation and expansion of these activities is strongly encouraged.

Ageing or deterioration processes are strongly influenced by three major factors as illustrated in Figure 6.2 below.

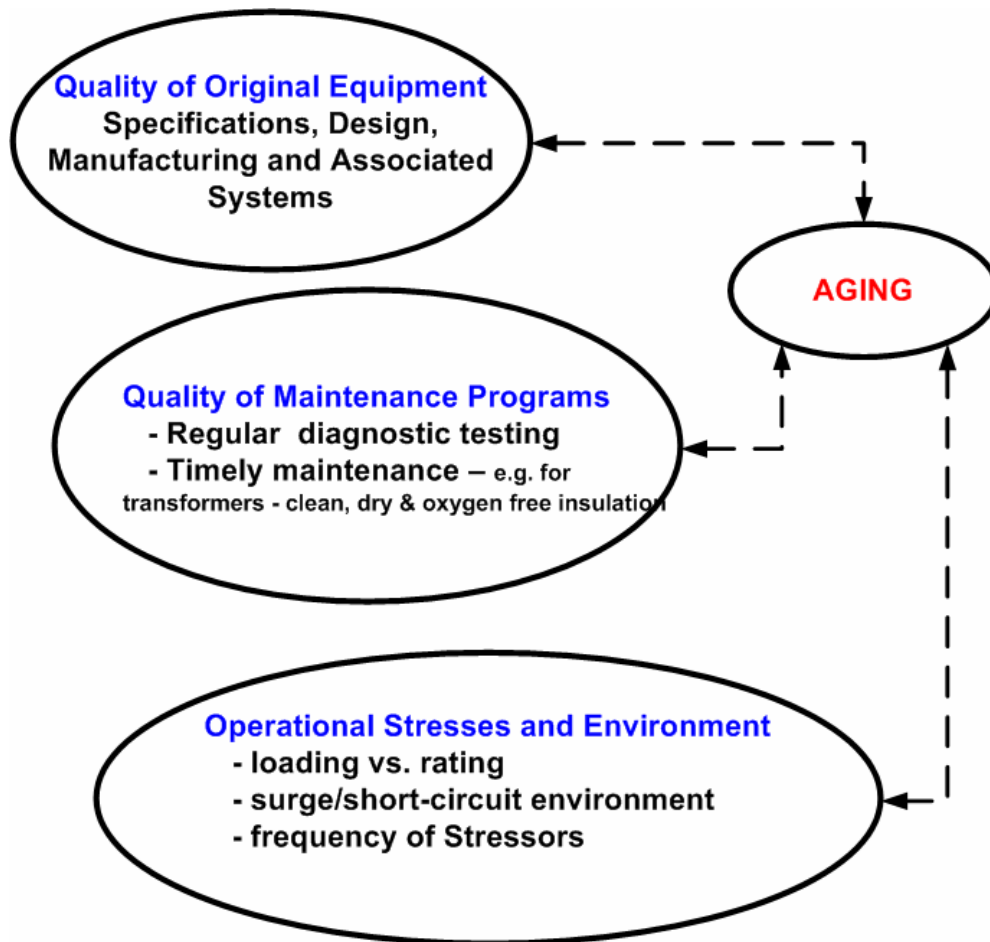


Figure 6.2 Influences affecting ageing

The integrity of the equipment and systems as originally put into service obviously provides the base from which ageing begins. The quality of design, specification, procurement, manufacture and commissioning can strongly influence how well equipment and systems perform in the long run. Recognition of superior quality at the procurement stage is increasingly difficult in business environments where cost reduction is a major force in decision-making. As well, competitive pricing pressures tend to force manufacturers to reduce design margins, use cheaper materials or reduce costs in the manufacturing processes, the long-term implications of which may not be known or recognized unless end users conduct very detailed design reviews.

Once in service, the quality of maintenance programs is another obvious factor affecting ageing of equipment and systems. Provision of regular inspections and diagnostic tests or monitoring followed up with timely attention to correction of any apparent problems can have a very significant benefit in sustaining reliable operation and extending the useful life of equipment. Integral to the effectiveness of such maintenance programs is rigorous documentation of diagnostic data [27], analysis to determine root causes for problems, post mortem forensic analysis of failures and analysis to identify any trends in equipment performance.

Lastly, the operational duties and stresses imposed on the equipment relative to the design basis for the equipment critically affect ageing. Clearly the harder some assets (e.g. overhead conductors, cables, switchgear, transformers) are worked the faster they will age. Recent industry trends to “sweat the assets” must take into account the affect this has on loss of life. For example in transformers, IEC and ANSI standards have long recognized the direct linkage of loading to hot spot temperatures and the effect that sustained operation at high hot spot temperatures has on ageing of the transformer insulation system. CIGRE working groups in the past have produced graphical data on failure rates for generator unit transformers (GSU’s) and network transformers as illustrated in Figure 6.3 below.

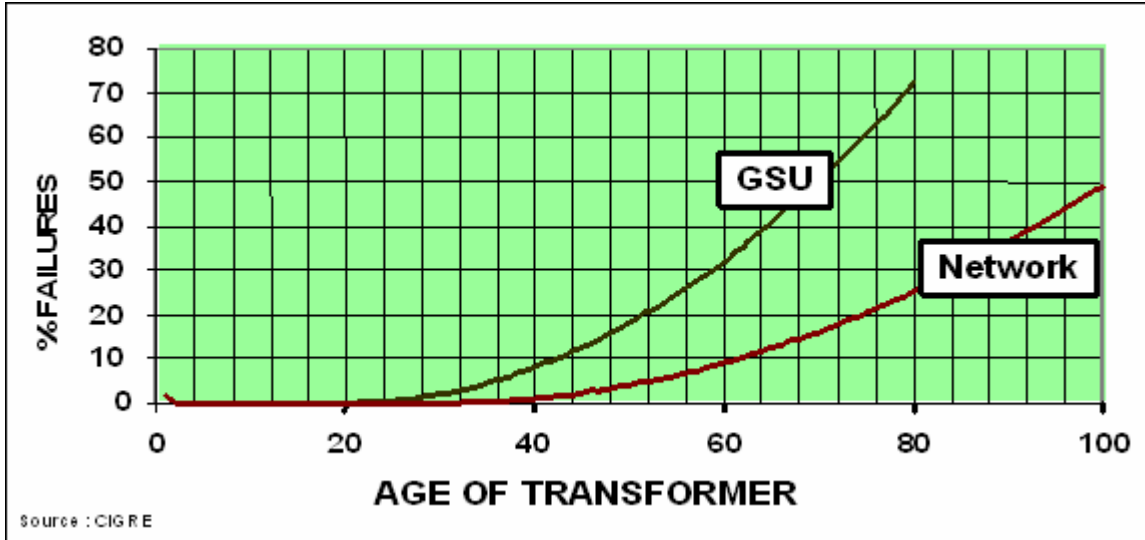


Figure 6.3 *The influence of loading history on transformer ageing. These hazard rate curves show the probability of failure at any specific age for generator unit transformers (GSU) and area supply network transformers (Network).*

This figure highlights that the hazard rate function for transformers is strongly influenced by the loading history. For transformers, the basis for this dependency is well documented and included in ANSI and IEC standards for transformer loading; however until recently quantitative methods to relate loading histories with the corresponding hazard rate function have not been available. It is now possible to develop hazard rate functions for specific loading histories and for specific insulation condition parameters [8]. Although such methods have been developed for transformers, it is important that study committees continue to improve fundamental data of this type for all types of assets, including conductors, transformers, cables and switchgear.

6.3 Rate of ageing

As assets age, the rate of ageing may increase. In some cases the physical and chemical changes taking place under constant levels of stress may remain steady; but many of these processes accelerate as the asset materials age because although macroscopic stress may remain constant (for example the applied voltage) local stress levels may have increased significantly (for example through tracking or partial discharge activity in insulation systems). As well, many of the stresses can act synergistically to accelerate ageing processes. For example, thermal stresses in transformers, may gradually weaken the mechanical strength of windings so that under short-circuit stress, deformation becomes more likely. Deformed windings may increase local electrical stress levels leading to arcing or partial discharge activity which leads to further physical and

chemical damage and so on. This slippery slope is illustrated conceptually in Figure 6.4 below.

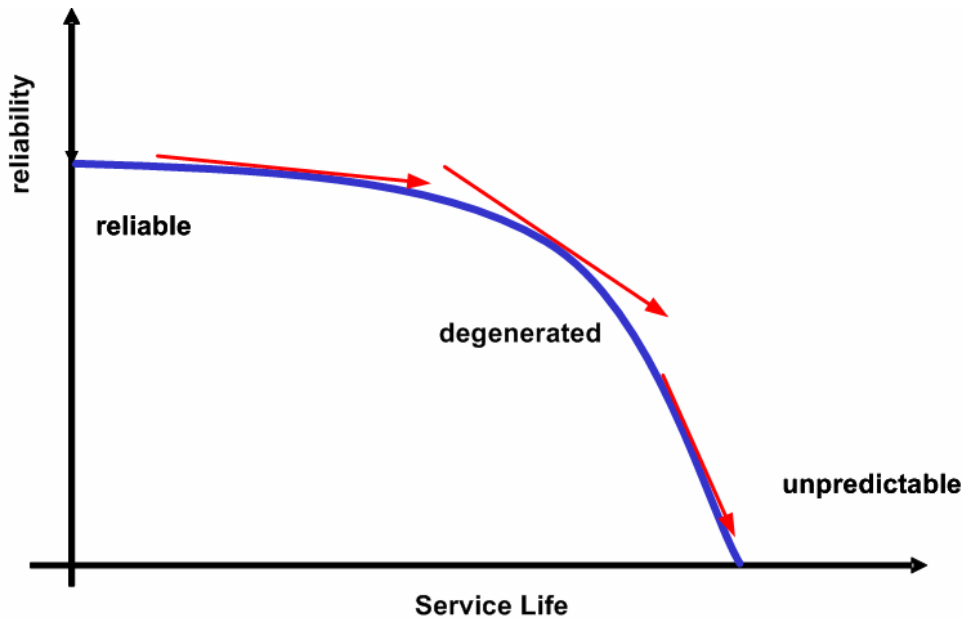


Figure 6.4 *Asset ageing rates increase if no action is taken to extend life*

Ideally asset managers would like to have a detailed and quantitative understanding of these ageing curves in order to support the several types of decisions that they might make to justify investing in maintenance, refurbishment or replacement programs for populations of such assets. For this reason, work has been carried out to model the ageing process mathematically. This is carried out by defining a number of operational states for the assets in question (for example excellent or new condition, good condition, somewhat aged condition, degenerated condition, and end of life) and the possible actions that asset managers might take to modify the state of the assets. This would include repair, refurbishment or replacement. These states and possible asset management strategies are illustrated for a simple case in Figure 6.5.

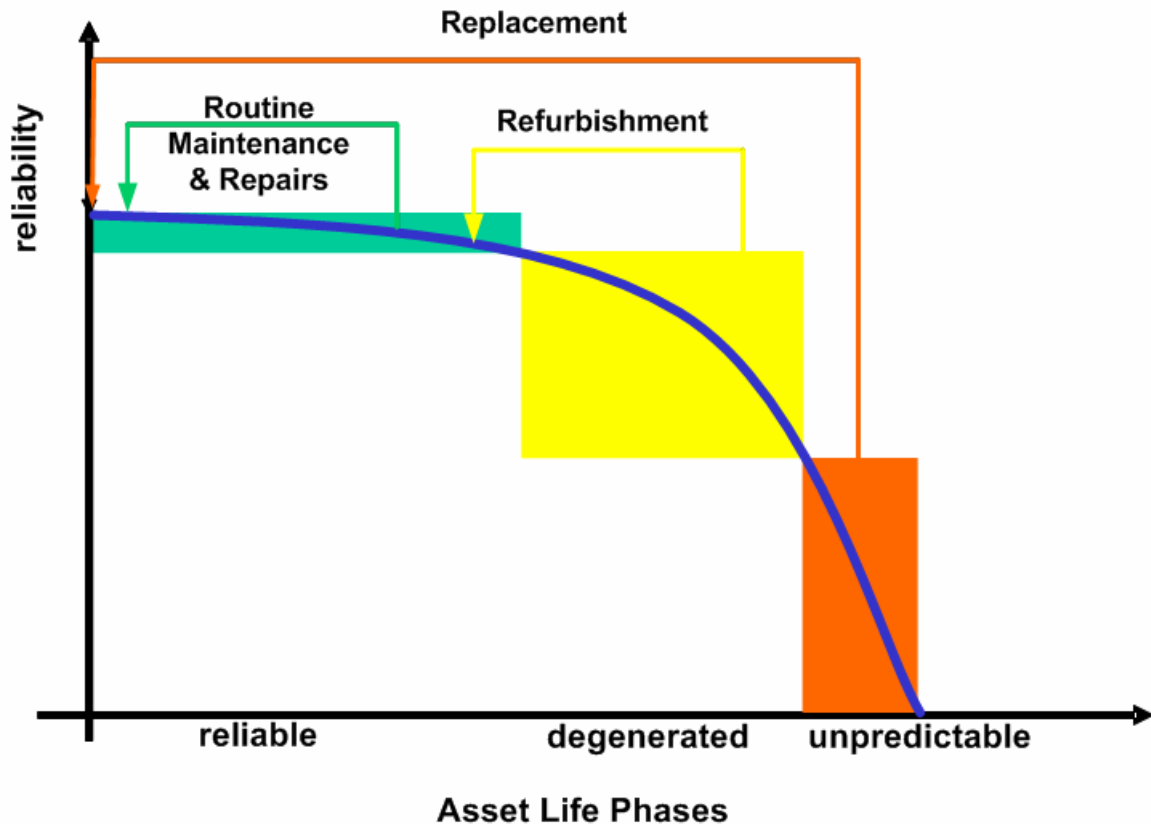


Figure 6.5 States of ageing concept and possible asset management actions

In the figure, routine maintenance and repairs include all of the normally budgeted actions carried out to monitor and sustain the assets. Refurbishment on the other hand relates to specific asset related options, which may be more significant in terms of cost, outage duration and potential benefit. Examples of refurbishment would include, re-conductoring overhead transmission lines, major overhauls of circuit breakers, drying and degassing transformers and so on. The most important aspect is to develop the asset ageing model. Such a model needs to describe the ageing of the assets and the actions, which can be taken to prevent reliability degradation. The figure shows a simple representation of the effects of ageing in which three different states are defined: reliable, degenerated and unpredictable. Also illustrated in this figure are the possible types of investment that an asset manager might consider for equipment in each of these states, namely minor repairs, refurbishment or replacement. As indicated by the arrows directed to the left in the diagram, and assuming these actions are carried out successfully (that is the equipment is not damaged by maintenance errors) the effective state of the equipment reverts to a point on the life curve corresponding to some amount of increased remaining life.

The objective in using such models is to consider different long term strategies for the total fleet of a specific type of equipment and to evaluate the benefit to, or impact on the reliability at certain System Delivery Points of adoption of these strategies. The financial costs and benefits to the company implicit with these strategies also need to be assessed. In the evaluation, the following details have to be taken into consideration:

- Evaluation of the complete life-cycle costs of an equipment
- Consideration of the requirements of the different stakeholders
- The complete fleet of equipment is treated according similar rules, no decisions for single equipment
- Feedback of the total process is taken into consideration (system dynamics model).

The approach in modelling this process mathematically is illustrated in Figure 6.6. In this Markov based model, a number of states are defined and the transition rates between the states and for the types of service/repair/ refurbish/replace actions are defined and used to determine estimates for the equipment remaining life. The transition rates can be determined through data mining of detailed maintenance records if available or through a reverse knowledge engineering process based on the experience of the appropriate domain experts.

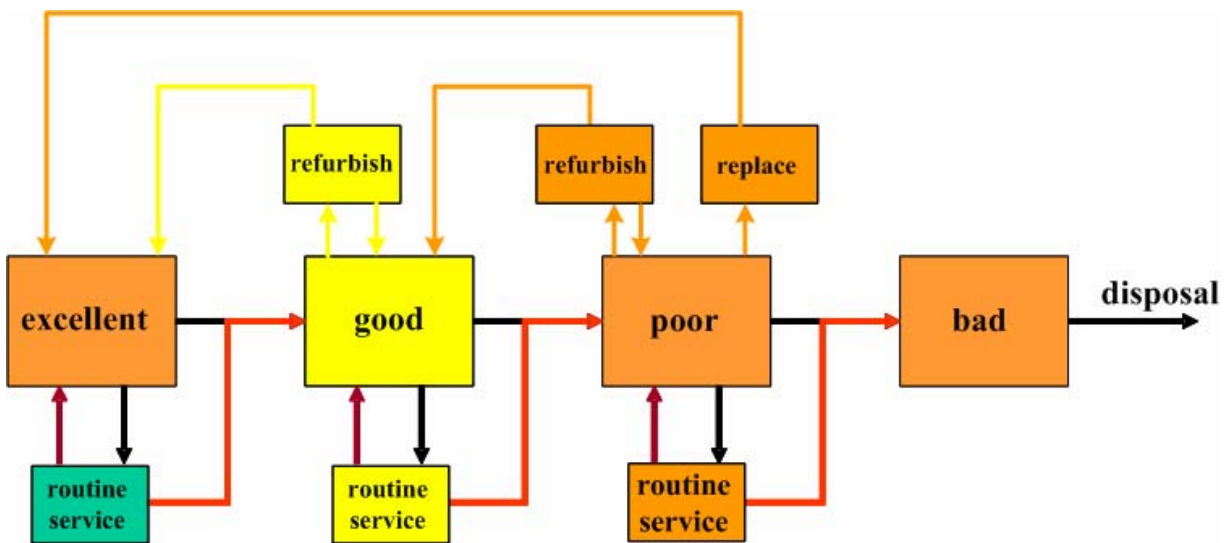


Figure 6.6 State-based ageing model [9, 10]

Such models can be analyzed to quantify the benefit in terms of remaining life of adopting more versus less aggressive maintenance policies, for example, strategies to minimize early maintenance costs with delayed refurbishment from the “poor” state compared with aggressive routine service and refurbishment if necessary at the “good” state. Such ageing models may be useful in analyzing life cycle solution options for the assets; however, there are a number of other issues that need to be included by asset managers in formulating asset management policies.

7. Asset Management Decision Methodologies and Strategies

To fulfil their role, Asset Managers must accurately forecast the implications that this ageing infrastructure has on the service quality delivered by the system and the changes to the historic levels of Capital and O&M costs, which will need to be absorbed by the rate structures. As the system ages it enters a new region of higher risk which may require higher levels of investment and a different allocation of costs. To effectively convince shareholders and regulators that increased investments are required to mitigate the risk level, there is a need to improve understanding of:

- The impact that equipment failures have on business objectives such as workforce safety, public safety and environmental performance.
- How the Delivery Point Performance (DPP) of the system will be affected when a significant proportion of the equipment is operating in this age region. The DPP is critical because this is the point at which customers are served and will experience a reduction in service quality.
- The relationship between specific equipment performance (breakers, transformers, lines, protection and control, etc.) and DPP, so attention can be given to the highest priority assets.
- How the frequency and duration of forced and planned outages change as equipment approaches end-of-life and the resulting impacts on the historical levels of Capital and O&M costs, reliability levels and the outage requirements imposed on customers. In heavily loaded networks there are fewer time slots or opportunities to take equipment out of service for preventive maintenance. This phenomenon may increase the long-term risk on DPP to an unacceptable level.
- The costs associated with refurbishing the various pieces of equipment and the related gain in equipment reliability and life expectancy. This enables an appropriate economic and technical comparison of refurbishment versus replacement options.
- Factors, which must be monitored at the equipment level to determine the condition of these assets and methods for determining the related risk of failure.
- The overall macro-level cost impacts the company is likely to experience, in terms of cost magnitude and cost allocation, to maintain the required levels of service quality. This information must be effectively communicated to the financial group within the organization and to the regulator to ensure these costs are accounted for and recovered in accordance with the related cost allocation and rate design principles.

Establishing the risk (probability and consequence) of asset failures on the Business Values of the company and determining the least cost means of correcting the situation, when warranted, is one of the most important results which must be delivered by an Asset Manager. An initial requirement for effectively determining risk associated with an ageing electricity delivery system is to understand the overall condition of the asset base and the resulting degree of reduction expected in equipment reliability performance. The quantification of risk to the Business Values requires an understanding of the asset failure

modes and related impacts on the DPP of the System and other Business Values such as Public / Employee Safety and environmental performance. To establish the impact on the DPP of the system, the Asset Manager must develop an understanding of how a change in equipment reliability performance will affect the DPP of the system. Since electricity delivery systems have built in redundancy for major loads, a reliability model, which relates equipment reliability to system level DPP, is required. Equipment reliability is related to key functions and key performance indicators. The need to take specific actions in the near term is driven primarily through ongoing assessments of the condition and utilization factors for the assets in the form of asset health indices and condition ratings.

7.1 Key performance indicators

Key performance indicators of the asset health have been carried out by the asset experts in other Study Committees. These have been summarized from several CIGRE Technical Brochures to provide an overview of the key functions of components and subsystems of the network.

Note that for overhead-lines and cables the key functions are not explicitly mentioned in the CIGRE Technical Brochures referred to. A list of relevant Technical Brochures is given in section 4.

Transformers (TB 227):

- electromagnetic ability to transfer energy
- integrity to carry current
- dielectric withstand strength (to earth/between phases/between windings)
- mechanical withstand strength (to short-circuit current and inrush current forces)

Circuit-breakers (TB 83):

- open/close on command
- not open/close without command
- ability to make/break the current
- ability to carry the current
- dielectric withstand strength to earth/between poles/across open contacts
- not locked

GIS (TB 150):

- dielectric withstand strength to earth/between poles/across open poles
- open/close on command
- not open/close without command
- ability to carry the current
- mechanical integrity
- SF6-tightness
- ability to relief over-pressure
- integrity of enclosure (no burn through)

- no partial discharges
- not locked

Overhead lines (TB 230):

- mechanical integrity of OH-line system (no collapse of towers, no broken conductors/insulators)
- dielectric/mechanical integrity of the clearance to the environment
- dielectric withstand strength to towers/between phases/between circuits
- ability to carry the current

Cables (TB 279):

- dielectric withstand strength
- ability to carry current
- integrity of sheaths to protect for unsafe situations

Protection systems (TB 87):

- selectivity
- dependability
- speed

The key performance indicators are normally defined in a negative sense; i.e. a maximum number of failures or a trend of the equipment not fulfilling key functions. Most experts distinguish explicitly between Major Failures (MF) (or Failures) and minor failures (mf) (or defects). A defect is seen as an imperfection in the state of the equipment that increases the probability of a Failure (TB 175). A MF (TB 83 and TB 150) or a Failure (TB 175) is a failure to fulfil a key function, while mf and defects are other failures. The failure data support reliability and availability calculations and are necessary to determine hazard rate curves (bath-tub curves) by means of curve fitting techniques and to perform risk analysis (criticality). To TB 211, such data are used at the equipment level (both MF and mf), at the system level (MF) and at the business level (system failures only). All equipment experts and asset managers agree that constructive feedback from service experience is vital.

So far the collection of reliability data has been performed by CIGRE Study Committee A3 (on circuit-breakers, TB 83), B3 (on instrument transformers, TB 57, and GIS, TB 150) and B4 (HVDC converter stations). Other SC have made efforts in surveys for some reliability/availability aspects only, for instance: TB 209 (short-circuit performance of transformers), TB 165 (electrical, dielectrical and environmental stresses on circuit-breakers). Nevertheless it is strongly recommended by most experts to collect MF/mf data, also for other equipment and subsystems.

Since 2004 a combined third worldwide enquiry is running on the reliability of circuit-breakers (single pressure SF₆ technology), of disconnectors, of earthing switches, of instrument transformers and of GIS. The enquiry covers all ages, but the older circuit-breaker technologies are not covered. In the two former worldwide enquiries on circuit-breakers (the first on all technologies and the second on single pressure SF₆ puffers only)

the population was limited to ages less than 14 years. Thus, from the SC 13/A3 surveys no conclusions on the reliability of older circuit-breakers can be drawn, although such information is very relevant for asset managers.

Other asset related key performance indicators are related to the maintenance and condition of the assets: maintenance frequency, maintenance actions, maintenance costs, failures due to maintenance, results from inspection and diagnostic tests, condition assessment, residual life estimation, etc. Most Study Committees have addressed maintenance, inspection, monitoring and diagnostic techniques, and studies can be found on generators (TB 2), transformers (TB 227), circuit-breakers (TB 83, 165, 167), cables (TB 279), OH-lines (TB 141, 175, 216, 230), instrument transformers (TB 57), substation secondary systems (TB 88), GIS (TB 150), HVDC (TB 130) and protection (TB 87). Maintenance management policies are dealt with in TB 165 (Life management of circuit-breakers) and TB 152 (An international survey of maintenance policies and trends).

Looking at Asset Management policies, it is important to note in particular TB 175 (Management of existing OH-lines), TB 211 (General overview on experimental feedback methods), TB 248 (Economics of transformer management), TB 210 (Maintenance outsourcing guidelines) and a SC B3 TB to be published soon (General principles of asset management information strategies). In Technical Brochures 175 and 248 much attention has been given to risk management considerations, as will be the case in the TB to be published by SC B3. In TB 175 predictable (normal and frequent incidents) and unpredictable (catastrophic and infrequent incidents) risks are expressed as expected costs, as NPV (net present value). However, no consideration has been paid to the comparison of real costs with stochastic monetary quantities. Also the discount rate in the NPV based on the WACC (weighted average cost of capital) and the inflation rate are variables which need to be considered taking into account the price projections of the equipment involved, economic forecasts etc. From the point of view of Asset Management such financial/economic considerations are thought to be very important factors in business case analysis and a comparison between utilities' experience and policies is strongly recommended to be a field of interest for SC C1. Another issue is that NPV calculations using typically assumed parameters (discount rate 5% or more points above the inflation rate) cause long term problems (costs) to appear to vanish, while asset managers are supposed to develop their strategies for the long run.

In TB 248, WG A2.20 addressed risk management at the level of the company's risk appetite as well as risk calculations to assess the risk due to life extension of transformers, to assess the risk of a lack of spare transformers, to assess the risk of overloading transformers. Further maintenance, diagnostics and repair versus replace are addressed. The Technical Brochure gives many examples, although the data given are taken from the literature. An example of the failure rate change by age is given, but the reader is warned that such trends vary as a function of several parameters, including loading history and transformer condition. However, reliable data on the failure rates by age are most interesting for asset managers and SC A2 should be encouraged to collect such information.

Some Study Committees have investigated relevant ageing mechanisms for equipment and for subsystems, thus providing useful information. In the interesting Technical Brochure 96 "Thermal aspects of transformers" reference has been made to IEC 60505

(2004) “Guide for the evaluation and identification of insulating systems of electrical equipment”. To this IEC document, ageing is defined as the irreversible deleterious change to the serviceability of the equipment. Such changes are characterized by a failure rate, which increases with time (bath-tub curve).

In TB 96 it is important to distinguish between ageing of the equipment and ageing of materials. Ageing of a material is an irreversible negative change of a pertinent property. For engineers such deterioration of materials is relatively easy to measure in a laboratory. From there they assume a one-to-one correspondence with the ageing of the equipment, but in reality such relationships are far more complicated. In the Technical Brochure the well-known Arrhenius law for life duration as a function of temperature is elaborated. Physically this law is applicable to the mechanical properties of insulating paper. And even this degradation process is complex, as the degradation for the tensile strength is much slower than for the retained bursting strength. Paper brittleness may lead to cracks and cracks may reduce the dielectric strength as well. Thermal effects are caused by chemical reactions in organic materials and are largely influenced by oxygen and moisture. The ageing of the insulating material in transformers thus is a very complicated function of the temperature, mechanical stresses, oxygen level, moisture content and dielectric stresses. Moreover it is very dependent on the history and the location of the spot of interest.

According to TB 96 Major Failures in transformers are mostly caused by overvoltages and system faults, probably in relation with transformer ageing (see figure 6.3). But according to TB 209 “The short-circuit performance of power transformers” there is good service experience with respect to the transformer’s withstand capability to short-circuit current forces. The TB recommends that operators keep track of the cumulative short-circuit currents, numbers of over-voltage surges and loading history. Also it is strongly recommended to observe the development of DGA (dissolved gas analysis) and the evolution of the oil (moisture, carbon content, particles). Furthermore, it is stressed that it is very important to keep a record of repairs, internal inspections and displacements; as such actions will also have negative consequences for the residual life. Special attention is directed to ancillary equipment (tapchanger, bushings, coolers, etc.), as these components may be decisive for residual life.

Circuit-breakers (TB 165) display similar patterns. The ageing patterns of certain parts of circuit-breakers show a wide spread. Most important are the ageing of gaskets and of nitrile seals, painting and corrosion, porcelain to metal joints. These show a variation of decades, and there is not much difference between old technologies and modern circuit-breakers. Also mechanical wear and electrical wear (arcing contacts) show a wide spread with respect to ageing due to usage; but here, modern technologies show a far higher endurance capability in terms of the number of operating cycles or cumulative number of short-circuit currents interrupted.

Looking at OH-lines (TB 175), again no firm relationship between age and residual life can be given. Deterioration, of course, is time related, but not according to a simple formula. Deterioration is mainly caused by wear, fatigue, corrosion, deformation, elongation, concrete cracking (due to frost) and loss of strength of aluminium conductors through annealing (loading related). Therefore OH-line deterioration is very dependent on the circumstances and local history.

With respect to ageing of the insulation of GIS, a joint SC 23/SC 33 study was published in *Électra* 176 “Insulation co-ordination of GIS: return of experience, on site tests and diagnostic techniques”, which states at two places (§ 2.2.1 and § 2.3) that pollution and ageing processes can be neglected for GIS. So far, the above conclusions from SC A2, A3 and B3 have not been withdrawn. On the other hand SC D1 continues investigation of the ageing process, as illustrated in Technical Brochure 228 “Service aged insulation – Guidelines on managing the ageing process”. It is stated that there is need to collect information from failures in a structured way in order to correlate forensic evidence with failure modes. Templates for a structured failure analysis have been set-up for instrument transformer insulation, stator winding insulation, XPLE cable joints and transformer pressboard insulation.

CIGRE Technical Brochure 176 focussed at the overall impact of ageing: “Ageing of the System – Impact on Planning”. It stresses that **a timely implementation of a strategy to replace assets, preferably in combination with network redesign options, is a key to success for Asset Management**. Ageing, however, still forms an area of interest where a large need for knowledge and information sharing exists and where CIGRE can play an important role.

Last, but not least, the topic of residual life, end-of-life decisions and life extension has been considered in Technical Brochure 165, together with service experience associated with circuit-breaker end-of-life decisions. Through an international enquiry, assessment criteria, decision methods and practices have been collected. The importance of properly addressing uncertainties has been noted in Technical Brochure 154 “Techniques for power system planning under uncertainties”. Such techniques are equally applicable to equipment issues.

7.2 *Asset Health Indices & Reliability Tools*

To develop an understanding of the overall condition of the asset base and the effect of ageing on the ability of equipment to perform its intended function, many utilities have begun to develop and apply indicators, which are representative of asset condition. These indicators, sometimes referred to as Asset Health Indices (AHI’s), are unique to each specific asset group. AHI’s enable utilities to rank their asset fleets by condition and criticality and to identify assets approaching end-of-life. The most important asset groups requiring the development of AHI’s are transformers, circuit breakers, protection relays, overhead lines and underground cables. The following table gives an example of AHI’s for transformers that are based on established diagnostic techniques (see for example [11, 12, 13]):

Condition Rating Condition Criteria	Very Good (Reliable Service for > 15 years)	Good (Reliable Service for 10 - 15 years)	Adequate (Reliable Service for 5 - 9 years)	Poor (Refurbish or Replace within 3 to 5 years)	Very Poor (Refurbish or Replace within 2 years)
Dissolved Gas in oil Analysis (DGA) [11]	Excellent Test Result	← Intermediate Results →			Very Poor Test Result
Furan Analysis (FA) [12]	Excellent Test Result	← Intermediate Results →			Very Poor Test Result
Doble Test Results (DTR)	Excellent Test Result	← Intermediate Results →			Very Poor Test Result
Frequency Response Test (FRA) [13]	Excellent Test Result	← Intermediate Results →			Very Poor Test Result
Asset Utilization (AU) Note1	Low Stress Application	← Intermediate Results →			High Stress Application

Table 7.1 Example of Asset Health Indices for Transformers

Note 1: *Low stress, defined as some combination of the following:*

- Applied in redundant arrangement
- Mostly loaded to 50 % and no occurrences of loading above limited time rating (LTR) over life
- Subjected to very few short circuit faults since in low storm area and /or connected to short lines

High stress, defined as some combination of the following:

- Applied in radial arrangement - regularly loaded to LTR and many occurrences of exceeding LTR over life.
- Subjected to many short circuit faults since in high storm area and / or connected to long lines.

Quantifying asset ageing, deterioration and condition is an important input for asset managers. Therefore, AHI's are required for all major asset groups and utilities would benefit by jointly developing such factors, which are necessary to understanding the need for a Run, Repair, Refurbish, Replace (RRRR) decision. Some utilities are in the process of developing algorithms for estimating the remaining life of an asset, from the various AHI's. The remaining life of a transformer for example, is a function of (DGA, FA, DTR, FR, and AU). The development of asset health algorithms (AHA's) will be important for establishing the risk of asset failure and the need for a specific RRRR decision. CIGRE Working Group A2.20 has developed an application guide for transformers [14], which discusses some of the concepts mentioned above. There is a

need for other CIGRE working groups to develop similar application guides for other asset categories. The key challenges in this area include:

- Identifying asset groups with sufficient granularity to develop effective work programs for incorporation in utility business plans.
- The availability of historical information, within any given utility to develop the AHA's.
- Developing methods for validating and improving the AHA's.

Having information related to the failure probability of a specific piece of equipment is not sufficient for an Asset Manager to make RRRR business decisions on the need for incremental expenditures. This is due to the fact that electricity delivery systems are typically designed with inherent redundancy to ensure the DPP to customers is consistent with the economic implications of loss of supply and / or reliability standards set by regulatory bodies. To fully understand the impact of degraded equipment performance on DPP the Asset Manager must have access to reliability assessment methods / tools, capable of calculating the change in DPP for changes in the reliability of the specific components making up the delivery system. These models must be capable of representing the major system components such as lines, transformers, breakers, switches, protection & control equipment, etc. The Guide on Economics of Transformer Management [14] provides some simplified analysis methods, which can be applied to Transformers.

Since much of the system evolved during the same time period, methods and models are needed, which are capable of simulating the performance degradation of multiple system components simultaneously. Reliability models having this type of capability will allow the Asset Manager to more accurately understand the consequences of system ageing on DPP. As part of its future work CIGRE Study Committee C1.1 should investigate the availability of methods and models capable of such performing such analyses and identify those, which are of assistance in this area.

7.3 Establishing cost-efficient, long-term plans to mitigate risks for Asset Groups

The approaches mentioned in the previous section are useful in a typical annual business planning effort, where the need for expenditures on the asset base is built-up by Utility Experts identifying the near term risks to business objectives and the least cost method of mitigating these specific risks. However, with a significant portion of the asset base entering the wear out region utilities are beginning to employ alternative methods to forecast the expected long term implications of system ageing / wear out. These methods of investigating longer-term implications require information related to project failure rates, repair / refurbish / replace costs and the demographics of the various asset populations. These forecasts are found to be useful for the following reasons:

- They provide a long-term view of the problem, which can be used to identify major changes in the historic levels of costs and system performance.
- They assist in ensuring that asset harvesting is avoided over the long term

- They are valuable for validating the sustainability of existing Capital and O&M costs, developed through the traditional Business Planning Process, through the application of an independent methodology and information sources.

Two main approaches, which are currently in use are described below:

a) Forecasting O&M Costs due to asset failures

This approach involves investigating historical failure rates of main delivery assets and the related historical repair / refurbishment costs (O&M costs). Asset demographic information is then used to predict how the number of asset failures is expected to change in the future. If the assumption that the new population of assets is expected to go through the same failure, repair / refurbish cycle is valid, then average failure rates and repair / refurbish costs can be developed and used to generate a forecast of future expected O&M costs.

The following five-step process has been effectively used by utilities to forecast expected changes in O&M costs, due to system ageing / wear out:

1. *Investigate the types of failures historically experienced on a selected asset type.*
For example, in one utility it was found that a standard transformer used in a typical system arrangement (and subjected to average loading levels and system faults) was expected to require major refurbishment of the transformer tap changer and cooling system prior to end-of-life. About 70% of these transformers are expected to go through this failure / repair cycle.
2. *Identifying the age during which these failures are expected to occur.*
In the above example it was found that the major refurbishment of the tap changer and cooling system is expected to occur between the ages of 35 and 45 years. As mentioned above this failure / repair cycle is expected for about 70 percent of the related transformer population.
3. *Reviewing the costs historically incurred to affect the necessary repairs.*
For the transformer example, the actual O&M repair costs were obtained from the historical records within the work management system. These records were used to generate an average repair / refurbish cost for these typical failure modes.
4. *Determining changes in the number of expected failures based on demographic information of the asset type.*
The demographic transformer information indicated that over the next 5 years the number of transformers within this age region would double and remain at this level for about 5 years.
5. *Establishing a forecast of work and related costs based on historical experience and demographic information.*

Based on the above analysis for transformers, the utility was able to predict the expected increase in O&M costs resulting from the ageing system. The utility was also able to proactively develop a mid-life management strategy for transformers, which coordinated the refurbishment of the tap-changers and the cooling systems. This reduced both the overall costs of the work and minimized outage requirements, as compared to the previous reactive based approach for dealing with these failure modes. The approach also enabled the utility to plan for the increases in O&M expenditures, driven by the demographic profiles, and provided the utility with the rationale and business case for including these cost increases in their Rate Case. Another benefit of determining these longer-term impacts is the ability to forecast the changes in work force experts, training and equipment needed to perform the work.

b) Forecasting Capital Replacement Costs due to asset failures

An approach currently in use by utilities, for the purpose of forecasting capital costs associated with replacing ageing infrastructure, is the use of probabilistic failure curves for the various asset groups which are convolved with projected asset demographic information. The approach is based on utilizing probabilistic representations of asset life for major classes of delivery assets and applying these to the related demographic information for each asset group. The probabilistic representations are obtained from available industry data sources and adjusted for the experience of the specific utility. A number of Regulatory entities around the world have required utilities to provide this type of information for the purpose of ensuring that their sustaining related investment levels are keeping pace with their ageing systems, thereby avoiding unexpected increases in capital investment.

As shown in the following diagram, Figure 7.1, the approach involves utilizing demographic information for either a specific asset group or an appropriate combination of asset groups. This demographic information is convolved with the hazard rate for the particular asset group or groups for each year ahead in the planning period to obtain a forecast of the expected numbers of failures for the population going forward in time. To obtain an estimate of the forecasted Capital expenditures, a per unit replacement and consequential failure cost is established and applied to the forecast of unit replacements, at each time interval. From a system perspective, the forecast numbers of failures in subsequent years can be useful in assessing the likely impacts of such failures on DPP and on overall system reliability.

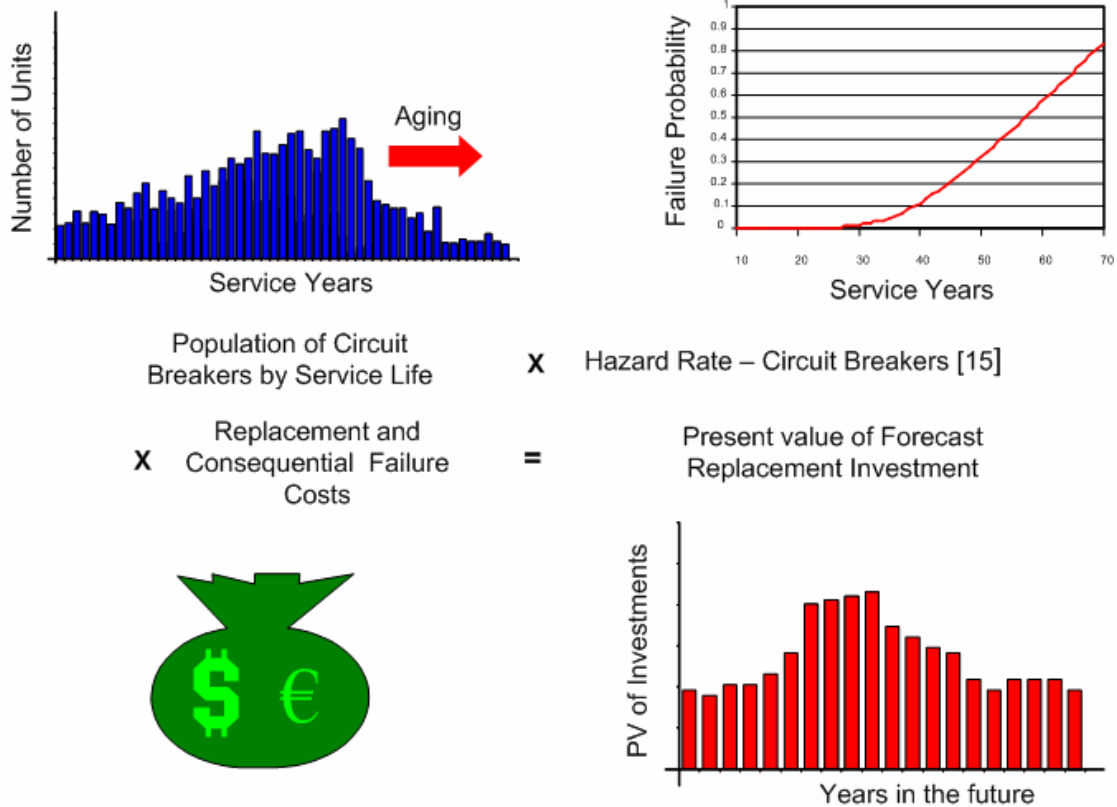


Figure 7.1 *Projection of investment needs for a population of assets*

This methodology for forecasting allows quantitative analysis of asset management strategies to smooth out the forecasted Capital expenditure levels over the long-term. The approach provides information that can also be used to independently validate the Capital replacement levels that are identified by the normal Business Planning process. Typically the normal Business Planning process involves collecting information from the field on the condition of the assets and making decisions on which need to be replaced in any given year. The probabilistic analysis above uses independent information sources to generate near-term and long-term expected levels of Capital replacement, due to asset failure. These Capital replacement levels can be compared to the results generated by the traditional Business Planning process and any significant differences can then be rationalized. Comparing and rationalizing significant differences between the two approaches results in increasing the degree of confidence in the reinvestment levels and represents prudent planning for this important business issue. With the introduction of Performance Based Regulation and the resulting longer periods between rate re-sets, the longer term view provided by utilizing this approach is increasingly valuable, in avoiding asset harvesting and the possibility of having unforeseen costs, which may not be properly factored into the rate base.

7.4 *Other Considerations in Developing Options for Managing Ageing Infrastructure*

Spares Strategies:

Utilities typically carry a sufficient number of strategic spares to cover catastrophic failures of major equipment critical to the operation of the system, such as transformers and some key switch-gear. The number of spares typically considers historical failure rates, the related replacement times and the impact of outages on customers. With a larger proportion of the asset base entering an age region where wear-out may be a concern an alternative to proactive replacement may be to carry additional spares, based on forecasts of an increased failure rate. The methods and models currently in use for establishing the number of spares typically assume that the in service assets are in the useful life region of the hazard rate curve. Depending on specific equipment demographics, the applicability of these methods and models should be reviewed to ensure that they remain applicable. If a large proportion of the asset base is approaching the end of life region, the probabilistic failure projection methodologies referred to earlier provide a more accurate basis to project spares requirements.

Life Extension Strategies:

There are a number of techniques used in the utility industry to extend the life of major asset groups. These include the following options:

- Increased maintenance or adapting maintenance to focus maintenance tasks on critical components within the equipment
- Refurbishment of equipment. This includes major overhaul activities or remedial maintenance tasks (for example, transformer drying, and degassing) which involve significant outage times and costs.
- De-rating of equipment. For stress related ageing processes reduction of the stress has the effect of moving the hazard rate function towards the right or to longer life expectancies in a statistical sense. See for example figure 6.3 which illustrates the hazard rate functions for relatively heavily loaded GSU transformers compared with more lightly loaded area supply network transformers.
- Installing fault limiting equipment such as grounding resistors / reactors or in-line reactors, to limit damaging stresses on the equipment
- Installing on-line monitoring to ensure loading follows ambient temperature constraints or to monitor the magnitude and frequency of exposure to transient faults, for the purpose of reducing these stresses, where possible

Run to Failure Strategies:

Many of the assets making up the Transmission System may be non-critical in nature, when considering the impact of a failure on the business values of the company. The

preferred strategy for assets, which are determined to be in this category, may be to simply allow them to run to failure and repair, refurbish or replace with new equipment, after failure. However, even a reactive strategy of this nature may require methods and tools to forecast the number of in service failures which will be expected, if large proportions of asset reach end of life within a short time period.

The industry would benefit from having in place, accepted evaluation methods to enable assessing the value of such options relative to a reactive strategy or a proactive replacement strategy.

7.5 Development of an Optimized Business Plan

Many utilities today utilize some form of investment optimization process and model to ensure that the most beneficial projects go forward, under the financial (Capital and O&M) constraints of the business. This optimization process and model should be designed to account for system age / wear-out related issues, including consideration of the following factors:

- Identifying and capturing efficiency gains associated with consolidating work for different asset groups at the same time. This effort minimizes outage impacts on customers as well as reducing overall costs.
- Identifying and implementing efficiency gains associated with coordinating sustaining based work and capital expansions for system growth.
- Exploiting synergies between replacement options and the need to upgrade network components for other reasons e.g. use the opportunity to increase plant capacity to meet future load growth or capture other system benefits, such as increased system security and / or reduced losses.

7.6 Information Requirements

Information that is critical for managing an ageing system includes asset demographics, hazard rate functions, historical repair / refurbish / replacement costs, performance statistics and utilization rates. Typical practice in many utilities for estimating the number of expected failures, in a given planning period, is to assume that what happened in the past will continue to happen in the future. This assumption is valid only if the population of assets being considered is in the useful life region of the well-known “bathtub” curve. The bathtub curve (hazard rate function) can be derived for any of the conventional probability distributions (Normal, Weibull, Exponential, Gamma, etc.) from their density and cumulative distributions. The hazard rate function quantifies the probability that a device, will survive up to a specified interval, and then fail in specifically that interval. As illustrated previously, projection of the expected numbers of failures for a population is obtained by multiplying the demographic distribution column by column with the value of the hazard rate function for each specific service year. As a

result, if improved estimates of the numbers of prospective failures are needed for populations near or overlapping the back end of the bathtub curve, an appropriate hazard rate function is needed. There are several ways that such functions can be obtained, including industry data, specific utility data and by derivation. For example CIGRE Brochure 176 [15] provides estimates of the mean life estimate and standard deviation around the mean. These data can be converted into the corresponding hazard rate function as illustrated by the hazard rate function for circuit breakers shown in Figure 7.2. In addition, CIGRE working groups in the past have produced graphical data on failure rates for generator unit transformers (GSU's) and network transformers (Figure 6.3).

As is well known, operating temperatures and therefore loading significantly influence transformer life. Therefore, it is to be expected that the hazard rate function for transformers be strongly influenced by the loading history (i.e.; generator unit transformers are loaded much more heavily and for longer periods of time than Network transformers, which typically have redundancy). For transformers, the basis for this dependency is well documented and included in IEEE and IEC standards for loading; however until recently quantitative methods to relate loading histories with the corresponding hazard rate function have not been available. Based on extensive materials research on oil/paper insulation aging [16], it is now possible to develop hazard rate functions for specific loading histories and for specific insulation condition parameters [7]. Although such methods have been developed for transformers, it is important that fundamental materials information be developed relating aging with stress levels be developed for other types of assets, namely for cables and switchgear.

There is considerable complexity in collecting and analyzing outage data for operating equipment [17]. Frequently on preliminary analysis, a clear trend of the failure behaviour is not recognizable, i.e. the failures may be randomly distributed up to service lives of 30 years. Due to the fact that various types of maintenance activities are routinely applied during operations time, it makes sense to evaluate the failure frequency depending on a parameter called the "event-free time" of a circuit breaker. The defined events may be failures, tests, services, maintenance measures or commissioning; therefore an event-free time interval is one in which there were no failures or any other maintenance and life-extension actions. Figure 7.2 shows the result obtained for the failure frequency of hydraulic drives of SF₆ circuit breakers. On the right side of the figure the three classic portions of the bathtub curve are illustrated, namely initial teething, random ageing, and finally wear out. These different regression curves are derived from the overall curve as plotted on the left side.

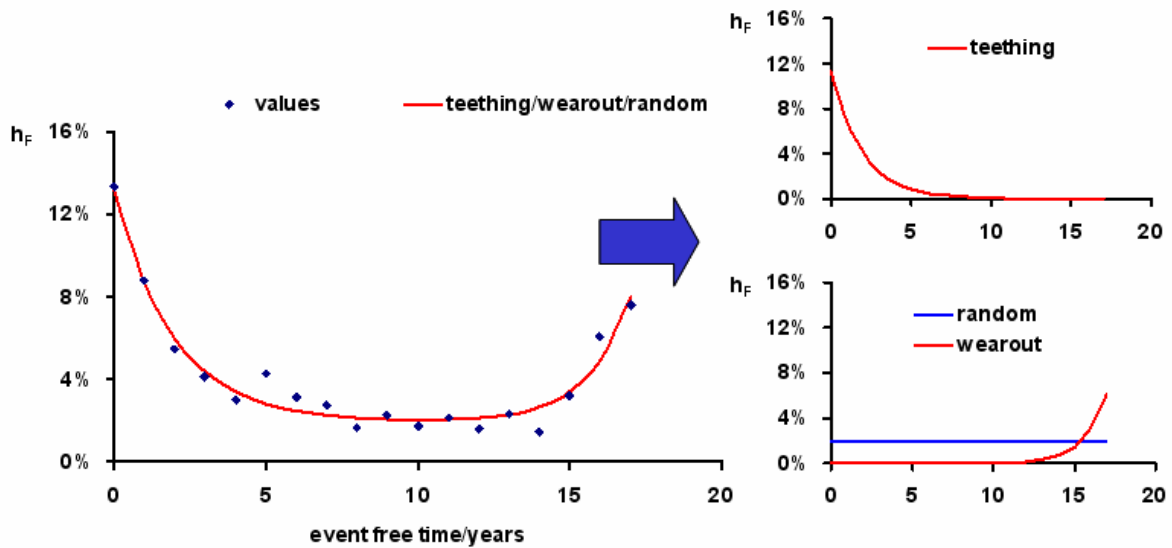


Figure 7.2 Hazard rate function for Hydraulic drives of SF₆ circuit breakers [17]

These data imply from the obvious teething portion of the curve that the probability of failure is higher for the shorter event-free times associated with maintenance activities, while if untouched failure probabilities increase only after intervals of up to 12 to 15 years. These results would appear to support the well known “if it ain’t broke, don’t fix it philosophy”

These results illustrate that it is possible for utilities that keep good records to develop hazard rate functions based on their own failure data. This requires that equipment failures be documented in terms of specific equipment type, operating environment and loadings, cause of failure, service age at failure and so on. The accuracy of the resulting hazard rate functions depends on how well such data can be sorted into common groupings and on how much data is available. There is an opportunity for utilities to benefit in terms of improved accuracy in projection through sharing and integrating common groupings of data. CIGRE “A” and “B” study committees are appropriately constituted to take a lead role in organizing such a common industry database.

7.7 Run, Repair, Refurbish, Replace Decisions

The asset management decision process can be divided in several parts:

- Allocation of a total budget for capital investment and operating costs on the basis of proscribed financial limits
- Consideration of an overall strategy for a system or fleet of equipment due to the requirements of the different stakeholders.

- Calculation of the total budget for the fleet regarding the actual or replacement value of equipment
- Determination of the total budget needed to sustain maintenance departments.

The next step of the asset management process is determination of the total asset budget and the decision making process to determine which components of the fleet of equipment that should be maintained, refurbished or replaced respectively. The maintenance activity, which fits best to the type of equipment, is the basis for the selection.

Figure 7.3 below illustrates some of the considerations, which contribute to effective asset management decisions.

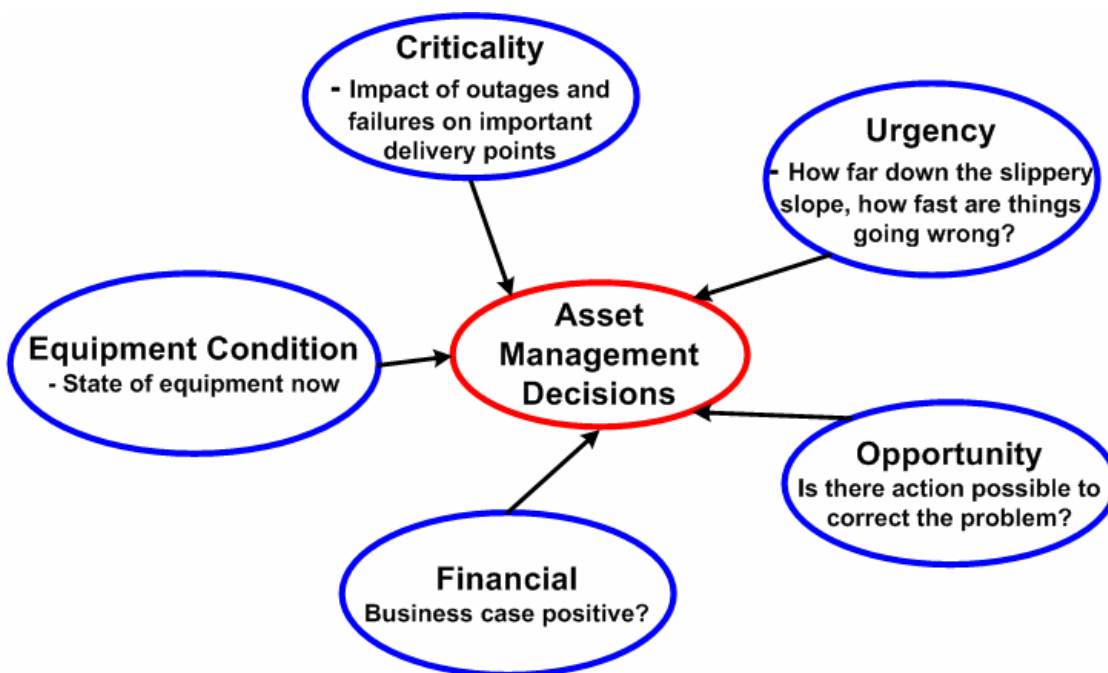


Figure 7.3 *Issues influencing asset management decisions*

Accurate knowledge of asset condition is a fundamental requirement for effective decision-making. This knowledge is obtained through acquisition of diagnostic data, supported by expert interpretation of the data to infer knowledge of asset condition. Knowledge of condition for each asset also allows assets to be ranked by condition.

Related to asset condition, it is important for asset managers to understand how fast the asset condition may be deteriorating. For example, diagnostic information early in life typically reveals routine deterioration, which will proceed at a normally slow rate. On the other hand, later in an asset's life, ageing processes may be detected that if allowed to continue will lead to failure in a short time. Asset managers need to recognize the urgency associated with such ageing mechanisms in order that timely remedial action is considered.

The importance to the system and to delivery point performance of an asset is also an important factor in prioritizing asset maintenance plans. Clearly performance measures and customer outage prevention are high priorities for all utilities; however system design allows for equipment outages, so assessment of asset importance or criticality needs to take these aspects in consideration.

Asset management decisions are also influenced by the opportunity or feasibility of potential corrective actions. In other words, given that an asset has been determined to have a problem, are there remedial actions that are technically feasible and likely to be successful in both the short and longer terms. But aspects like capacity, functionality, environmental issues, and stresses must be taken into account as well. As stated in [15], a timely implementation of a strategy to replace assets, preferably in combination with network re-design options, is a key to success for Asset Management.

Lastly all asset management decisions need to meet company practices for financial analysis and justification for spending.

For example, one element of an overall asset management strategy is the maintenance strategy. Common maintenance strategies include:

- corrective or remedial maintenance
- time based maintenance
- condition based maintenance
- reliability centered maintenance
- duty-based maintenance
- risk-based maintenance

Although as discussed above, there are numerous factors influencing asset management decisions, one common way to classify asset management strategies is to distinguish whether the condition of the component is considered on the one side and whether the importance of the component is considered on the other side. Figure 16 gives an overview of this classification. Both the condition and the importance of components can be defined in many ways, depending on the desired level of detail and the availability of appropriate data. For example, the definition of importance may be oriented at quite simple aspects like e.g. the number of feeders of a substation, or at more sophisticated indices such as, the share of the energy not supplied in time caused by failure of each respective component.

The most simple maintenance strategy according to this classification is the so-called Corrective Maintenance. In fact, there is no maintenance at all in this strategy – the component is operated until it fails. After failure, the component condition is assessed and a decision is reached as to whether the component can be repaired or whether it must be replaced. For transmission systems, this strategy generally does not result in the lowest total cost, as the damage caused by failures of components may create more cost in the end than a more proactive maintenance strategy. Of course, this strategy also may

significantly reduce supply reliability, which may cause additional economic consequences for the network operator. This strategy may be suitable if the specific equipment is non-critical and consequences of the failure are not serious. In distribution networks this strategy is widely used for MV-XLPE cables and many other components where the numbers of components are excessively large, or where no preventive maintenance measures are available and/or where inherent failure rates are very low or overruled by others, like third party damage.

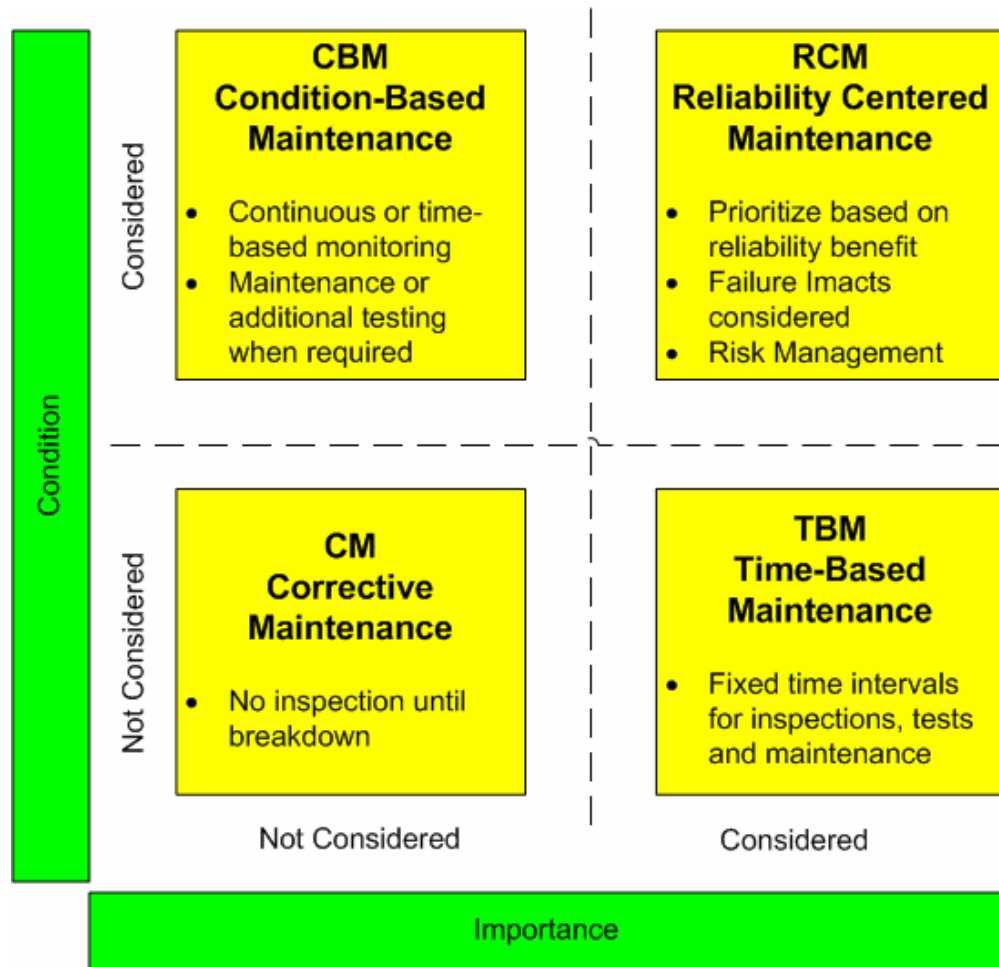


Figure 7.4 A Classification of Asset Management Strategies

In transmission systems, preventive maintenance is typically required in order to prevent failures and the significant damage or even destruction of equipment that may result from failures. The traditional approach, and the strategy still widely used today, is the so-called Time Based Maintenance strategy in which, fixed time intervals for inspections and for certain routine maintenance work are established. These time intervals are either suggested by the manufacturers of the equipment or they are based on the experience of the network operator. However, experience has shown that the time intervals chosen in

the past were typically too far on the safe side, as many such inspections reveal no problems at all. So, maintenance time intervals obviously could be extended – the question is by how much? At what point will the occurrence of failures increase significantly because emerging problems or deterioration was not detected. This method is often appropriate for those instances where an abrasive, erosive or corrosive wear out takes place and/or material properties change due to fatigue etc., and where the wear-out mechanisms as a function of stress including their rates, are quantitatively understood. This strategy was widely used in maintenance of HV- and MV-grids in the past. Depending on the length of the intervals it combines an acceptable availability with comparatively high maintenance costs.

In order to be able to determine the condition of the equipment, additional information on the current condition of the component is required. This current condition is described by certain indices, and in the concept of Condition Based Maintenance, maintenance activity is triggered by the estimated condition reaching certain thresholds. Of course, the determination of the component condition is not trivial; Asset Health Indices as described previously and diagnostic methods described in the following sections are used to determine asset condition. Condition based maintenance leads to high availability with moderate maintenance costs and is mainly in use within EHV and HV-grids [15]. Recently, many utilities are adopting this approach also for the medium voltage level.

In practice, the limitation of both financial and logistical resources requires the additional definition of priorities. And especially in competitive markets, the effectiveness of any activity is monitored with special interest. These aspects relate to the importance of the network components to the system and to delivery point reliability. Of course, the importance should be defined as objectively as possible. Supply reliability in distribution systems is a key technical characteristic and it can be calculated and quantified by a set of well-defined indices [18]. In EHV grids, focus in importance evaluation is on system integrity, scheduling of power stations and the prevention of bottlenecks in transmission capacity. Therefore Reliability Centered Maintenance (RCM) does not only consider the condition of the system components, but also takes into account the impact on the performance of the system [17]. Note that RCM here is used in a broader sense than strictly in accordance with the formal definition as initially implemented in the aircraft industry (FAA) and as described recently in SAE-Standard JA1011(1999).

RCM not only evaluates priorities for maintenance actions; but is also a powerful tool for the ranking of replacement and refurbishment activities, because bad equipment conditions lead immediately to the question whether it is more economical to do further maintenance or to replace the equipment. This analysis can be done for single components as well as for complete substations in transmission grids where a combination of the conditions of the different parts (concrete and steel, primary and secondary equipment) is taken into consideration. If the economical consequences (penalties, kWh not supplied, change of generator merit order) resulting from different actions or lack of action are taken also into consideration, the RCM approach is extended to what is termed Risk-Based Maintenance.

Figures 7.5 and 7.6 show an example of the utilization of the reliability centered maintenance. The basic procedure [18, 19] is to assess the components regarding their

condition and importance for the system, which leads to a two-axis system with a linked distribution of conditions and importance as shown in Figure 7.5 (110 kV circuit-breakers). This means, the condition index of the item of equipment is marked on the ordinate and the importance index for the same item on the abscissa. The *c* and *i* axes are scaled in such a way that the *c* and *i* values can at maximum assume the value 100. The distances between the crosses and the additional line define in which order the equipment has to be maintained or replaced depending on the condition. For example a prioritization in different classes is possible according to Figure 7.6. Typically financial constraints will limit the number of components that can be maintained. The sequence listed in Figure 7.6 starting from the left side indicates the priority for investment based on both importance and component condition.

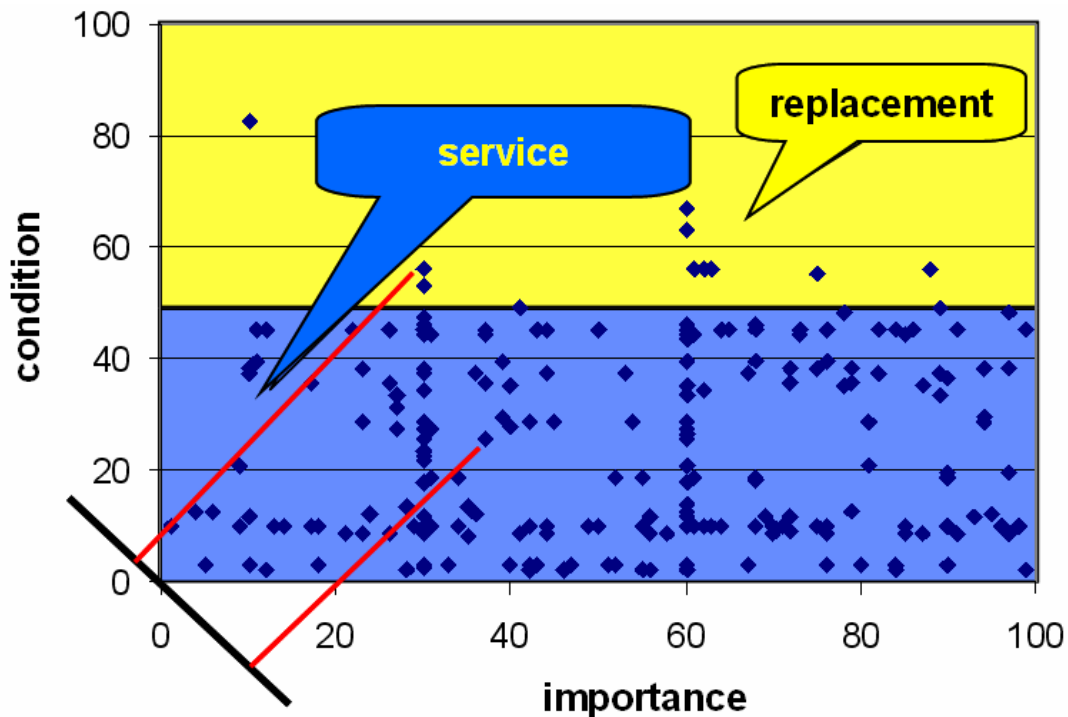


Figure 7.5 Condition and importance assessment of 110 kV circuit-breakers [18]

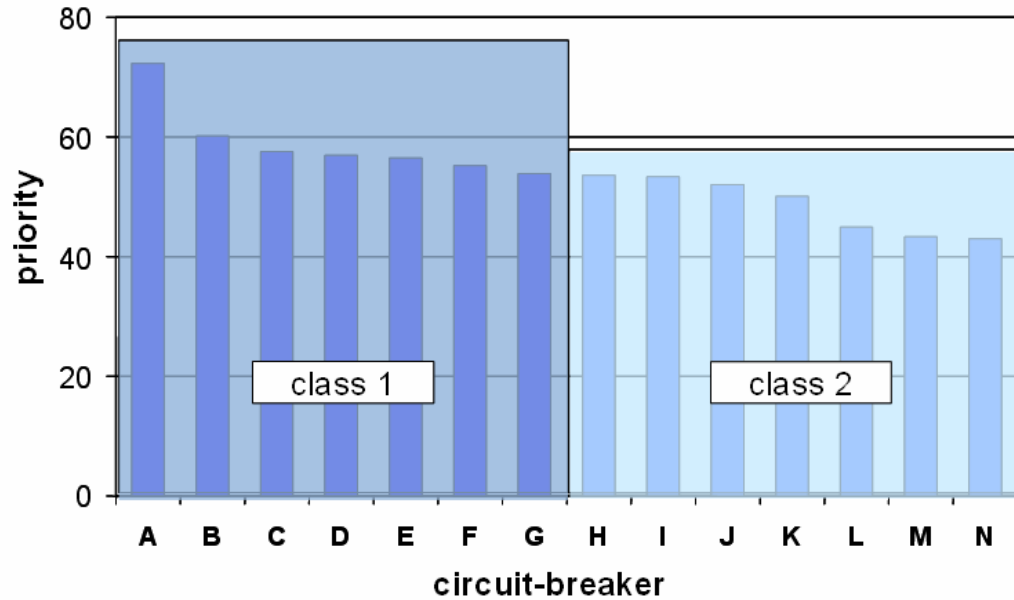


Figure 7.6 Prioritisation of the service activities of 110 kV circuit-breakers [18]

Problem	Benefit
Under Funding	<ul style="list-style-type: none"> Identifies where cutbacks may be prudent Identifies consequences of reduced maintenance Links maintenance requirements with utility goals and objectives
Reduced Reliability	<ul style="list-style-type: none"> Identifies appropriate tasks for preventing loss of function and risk of failure Establishes realistic reliability goals Suggests design changes to improve reliability
Inefficient use of Data	<ul style="list-style-type: none"> Identifies what data is needed for maintenance and how it is to be used in a continuous improvement process Reveals how data can be used on a predictive basis
Lack of Executive Support	<ul style="list-style-type: none"> Tightly links maintenance activities to executive goals Measures continuous progress Identifies risks associated with program changes Re-assures regulatory bodies that maintenance is being effectively managed.
Regulatory Oversight	<ul style="list-style-type: none"> Ensures regulatory requirements are followed Charts progress Provides a documented basis for current approach.

Table 7.2 Benefits of Performance Focused Maintenance

In recognition that reliability is only one measure of performance that is important for utilities, reliability centered maintenance be broadened into “performance focused maintenance” (PFM) [20]. At the highest level, PFM is a methodology to answer the question: Are my maintenance resources being used in the most effective and efficient way to achieve the desired performance goals of my utility? Dissatisfaction with its existing maintenance program is not a necessity to apply some or all of the PFM concepts; in fact, it is generally true that existing maintenance programs are servicing the utility well. It is also expected that the some of the PFM elements are currently incorporated in the utility’s maintenance strategy but that there is room for improvement. PFM provides a structured but flexible approach to improving overall maintenance effectiveness that can adapt to an individual utility needs and resources. PFM directs review and analysis only at the areas targeted for improvement. Potential benefits of PFM are listed in Table 7.2.

PFM is designed to:

- Provide a framework to effectively and appropriately evaluate new maintenance concepts
- Incorporate risk-analysis
- Identify approaches for managing and prioritizing maintenance of specific assets and an overall approach to optimize asset and task performance.
- Allow utilities to build their own individual maintenance strategies with assurance that the methodology will result in the best fit for their own specific corporate and customer service objectives
- Leverage currently available data and information resources for use in algorithms to predict asset deterioration and numbers of future failures.
- Embrace business goals and customer service objectives by employing maintenance approaches that are both technical and economically effective
- Support dynamic prioritization
- Set realistic maintenance goals
- Identify models that take greater advantage of data and underutilized native intelligence to trigger maintenance and replacement decisions

In its simplest form, the PFM can be broken into seven major sequential processes. These processes are:

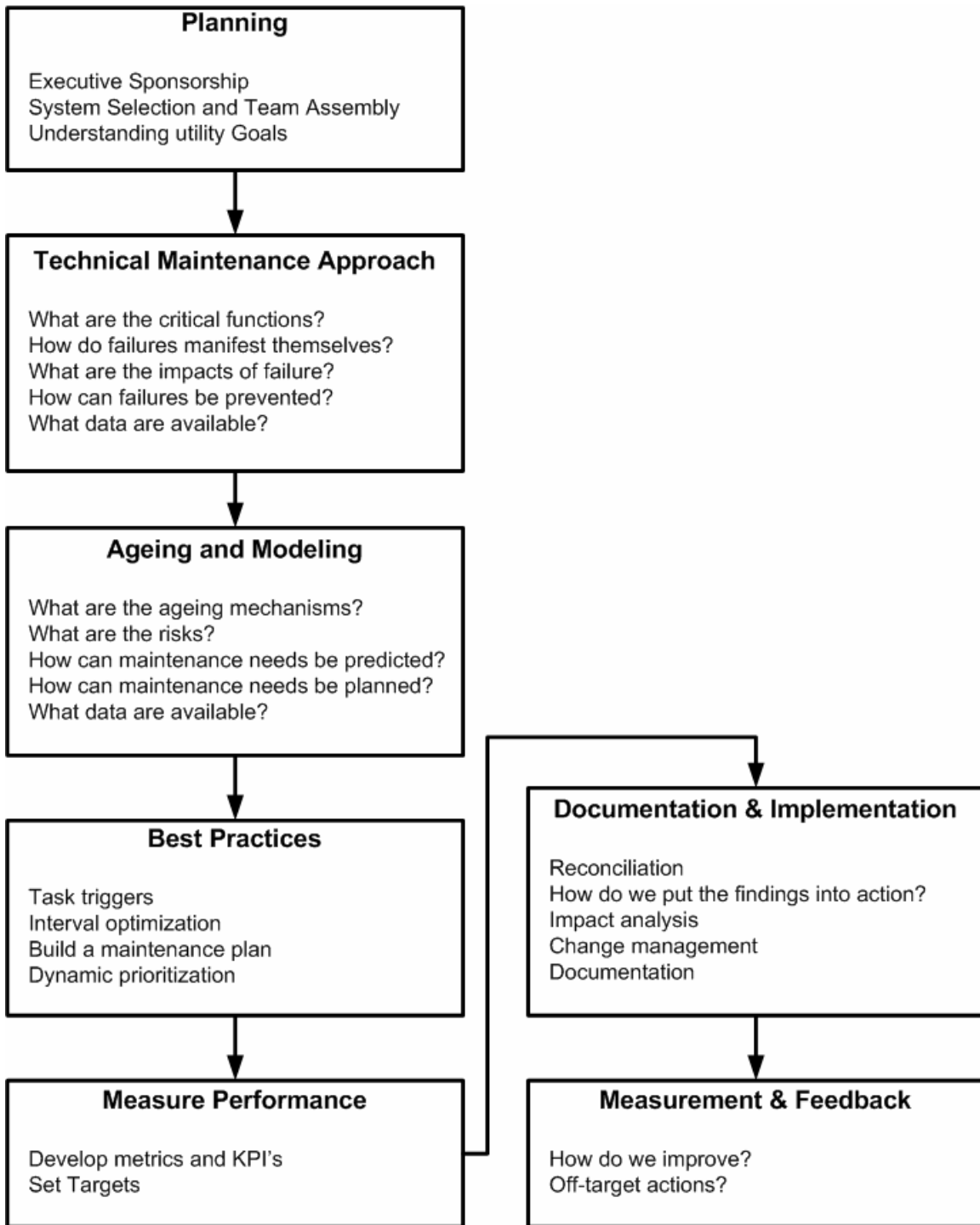


Figure 7.7 Performance Focused Maintenance Processes

Figure 7.8, shows a 9-field matrix in which the classification of risk depends qualitatively on the relation between “consequences” and “probabilities of occurrence”. The latter is roughly distracted from the susceptibility for failures of a circuit, asset or a subsystem. The consequence axis aims to take the different stakeholder categories into account. The approach forms the basis for a number of (commercially available) tools commonly used by some utilities. For reasons of understanding and learning this section describes the basic approach including an example. Once understood an internally developed, spreadsheet based, software support tool will provide most engineers and analysts with good service. Of course one can make a more detailed matrix (16, 25 or even 36 fields) in order to further detail the decisions to be made.

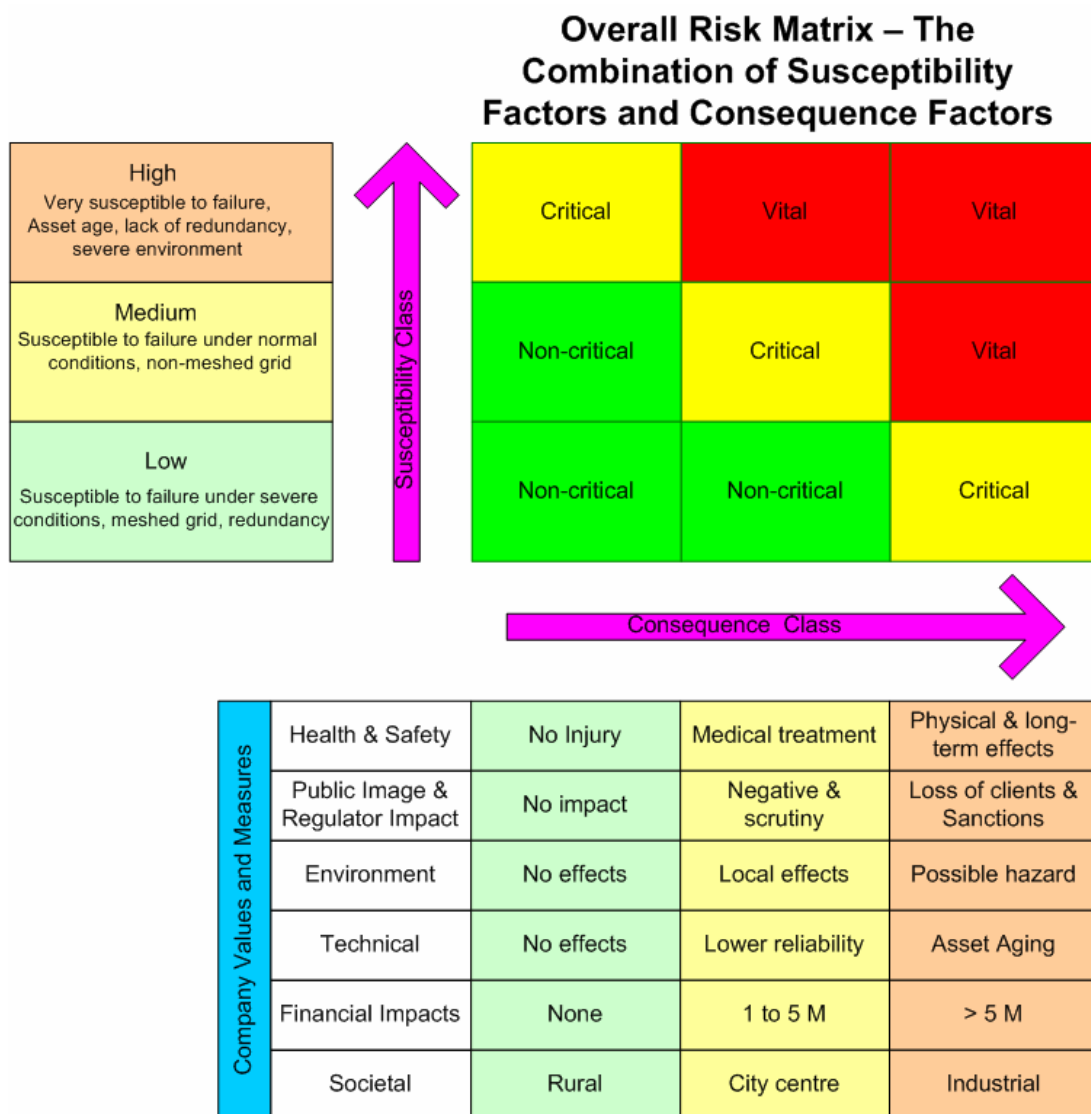


Figure 7.8 A qualitative PFM framework

7.8 *Diagnostics and Monitoring*

Interest in diagnostics and monitoring technologies continues at a high level. However these technologies are logically being applied carefully and typically only when tangible cost savings can recover the cost. Diagnostics and monitoring has traditionally been applied to gather information for several possible reasons, including: 1) to monitor the loading or stresses on equipment in order to manage life expenditure and to ensure that equipment ratings are not exceeded, or 2) to monitor for symptoms of ageing or deterioration for the purpose of warning of impending failure in the short term or to provide data to support condition assessment and information useful for the guidance of condition-based maintenance activities or for support of asset management repair/replace decisions, or 3) to detect and locate failures and defects. However, diagnostics and monitoring technologies are only useful to the extent that they actually influence operational or asset management decisions. Concerns about the interpretation of data provided by such systems, the long-term reliability of monitoring systems, the timeliness with which the information can be provided for decision makers compared with the time to failure, and lastly the volume of data needing analysis have dampened the application of diagnostic monitoring systems.

Diagnostics and monitoring technologies are available for a wide range of applications including overhead and underground line thermal monitoring, transformer thermal monitoring gas in oil monitoring, moisture monitoring, circuit breaker monitors of various types instrument transformer failure anticipation monitors and so on. There is no consistent approach or application standard for any of these monitoring or diagnostic systems. Methods for assessing the benefits of diagnostics and monitoring technologies typically follow the approach illustrated in Figure 7.9 below for transformer monitoring.

In this figure the probabilities for each branch at each decision diamond are estimated so that the overall probability of avoiding failures and therefore achieving benefits can be calculated. Life Cycle Costing or similar analyses are required by users to assist in making the decisions as to whether particular systems or technologies can deliver cost benefits, whether they are in capital cost reductions, reduced maintenance, fewer replacements, higher availability or manpower reductions.

A recent CIGRE brochure [21] reaches the following conclusions with respect to diagnostic and monitoring technologies for switching equipment:

As with all good things, there need to be some words of caution. A particular concern in the area of monitoring is the need to provide the user with information that can be used to provide benefit. The generation of vast quantities of data by monitoring systems which cannot be easily assimilated or requires teams of engineers to interpret will be of little benefit to the user. It is therefore essential that monitoring systems contain sufficient "intelligence" to provide simple, unambiguous diagnoses for the user. Fortunately the rapid developments that are occurring in the field of computer science are providing techniques and hardware that can handle the outputs from the multitude of sensors that are available and will be continually developed in the future.

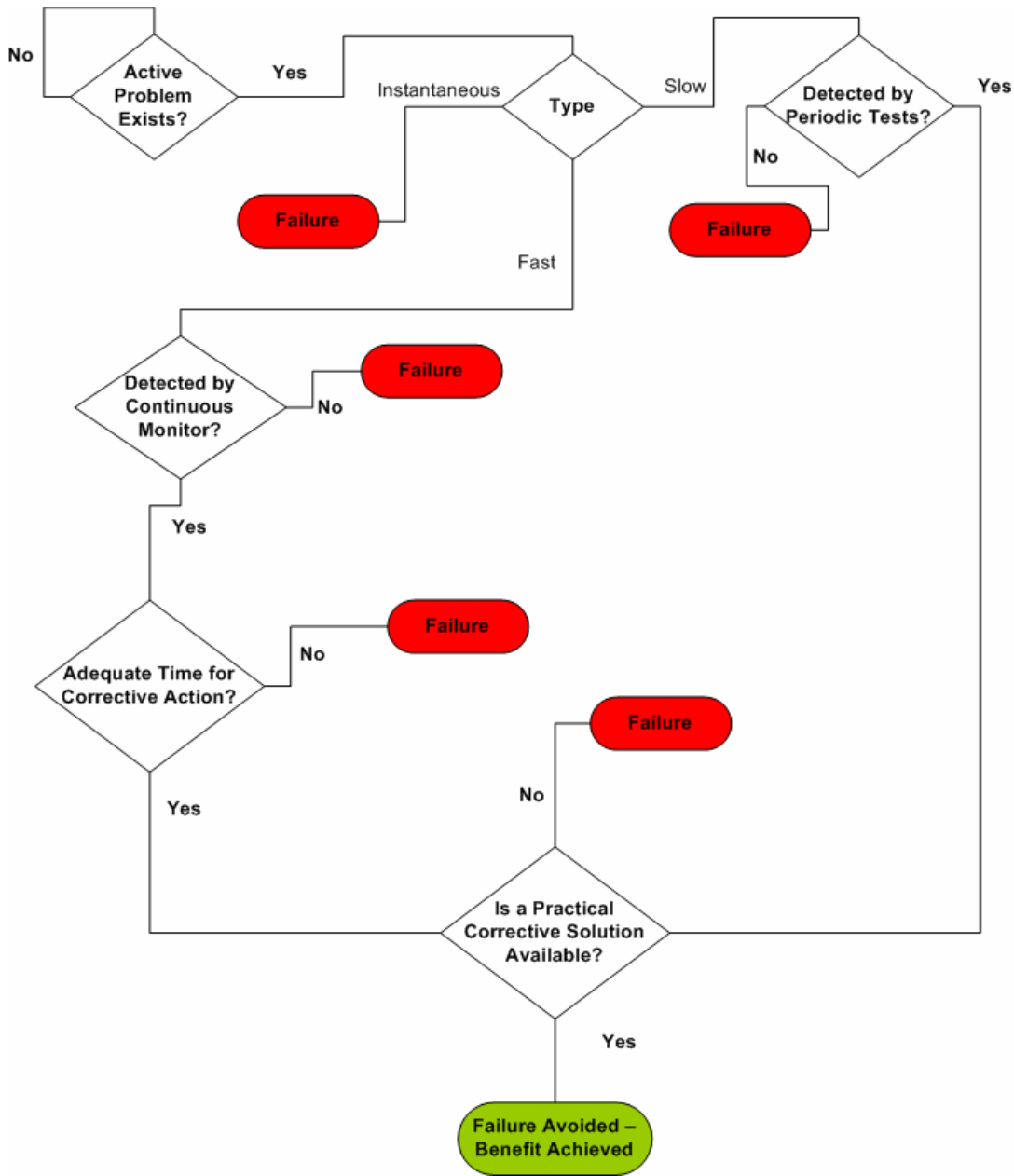


Figure 7.9 Logic diagram to assess probability of payback for monitoring systems.

Some specific conclusions:

- There is now clear evidence that the application of diagnostic techniques and condition monitoring can bring benefits to users and suppliers of switching equipment. These benefits can generally be given some financial value.
- The application of diagnostics and condition monitoring will become more commonplace and easier to justify in the future

- There is a trend towards the use of continuous on-line condition monitoring to supplement off-line or periodic monitoring
- Users require simple information in a timely manner rather than large quantities of data that require analysis. Monitoring systems that incorporate expert systems to provide such information will be of greater benefit to users. There is however still considerable work to be done in this area with very few monitoring systems having the ability to provide users information on such aspects as when and what to maintain.
- A variety of sensors, Intelligent Electronic Devices (IED's) and monitoring systems already exist in substations. Unfortunately, at present, there is little standardization on the communication of data. Work which is currently ongoing in this area will allow significant benefits to be achieved and all users are encouraged to be aware of the opportunities for integration of sensors, monitoring, control and protection systems.
- It is not possible to provide a single approach that will cover the justification of the implementation of condition monitoring to switching equipment.
- The application of diagnostic techniques and condition monitoring can provide:
 - Improved equipment availability
 - Reduced failure rates
 - Improved operator and system safety
 - Lower life cycle costs
 - Opportunities for life extension
 - More informed decisions on end of life
 - Improved maintenance effectiveness
 - Improved equipment performance
- From a utility point of view, in some cases it is much more important to monitor old, unreliable equipment than the new equipment. Unfortunately this task is not easy to accomplish, because application of appropriate sensors is linked with an intrusion into the existing construction. The task sometimes can be impossible without the consultation and help of the manufacturer. Very often the production of particular designs of equipment is discontinued, in which case, the only possible approach is to monitor some selected parameters by means of separate monitoring devices.
- An essential matter in the context of diagnostic testing and monitoring is the interpretation of the measurements. In some cases it is straightforward to convert measurements into useful information about the condition of the equipment, in other cases it is not. Hence, the significance of the measurements needs to be thought carefully about before data is collected. Criteria determining whether equipment is "healthy" or not must exist. A major challenge is to establish criteria that are generally valid. Quite often, a correct evaluation of measurements requires detailed knowledge and experience with the type of switching equipment under consideration. For example, a deviation in operating time of 2 – 3 ms from one year to the next may be within the normal variations for some circuit breakers, while for others this is a reliable early warning of problems with the operating mechanism.

- Suppliers of sensors and monitoring equipment should be responsible for ensuring the continued availability of spare parts or interchangeable units for a period of at least ten years from the date of final manufacture of the monitoring equipment. This includes also the tools that are necessary for maintenance and commissioning of these spare parts.
- Condition monitoring and diagnostic techniques should allow not only a better understanding about the real current state of an apparatus, but also provide trending of apparatus condition over time and in various situations (temperature, load, fault current to interrupt, etc.) and as well provide a common basis for comparisons to be made between similar apparatus exposed to similar conditions. This knowledge of growing importance as equipment tends to be used at the limit of its capacity and as end-of-life determination becomes a more critical requirement.

8. Conclusions and Recommendations

8.1 Conclusions

- Asset Management involves the central key decision making for the network business to maximize long term profits, whilst delivering high service levels to customers, with acceptable and manageable risks.
- Asset Management provides for the economic assessment of tradeoffs between alternative actions and investment strategies from the network- or system-level perspective. At the same time, it allows for the more complete comparative analysis of options for individual projects.
- The development and approval of Business Values, Key Performance Indicators and Risk Tolerances provides the high level framework for effective decision-making within the Asset Management function.
- Generic Asset Management approaches and analysis methodologies have to be in place, but a key challenge is making the best use of limited data available, especially when assigning some level of predictability to the uncertainties at hand.
- 90% of surveyed organisations have separated their Asset management function from the Service Provider function, while about 50% have separated the Asset Owner function from the Asset Manager function.
- The delicate relation between Asset Manager and Service Provider is described and special attention is given to establishing a productive culture and to skill retention and development.
- Outsourcing has been studied by an enquiry among the members of WG C1.1 and the responses show that all companies perform the core Asset Management activities themselves. All do grid operation, customer service, project management, procurement themselves. Most utilities perform the core maintenance internally, often assisted by external forces, but construction work and non-core maintenance is largely outsourced (to external Service Providers).
- The key performance functions of the assets can be derived from the publications, such as CIGRE Technical Brochures, of other Study Committees. These CIGRE studies are also a source of asset information (reliability data, maintenance data, ageing data) and information on Asset Management policies (maintenance outsourcing, information strategies, life management, economic considerations, risk management, dealing with uncertainties, diagnostics, ageing assets). An overview is given, as well as an inventory of the present CIGRE activities related with Asset Management.
- The ageing process and methods how to take decisions on populations of old assets have been discussed. The related collection of data and information to

assess the assets' condition is stressed and optimization through risk management highlighted.

- Ageing is defined as the irreversible deleterious change to the serviceability of the equipment (IEC 60505, 2004). Such changes are characterized by a failure rate, which increases with time (bath-tub curve). The need for sharing failure data among users in order to establish hazard curves is emphasized.
- A timely implementation of a strategy to replace assets, preferably in combination with network redesign options, is a key to success for Asset Management. Ageing still forms an area of interest where a large need for knowledge and information sharing exists and where CIGRE can play an important role.

8.2 Recommendations

- The importance of international surveys on the reliability, availability and maintainability of equipment has been stressed. Information on stresses in service, maintenance management, diagnostics and end-of-life decisions should be shared as well. Like the worldwide survey conducted from 2004 to 2008 by CIGRE SC A3 and B3, other SC's are strongly encouraged to collect similar information. SC C1 could play a stimulating and co-ordinating role.
- Asset Managers are interested in such information on both old and younger equipment, in order to detect ageing patterns, economic developments, to compare the old equipment with modern equipment (as new equipment is not necessarily more attractive than the equipment, that already survived decades). SC C1 could emphasize the need for failure curves over time (hazard rates) for relevant equipment and subsystems.
- Experts, for instance from SC D1, are interested in failure analysis and forensic information to further establish models for the ageing process (the relationship between minor failures/defects and Major Failures) and to improve diagnostic test techniques and monitoring systems.
- Worldwide surveys show a large improvement in the reliability of certain equipment (for instance circuit-breaker technology and protection relays). Asset Managers have to consider the impact of such improvements on the topology of the system or subsystems: no disconnectors, less circuit-breakers, simpler schemes, no circuit-breaker back-up protection, no redundancy in protection systems and so on. But in this respect the new role of spare parts, special knowledge, standardisation of equipment, manufacturer support should be noted as well. Such studies should be triggered by corporate level Asset Managers.
- Further develop risk management and exchange experience will help the Asset Managers. In this respect it must be emphasized that sharing the already published studies (for instance CIGRE Technical Brochures) is very helpful,

but, apart from generic considerations, special interest is with companies' real experience. Benefits, societal responsibilities, risk appetite, acceptance within the company and within the environment, driven by regulators and authorities, acceptance of outcome, applied examples, developed theories, should be a responsibility for a future SC C1 Working Group on Asset Management.

- The exchange of detailed information on financial/economic models has to be facilitated, with, on one hand, questions as what policies with respect to discount rates are used or how the depreciation period fits with the expected life and, on the other hand, how the short term scope of the financial experts has to fit with the long term responsibility of the Asset Managers.

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27. CIGRE WG D1.17, "Fundamental Aspects of Data Quality for HV Asset Condition Assessment", to be published in Électra.

Appendix 1: Key Reference Papers

Paper 1: Bartlett, S. “Asset Management in a De-Regulated Environment”
CIGRE SC 23 Session 2002, Report 23-303

Paper 2: Ault G. et al “Asset Management Investment Decision Processes”
CIGRE Sc C1 Session 2004, Report C1-106

ASSET MANAGEMENT IN A DE-REGULATED ENVIRONMENT

By

S. BARTLETT*

On behalf of CIGRE TF23.18 and Australian Working Group – Asset Management

1. INTRODUCTION

Electricity reform and increased commercial pressures on transmission businesses have created a new interest in Asset Management as a means of concentrating on core functions of the business to maximise profits, whilst delivering high service levels to customers, with acceptable and manageable risks.

Task Force 23.18 was established in September 2000 to investigate the role and needs of Asset Managers of transmission networks, particularly when operating in a deregulated electricity market. The Task Force currently has 27 members drawn from Study Committees 23, 37, 12, 13 & 22, as well as other international experts on Asset Management. Membership is primarily drawn from transmission businesses and includes representation from Europe, North America, South America, Japan, South Africa, Australia and New Zealand.

The terms of reference for the Task Force include:

- Defining the role of Asset Management.
- Identifying core skills for Asset Managers.
- Examining organisational issues.
- Identifying the impacts, drawbacks, and benefits of separating Asset Management functions from engineering and maintenance functions.
- Examining risks from loss of ownership and core skills by Service Providers and proposing strategies to manage these risks.
- Developing guidelines for Asset Managers to undertake their core functions.

The Task Force has conducted a survey of Asset Management practices and experiences to identify the key roles and skills required by Asset Owners, Asset Managers and services providers as well as the organisation arrangements that are being used to separate these functions.

Motivation of people and the retention of core skills have been identified as a key issues to be managed when implementing an Asset Owner / Asset Manager / Service Provider business model. The Task Force has investigated these issues and proposed options for managing these people related risks.

This paper is a progress report by the Task Force and includes a summary of the findings of the survey. The plan for future work by the Task Force is also presented.

2. WHAT IS ASSET MANAGEMENT

Asset Management is an evolving concept in transmission network businesses with a variety of Asset Management models being applied. The definition of Asset Management ranges from a narrow focus on operating and maintaining existing network assets to minimise costs and maximise asset performance, through to a broader definition of managing all aspects of the network business to maximise long term profitability.

The Asset Management of a transmission business operating in an electricity market involves the centralisation of key decision making for the network business in the pursuit of maximising long term profitability and business success.

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It involves developing and implementing an integrated set of strategies and decisions as well as managing the relationships with key internal and external parties. It can be much more than managing maintenance, refurbishment and capital investment to minimise costs and meet performance targets. Asset Management can encompass revenue optimisation, stakeholder management, risk management, and legal compliance to optimise the technical and commercial performance of the network and to meet the expectation of the key stakeholders.

The Asset Manager can set the vision for the network business and manage the activities of the Service Providers that undertake the many activities to plan, build, operate, maintain the network assets and service the business.

3. SURVEY OF ASSET MANAGEMENT PRACTICES

The Task Force has surveyed its member organisations to gather information on:

- Benefits of adopting Asset Owner / Asset Manager / Service Provider business models.
- Roles of Asset Managers, Asset Owners, and Service Providers.
- Organisational arrangements.

This survey covered 16 transmission networks with an average transmission line length of 14,000km, one consultant and two manufacturers. The results, which are, summarised below show the percentage of positive responses from the 16 network owners only.

There was a wide range in responses to the survey, which confirms that Asset Management is still an evolving concept and that the roles and organisational arrangements vary widely. Nevertheless, the survey results are believed to be useful in developing and refining Asset Management models.

Respondees claimed that the adoption of an Asset Management / Service Provider business model had improved their business performance in the following areas:

	(% of respondents)
Operating Costs	81%
AM Decision Making	81%
SP Efficiencies	75%
Capital Expenditure	69%
Stakeholder Management	56%
Customer Focus	44%

The regulatory environment was seen as having a major impact on Asset Management strategies and decisions, with the biggest impacts being:

	(% of respondents)
Investment Decisions	81%
Capital Spending	75%
Refurbishment Decisions	63%
Operational Spending	56%
Maintenance Strategies	56%
Outage Management	38%

3.1. Organisational Structures

Many transmission businesses in a deregulated environment are moving to separate their Asset Ownership, Asset Management and Service Provider functions in the belief that role separation will lead to greater efficiencies.

The Asset Owner may be the government, the board of a corporation or an investor that owns the network assets and is ultimately responsible for the network. The Asset Owner has the ultimate discretion to set the business direction, take key decisions and to delegate more routine management of the business to an Asset Manager.

An Asset Manager is engaged by the Asset Owner and assigned responsibilities for the management of the network assets. The role of the Asset Manager is determined by the Asset Owner and could range from the operation and maintenance of the existing assets through to the entire management of the network business under broad guidelines.

The actual work on the network assets is undertaken by Service Providers who are engaged and controlled by the Asset Manager. Service Providers could be either internal or external to the business and could cover such factors as maintenance, engineering, operations or corporate services.

Some 81% of the network organisations that were surveyed have separated their Asset Management function from their Service Provider function.

The organisational structure that was used for this separation varied, as summarised below, with the most common being separate business units within the one organisation, followed by separate legal entities:

	(% of respondents)
Separate Business Unit	50%
Separate Legal Entity	38%
Separate Group in Overall Structure	25%
Part Of Corporate Function	19%
Separate Level of Management	19%

Some 50% of surveyed organisations have separated their Asset Management function from their Asset Ownership function. The range of mechanisms, which are being used to achieve this are indicated below:

	(% of respondents)
Separate Legal Entity	38%
Part Of Corporate Function	25%
Board of Directors & Chief Executive	19%
Separate Business Unit	16%
Separate Level of Management or Group	12%

3.2. Role of Asset Owner

The following functions were identified as being key components of Asset Ownership for which key skills need to be developed:

	(% of respondents)
Policy and Direction	88%
Funding	81%
Regulatory Management	75%
Budget Review / Approval	69%
Business Development	63%
Community Relations	56%
Legal Compliance	56%
Capital Expenditure Management	50%
Network Planning/Investments	44%
Customer Relations	38%

It would appear that the role of Asset Owner depends on the level of delegation to the Asset Manager, but would normally include business policy and direction, as well as financial issues that underpin the revenue and budgets for the business. In some organisations, there is a tendency to delegate to the Asset Manager the traditional corporate functions of legal compliance, community relations, planning and customer relations.

3.3. Role of Asset Manager

The following functions were identified as the core Asset Management functions of transmission businesses:

	(% of respondents)
Maintenance Strategies	100%
Refurbishment / Replacement Decisions	81%
Risk Management	81%
R & D / New Technology	75%
Maintenance Management	69%
Capital Expenditure Management	69%
Customer Relations	69%
Network Planning	63%
Expenditure Targets	63%
Community Relations	56%
Legal Compliance	50%
Regulatory Management	44%

3.4. Service Provider Functions

The survey of Service Provider functions differentiated between:

- External Service Providers
- Internal Service Providers
- Internal Asset Workers

Internal Asset Workers refers to functions performed internally, but not under a formal Asset Management / Service Provider contract or internal agreement.

The following functions are most commonly provided by External Service Providers:

	(% of respondents)
Project Erection	81%
Test & Commission	69%
Field Maintenance	56%
R & D Work	50%
Engineering Design	44%
Project Management	38%
Procurement	38%

Internal Service Providers provided the following services:

	(% of respondents)
Financial Support	63%
Procurement	50%
Business IT	44%
System Operations	44%
Project Management	44%
Field Maintenance	44%
Engineering Design	38%
Project Management	38%
Maintenance Management	38%

Internal Asset Workers performed the following functions:

	(% of respondents)
Asset Database Management	69%
Network Planning	69%
Fault Analysis & Failure Investigations	63%
System Operations	63%
R & D Investigations	56%
Network Switching	56%
Maintenance Management	50%
Stores Management	56%

4. RISK MANAGEMENT OF ROLE ISSUES

Traditional organisation structures had collective ownership of assets (i.e. between planners, designers, and maintainers) Whilst shared ownership heightened pride and motivation in each sector of the business, there was sometimes a conflict of priorities, for example whether to invest in new assets or refurbish aged assets.

The move to an Asset Manager who is responsible for these decisions across the full life cycle of the assets has reduced this potential for conflict. To be effective, the Asset Manager must possess a broad range of technical, commercial and legal skills. This includes new skills required to meet customers needs in a deregulated electricity market.

A downside of establishing an Asset Manager to take these decisions can be a lessening sense of ownership on the part of the Asset Workers / Service Providers.

The impact on the Asset Workers motivation can be even greater if the Asset Manager is perceived to exert unfair power over the Asset Worker. In some instances, this has created enormous tensions between Asset Managers and Asset Worker / Service Providers and led to inefficiencies or even rejection of the Asset Manager / Service Provider model.

The challenge therefore is to create the two separate roles without reducing the care and attention by the Asset Worker for the equipment, or the competence of the Asset Manager, as this could impact on system reliability. Achieving overall Asset Management objectives requires close teamwork between the two functions. There are two challenges here:

- Setting the level of skill retention and its ongoing development.
- Establishing a culture where the roles of Asset Manager and Service Provider work productively together and avoid unnecessary conflict.

4.1. Skill Retention and Development

The type of skills and knowledge to be retained by Asset Managers or Asset Workers is a fundamental decision for each organisation. It will depend on their views of the strategic importance of retaining certain skills or knowledge and the economics of retaining some non-core skills within each organisation.

Organisations using outsourcing of both intellectual and labour resources claim a number of benefits. However issues such as the loss of basic technical knowledge or understanding of the condition of their assets and the impact of outsourcing on the skill retention and development of the internal and outsourced workforce are amongst other factors which must be considered.

These issues must be considered when setting up outsourcing models to avoid costly outcomes at a later stage. Organisations proceeding on this path firstly need to identify the mainstream functions for which a distinct knowledge or skill base is an essential component and whether it is a core function or not. Once the extent of these functions in the organisation is identified, the relevant skills and the level of retention can be assessed.

Prior to assessing whether a skill or knowledge base is to be retained or outsourced, it is important to have a process to clearly understand who is currently providing the key knowledge. The capacity of the provider to continue to provide the skill over the longer term should be assessed and be able to be monitored.

4.2. Factors in Deciding Level of Skill Retention

The following factors determine the level or degree to which specific skills or knowledge should be outsourced and also when these processes should be implemented.

- Cost difference if skill is outsourced;
- Importance and availability of emergency response;
- Completeness of maintenance standards;
- Ease or difficulty in specifying and assuring quality performance;
- Uniqueness of the skill or knowledge;
- Need for internal Asset Workers to grow their own business using this skill;
- Organisational need to exploit new technology;
- Need for delegated responsibility in the Asset Worker;
- Level of condition monitoring information available to the Asset Manager;
- Commonality of strategic directions between Asset Manager and worker;
- Age of the asset base;
- Status and capability of industry training organisations and processes;
- Retention of sufficient expertise so that the Asset Manager can be a knowledgeable buyer of outsourced Service Provider skills;
- Availability of skills with suppliers and consultants.

Another input to this process is to consider the relevance of different business drivers of internal and external Service Providers and their synergy with the organisations for different activities.

4.3. Skill Retention Under Different Organisational Relationships

There are a number of possible organisational relationships that will achieve the required level of skill retention. Also, if high performers are suitably positioned in the relationship they can make less than optimum organisational relationships still function well. The aim however should be to have organisational relationships that facilitates skill retention and development, independent of personalities. To this end it is important to recognise the relevant strengths and weaknesses in the different organisational models.

One way to facilitate this is to have very clearly defined areas of responsibilities. It might not matter who has the individual responsibility, provided the associated activity can fit in with the training and skills of the assigned group.

4.4. Establishing A Productive Culture

A preferred path is to create a culture where both the Asset Manager and the Asset Worker understand their respective roles, take pride and are motivated by their responsibilities. Hence, emphasis is required on increasing teamwork and co-operation between these respective groups by increasing their level of understanding of each other's roles and the importance of each role. If this teamwork can be achieved priorities should be aligned.

Possible ways to enhance teamwork include:

- Developing maintenance policies and standards through a process led by the Asset Manager with representatives from both groups. This process draws on the collective experience from both groups within the organisation and ensures collective ownership of the policies.
- Involvement by the Asset Worker in expenditure decisions made by the Asset Manager. This ensures that first hand knowledge of the assets and any system operating problems are taken into consideration in any decision. The priority of projects can also be jointly agreed. The long-term goals of the Asset Manager and the immediate security concerns of the Asset Worker can be addressed through such joint decision making processes.
- Delegating to the Asset Worker full responsibility for expenditure decisions for routine maintenance work in accordance with the Asset Manager's:
 - Maintenance policies and standards.
 - Long-term strategies for the transmission assets.
 - Strategies specific to particular plant items.
 - Any other guidelines issued by the Asset Manager.
- Application of common performance measures for any group where their input has an impact on an asset. An integrated process of asset operation would allow teams and individuals to identify where their contribution makes an impact. This would ensure that all participants are seen as important contributors and that their input can be identified.

4.5. Another Cultural Strategy

Another strategy is that of Alliances or Partnering with an external Service Provider, who may for example be an equipment manufacturer or engineering company. This is useful in the application of new technology and in the more effective utilisation of existing technology. A new design of equipment offering a step reduction in operational costs can be introduced by a co-operative effort early in the production process with both parties sharing any inherent risk that may be associated with its early performance. With existing technology a Service Provider / Manufacturer may be in an advantageous position to provide advice in relation to his equipment on:

- What is the minimum maintenance to sustain life.
- What maintenance practices will allow design life to be achieved comfortably.
- What operation and maintenance strategies will prolong service life beyond design life.

Alliances / partnering, correctly applied, have broad potential for cost savings in relation to specification, tendering, marketing and contract management. For a win / win outcome it is essential for the alliance partner to share responsibilities and rewards for performance based outcomes.

4.6. Maintaining Capabilities Over the Long Term

Industry restructuring can give rise to a number of risks associated with loss of expertise. However, these risks may take a long time to materialise, especially if an industry is particularly well supplied with skills at the commencement of the restructuring process. Once lost, these skills may be very difficult to rebuild.

It is important that an appropriate long-term perspective on skill retention is maintained. Industry training organisations and processes should be fostered to ensure the long-term provision of adequate specialist skilled resources to meet industry needs.

5. FUTURE WORK

The future work of Task Force 23.18 includes the development of guidelines for Asset Managers on such topics as:

- Effects of institutional change on Asset Management.
- Managing networks to minimise their adverse impacts on electricity markets by increasing maximum network capabilities, co-ordinating outages and maximising network availability.
- Life extension of transmission assets, replacement / refurbishment decisions of aged plant.
- Managing risks to transmission plant and minimising potential liabilities.
- Strategic importance of new technology and innovation.
- Managing the interface with engineering, construction and maintenance Service Providers.

It is planned to undertake this work during 2003 and to prepare a CIGRE brochure for the publication of the guidelines in 2003/04.

RELATED CIGRE PUBLICATIONS

1. JWG23/39-14, London SC23 coll., June 1998, An International Survey of Maintenance Policies and Trends
2. JWG23/39-14, Paris SC23 August 2000, Outsourcing of Maintenance in View of Market Liberalisation
3. Ph. Wester, Cigre SC23 coll., October 2001, Maintenance Outsourcing Processes in electricity utilities,
4. JWG23/39-14, April 2002, Maintenance Outsourcing Guidelines, Brochure

ASSET MANAGEMENT INVESTMENT DECISION PROCESSES

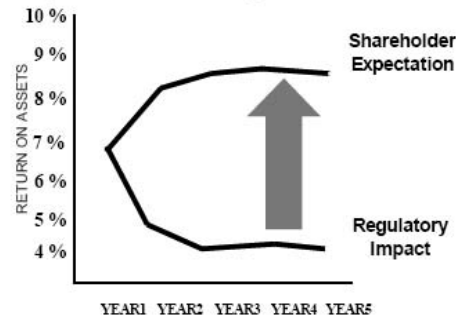
Graham W. Ault, University of Strathclyde, SCOTLAND,
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Joe P. Toneguzzo, HydroOne, CANADA
Ian Welch, National Grid, UNITED KINGDOM

On behalf of CIGRE Work Group C1-1
Asset Management of Transmission and Distribution Systems

1 Business Environment

The global impact of competition and deregulation of traditional Utility companies has motivated fundamental thinking about their primary role and purpose in the community and how they will service both the needs of customers and shareholders in a partially regulated and partially market driven environment.

Naturally monopolistic activities are subject to comparative or yardstick comparison. Those activities, which will remain natural monopolies, such as Transmission and Distribution system infrastructures, are subject to simulated competition, in the form of Performance based Regulation. The use of comparative or yardstick competition has allowed regulators to understand the efficiency frontiers, which are achievable within the monopolistic activities and set regulatory price controls to incentivise improvements in efficiency, in line with these challenging efficiency frontiers.



To secure the shareholder appeal on a lasting basis it is crucial to deliver the shareholders' expected return on assets, whilst the regulatory pressure tends to substantially reduce the return on assets. This has forced utilities to find new and innovative ways of reducing cost levels whilst simultaneously delivering high customer service. Figure 1 shows a representation of the gap between shareholders expectation and regulatory impact [1].

Figure 1: Gap between shareholder expectations and regulatory impact

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2 Worldwide strategic response

As outlined in Section 1, the regulatory process gradually erodes organisations' resources whilst imposing a higher level of outputs. This makes the delivery of customer service and the development of shareholder value increasingly difficult.

Many companies throughout the world have successfully met this significant challenge through the application of the Asset Management Model. Best performers in the application of the Asset Management Model have been capable of delivering an improved supply quality while at the same time achieving a reduction of operational and capital costs.

Generally there have been four mechanisms for cost reductions in a utility organisation, these are shown in figure 2 below.

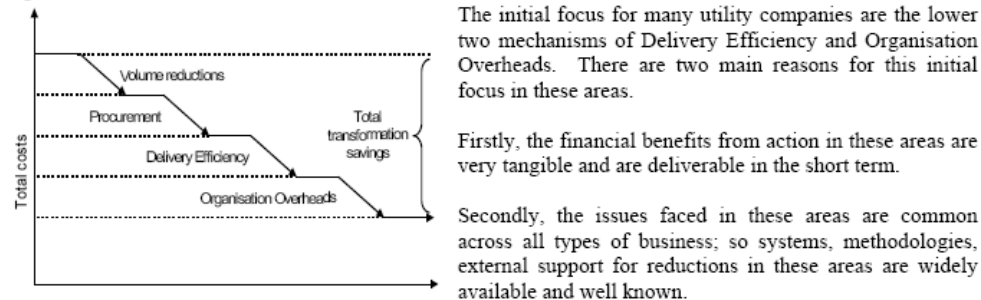


Figure 2: Mechanisms for cost reductions

The next mechanism usually adopted is in procurement with organisations aiming to procure goods and services in the most efficient way possible. Again, benefits are reasonably tangible and support is widely available.

The last three mechanisms mainly focus on continued efficiency i.e. carrying out the same amount of work for less money. Obviously, the strategy of continued efficiency has a finite life. Any utility has a minimum level of costs required to operate the business. This is where the fourth mechanism, work volume reductions, allows further cost reductions to be made.

However, volume reductions must be made on a managed basis. If an organisation pursues efficiency below its finite level and reduces investment volumes on an unmanaged basis, then the output performance and long-term sustainability of the business is at risk. The key to successfully implementing continued cost reduction strategies is being effective at understanding the volume of work necessary to maintain an agreed level of business performance.

Finally, once all four mechanisms are being utilised and there is still a requirement to reduce costs then organisation overheads again become the focus and business consolidation becomes the vehicle for delivery.

This paper will briefly explain the Asset Management Model and then focus on a core part of the model, which is the investment decision processes.

3 What is Asset Management?

In the CIGRE Joint Task Force JTF23.18 [2] a definition is given for Asset Management:

"The Asset Management of Transmission and Distribution business operating in an electricity market involves the central key decision making for the network business to maximise long term profits, whilst delivering high service levels to customers, with acceptable and manageable risks."

Asset Management is a formalised and systematic approach to the management of the physical assets of a network company. The aim is to remove any subjective and individualistic investment decisions by developing and implementing processes, which eventually become technology based, to provide an accurate picture of the complex issues relating to asset needs and focusing the options on delivering the required levels of transmission and distribution service performance, while maximising return. The result is that the best range of investment opportunities to meet an organisation's stated vision and objectives can be identified, quantified, delivered and operated.

4 Roles & Responsibilities

The Asset Management Model involves an understanding of both sides of performance, cost and risk management "doing the right things" and "doing things right". This is 'asset management' and is usually implemented by developing clear organisational accountabilities between these two equally important utility functions Asset Management and Service Delivery. These two distinct functions require very different skill bases, cultures, processes and information systems to effectively deliver on their responsibilities. However, the two functions must work in close partnership to achieve a high level of performance.

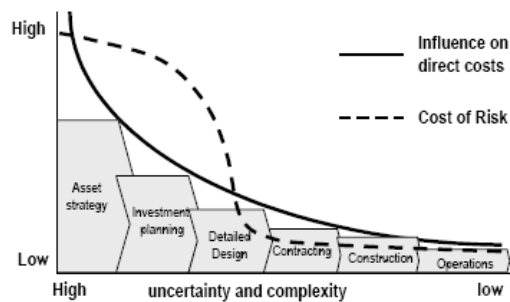
These are the key roles of Asset Manager and Service Provider. In CIGRE Joint Task Force JTF23.18 [2] also the role of an Owner has been mentioned. The role of the Owner is "giving direction" as to where the network company is heading. The responsibilities of the three distinct roles can be summarised as follows:

Owner – Accountable for the business strategy, the direction of the network company and the overall financing of investments;

Asset Manager – Accountable for making investment decisions to balance asset/service performance, financial performance and risk; and the

Service Provider – Accountable for making decisions related to delivering work on time, within budget and in a safe manner in accordance with agreed specifications.

5 Asset Management Processes and their Value Chain



In general asset based business processes can be characterised in the following value chain: Asset Strategy, Investment Planning, Design, Contracting, Engineering & Construction and Operations.

The level of influence on direct costs and the degree of cost risk depends on the position in the value chain. In figure 3 the level of influence on costs of each part of the value chain is shown.

Figure 3: Influence on costs and risk in the value chain

In the asset strategy process macro-level decisions are taken on mid-term to long-term costs. For example, what is the economic long-term plan for managing the fleet of high voltage transformers employed within the system? This helps set the longer-term investment requirements of the business plan (in years 3 to 5). The investment planning process decides, for example, whether or not to increase system capacity with a new substation or specifically which transformers need to be refurbished or replaced within the next two years. In the investment planning process, the influence on cost is limited within the selected asset strategy. For example, limited to different options for busbar arrangements or different options for basic technologies such as AIS,

GIS, HIS. The investment planning process results in the development of the near term investment plan, for implementation by the Service Provider. During the engineering process a detailed design is made based on different design options. In the contracting phase equipment is purchased and sub-contractors are engaged to minimize project costs. The process of construction management organises the construction work according to the specifications. Only relatively small deviations from budget are allowed – i.e. within the “risk margin”.

Referring to Figure 3 and looking along the process value chain from left to right, the risk level caused by the number of uncertainties and risk exposure seen from the business decreases as the uncertainty and complexity reduce; for example, we can take the capacity extension of the system with a new substation; the specification can often not be frozen in quantity and time before the right of way and/or the land permission to build on have been acquired. This is typically at the beginning of the design process. The risk profile through the value chain is shown in figure 3 as a dotted line.

Despite the clear definitions of the three roles within the Asset Management Model, in practice there always exists an overlap between the tasks of the Asset Manager and Service Provider. As discussed and also shown in figure 4 the overlap often can be found in the design phase.

The overlaps raise the question of which parts of the value chain the Asset Manager should be accountable for? What criteria should one adopt to make this decision? The criteria appear to be not only the influence on costs, but also more importantly the ability to control and manage the risks. The Asset Manager should manage the major risks influencing the business performance objectives.

A pragmatic solution is for example that the Asset Manager is accountable for all processes up to and including design. In practice the Service Provider can perform much of the design work. With a simple Service Level Agreement (SLA) between Asset Manager and Service Provider the design workflow and responsibilities can easily be arranged as shown in figure 4. Often the Asset Managers are responsible for system design and Service Providers are typically responsible for component or equipment design details. Other similar choices and solutions exist for other overlaps between the three roles.

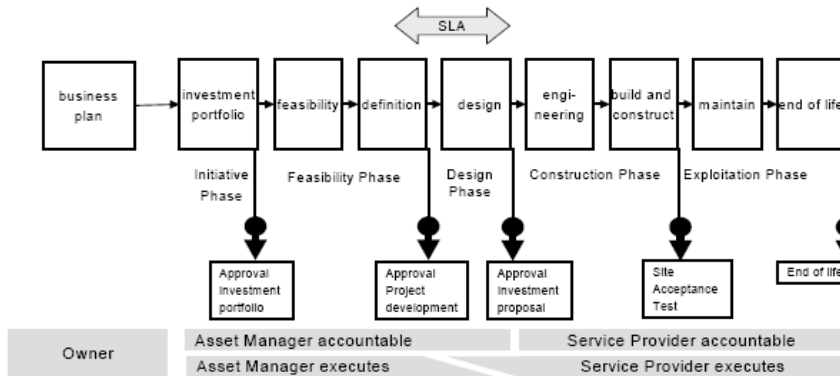


Figure 4: Process profile and responsibilities

6 Products & Major Milestones

In the asset management processes different core products can be identified with typical timelines. In general the primary components of transmission and distribution systems (sub-stations, overhead lines, cables and transformers) have a long technical life span of 40 years or more. This means that in setting the strategy for the network infrastructure it is wise to have a certain long-term vision (about 10 to 20 years). This allows the security of long-term investment efficiency and safeguards objectives such as long-term transmission service reliability and long-term security of supply.

Within this vision, short to medium-term projects are developed to resolve network risks forecasted to occur within the coming 1 to 5 years. The Asset Management Plan (10 to 20 years) describes the policy on investment; e.g. maintenance, refurbishment, replacement and 'fix on fail'. The Business Plan (typically 5 years) contains the business direction of the network company and the main market and financial oriented business drivers. The 5 year Investment Portfolio gives the total investment options including capital expenses as well as operational expenses. The maintenance code outlines the lifecycle based maintenance policy. Individual projects are selected from the options in the Investment Portfolio and specified in more detail in Project Plans (1-3 years). On an annual basis the capital and operational investments are specified in work plans and work programmes.

The short term market and risk oriented decisions are often based on 5 year time span, but the effects of the decisions can have their influence throughout the whole life span of the asset. Therefore, the financial effects of each decision are evaluated over the whole life cycle of the assets. This can be done using a number of techniques such as the comparison of the calculated net present values.

The main sources for the investment portfolio are long term asset driven initiatives and the short-term customer driven requirements, i.e. the long-term asset management plans and the market driven business plans. It is a real challenge for the Asset Manager to find a proper balance between the asset oriented and market / regulatory oriented business drivers.

7 Information for making good decisions

An Asset Management business is dependent upon "quality" information inputs: optimal investment decisions cannot be made without supporting information on asset age, performance, condition, capacity, utilization and cost with the aim of developing life cycle costs for each asset type and their operational groupings [4], [5]. Therefore an Asset Management business needs to collect data that supports the business needs and turn this into the information on which decisions will be based. In other words, the use of information determines what data needs to be collected [6].

The data collection, handling and input into the information systems are tasks that are often seen to be 'disconnected' from the delivery of the work on the assets. In reality it is a critical stage as it forms the basis of a large proportion of the asset investment decisions. A solution to this problem can be to include the collection of data from site within the SLA for the work completion, because of the cost and strategic implications.

Clearly, the correct storage and manipulation of the data is vital to the success of the business and depends on the company having "state of the art" ICT systems. The systems need to be interconnected to allow retrieval of data from any part of the integrated system. The integration of the data also allows detailed analysis and cross comparison of different elements of the data. It is this ability that facilitates the raw data being turned into the information on which effective investment decisions can be based.

One of the key drivers for extracting value from regulated infrastructure businesses is the accuracy, relevancy and appropriateness of the data relating to assets, load growth, processes and customers that comprise the business. For this reason, Asset Management organisations are normally centralised with data being manipulated and analysed at their central location, so that the risk of duplication is limited and data is easy to retrieve.

Few, if any, asset management organisations have as comprehensive a set of data as they would ideally like. Likewise, few have a full range of integrated ICT systems to support their decision-making. Therefore, good asset management should manage the risks associated with incomplete and inaccurate data and disparate systems whilst still making investment decision that are as effective as possible. This is done alongside prioritised efforts to acquire and improve the relevant data and ICT systems.

8 High Level Investment Decision Making Processes

A generic framework for Investment Planning is given in figure 5.

8.1 Asset Information

This area of the framework covers those tools, systems and processes that are used to record the information relating to the asset base. This includes 'real time' data from any telemetry, 'dynamic' asset data in terms of condition and utilization and 'static' asset data in terms of asset attributes including history. The asset information should include capacity versus loading information, text information and also geographic information. General reporting and geospatial reporting are also covered in this area.

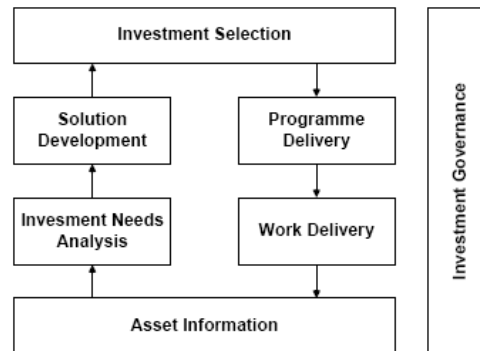


Figure 5: Framework for investment planning [7]

The importance of this area and the methods by which it may be undertaken are given in Chapter 7.

8.2 Investment Needs Analysis

Investment Needs Analysis covers those tools, systems and processes that are used to analyse the information held, or known, about the asset in order to understand where investment in the asset may be required. This area includes analysis of where the assets need or may need investment based on their compliance, capacity or condition. The area includes any asset or output performance modelling that is used to analyse historical or predict future performance.

After having set the goals with the Owner, the Asset Manager analyses which business objectives are at risk. The Asset Manager first identifies the risks by assessing the current network performance, evaluating the current service performance and determines what future performance is to be expected based on regulatory requirements, customer requests, load growth and future network capacity requirements. Having gathered data and information from numerous sources, the Asset Manager continues to evaluate the possible courses of action for individual asset groups.

8.3 Solution Development

This area of the framework covers those tools, systems and processes that are used to develop the solution options required to solve the deficiencies identified in Investment Needs Analysis. Solution Development includes the design of solutions, from both a capital and operating cost perspective. This area also covers the determination of the benefits that each solution will provide.

Once the most 'needy' assets have been identified and prioritised then an understanding is required of the options that are available to solve the individual problems. This optimisation should initially be as unconstrained as possible with many innovative solutions being identified. These initial solutions can be rapidly rationalised by 'good engineering practice' and also by their adherence to any standards or policies. Once the initial rationalisation has been undertaken, the identification of the best option for each problem can only really be done when the remaining options have been valued and compared in the same way. It is vital therefore to understand the effects of each option in terms of 'value' to the business. This is usually done by determining the effect that the options will have on the future performance of the network. Traditionally this has been done in asset terms comprising age, condition, reliability, capacity and loading however, more and more it is being done in terms of service performance measures; availability, capacity, operating cost effects, customer service, health and safety etc. This valuation can be done in either absolute or risk terms.

8.4 Investment Selection

Investment selection covers those tools, systems and processes that are used to decide the strategies and schemes that should be selected for delivery. The area also covers the lifecycle cost analysis (both operating and capital costs) of the proposed investment plan or strategies and the effects of the plan on the finances of the business.

Having evaluated the possible courses of action for a group/population of assets and generated a priority list, the asset manager then selects from the list. The selection from the list will depend on the value for money of the proposed programme for the asset and the criticality of the asset in its current state.

The asset manager needs to spend the available budget on the most 'valuable' projects. However, the decision is complicated by the fact that the budget is often constrained and that scheduling critical work may be complicated by other factors. Ideally the asset manager uses some further tools to assist in this process of selection. These tools would provide information on the consequences of the courses of action taken. For example, the effect of constraining the budget further or relaxing the budget could be evaluated. The effect of delaying some critical works for a period might be assessed with respect to the overall risk and performance position. This type of information would provide essential insights for the asset manager whose responsibility is to balance costs, performance and risks of the asset base to deliver the desired performance over the range of investment needs.

8.5 Programme Delivery

Programme Delivery covers those tools, systems and processes that are used to determine the programmes of work required to deliver the investment plan. The area also covers the overall management of those programmes of work through to delivery, including financial, volume and benefits progress. The area includes the management of any contracts or service level agreements required to deliver the programme and any feedback required to modify the investment plan and /or programmes in light of actual delivery information.

8.6 Work Delivery

Work Delivery covers those tools, systems and processes that are used to deliver the programmes of work. This includes any detailed design work, project management, maintenance scheduling and work management. The area also includes the collection of data from the work completed and the return of this through to asset information. System Operation and all the related facets of this function, such as customer interaction to schedule outages and work protection with the work force, may also be included in this area.

8.7 Investment Governance

Investment Governance covers those tools, systems and processes used to manage the overall investment process through the six stages listed above. This area includes the rules and procedures for investment authorisation and approval and also exception management for time, cost and benefit variances.

9 Risk Based Investment Selection

Linkage of investment requirements with the strategic objectives of the business forms the basis of effective asset management. A key requirement is the development and application of an effective and consistent method of bridging the gap between strategic intent and asset investment decision-making, ensuring that only those investments that contribute the most to achieving business objectives are chosen.

An initial phase in the development of an effective decision-making framework is to establish the critical performance measures for the business and to obtain agreement from the Asset Owner that meeting these Business Performance Measures (or Business Drivers) constitutes a successful business outcome. This

supports an approach to the management of the assets and the selection of investments that is based on the output performance of the business as a whole.

For effective Asset Management however, simply establishing the high level Business Drivers (e.g.: documenting the Firm's financial targets, system reliability targets, customer response targets, etc) is not enough. Since risks are always present in the business it is important for the Asset Manager to understand the Owner's tolerance for risk and to operate the business within the risk tolerance levels acceptable to the Owner. Knowing the Owner's propensity for risk, within each of the Business Drivers, enables the Asset Manager to understand where conservatism must be applied to minimize risks and where it is possible to be more tolerant of the risks and possibly reduce expenditures.

At the highest level, the Asset Management decision-making framework therefore requires a hierarchy of Business Performance Measures complemented with performance targets and risk tolerance levels, which enable the Asset Manager to operate various aspects of the business within specified risk zones.

An example of a typical Business Performance Measure hierarchy follows:

Business Driver – System Reliability (Meet or Exceed System Reliability Targets Established by the Regulator)

Key Performance Indicator – System Level Unsupplied Energy

Planning Indices – Unsupplied Energy targets for various sub-systems

Typically, to be meaningful to both the Owner and the Asset Manager, the performance targets and Risk Tolerances must be established at the Key Performance Indicator level. However, in order for the performance targets and Risk Tolerances to be meaningful to the Strategists and Planners who work within the Asset Management function, it will also be necessary to establish targets at lower levels. These sub-level targets (or Planning Indices) must be designed to contribute to the overall Key Performance Indicators. In the above example Unsupplied Energy targets could be established for the various sub-systems, based on the historical contributions of these sub-systems, to overall System Level Unsupplied Energy.

Once the Planning Indices are established the Strategists and Planners working in the Asset Management function can relate the equipment risks they encounter in their daily activities, such as decreases in the mean-time-between-failure of specific equipment or system demand exceeding capacity, to the Key Performance Indicators of the business. The following table provides a representative sample of a risk tolerance scale for the above-mentioned Business Driver.

Table I: A representative sample of risk tolerance

Business Driver	Key Performance Indicator	Risk Tolerance Level 5	Risk Tolerance Level 4	Risk Tolerance Level 3	Risk Tolerance Level 2	Risk Tolerance Level 1
		Catastrophic (threatens business)	Severe	Major (significant deterioration)	Moderate	Minor (noticeable deterioration)
System Reliability	System Unsupplied Energy	Target Missed by > 40%	Target Missed by 20% - 40%	Target Missed by 10% - 20%	Target Missed by 5% - 10%	Target Missed by 1% - 5%

The development and approval of Business Drivers, Key Performance Indicators and related performance targets and Risk Tolerances provides the high level framework for effective decision-making within the Asset

Management function. One of the key attributes of the discipline of Asset Management is that all business units must make decisions based on the same Business Drivers, Key Performance Indicators and Planning Indices.

A means of achieving this consistency throughout the company is to develop a standard template for quantifying the costs and benefits of the various investment proposals. This quantification should be undertaken in terms of the impact that each proposal will have the Business Drivers, Key Performance Indicators and Planning Indices. This quantification can be achieved in a number of ways from a simple subjective assessment through simple risk matrices to sophisticated risk models and calculated impacts. The quantification requires a multitude of business analysis tools and methods to calculate project level and business level financial impacts, sub-system and system level reliability impacts, improvements or degradation in customer service response times, etc.

This suite of business analysis methods and tools must be developed and documented to facilitate training of staff and to identify gaps in the competencies required to make effective Asset Management decisions. The documentation of these methods and tools is also important from a perspective of having a good audit trail as the basis for the decisions made and to identify the root causes of substandard performance.

Given the complexity and changing nature of the business, quantification of risk and the degree to which it can be mitigated through investments, will require the use of probabilistic based methods and tools to effectively represent the various risks and the value of the investments. The development of a Business Risk Manual, structured in accordance with the Business Drivers and Key Performance Indicators, is a significant asset within an Asset Management business. It provides the all important audit trail for rationalising decisions and is invaluable for training staff in the required concepts.

Some typical methods / models that are used for effective Asset Management include:

- A Business Level prioritisation methodology and model, which stages the various investment proposals in accordance with the Business Drivers. This type of tool can utilise an Analytical Hierarchy Process and requires that the Asset Manager or the Asset Owner weight the various Business Drivers. A more sophisticated way of achieving this is the use of an optimisation method, which enables the asset manager to select the optimal portfolio of investments taking into account the weight of the Business Drivers and also the performance targets the business is trying to achieve.
- Deterministic and probabilistic methods and models for calculating project level and business level financial impacts. This includes methods and tools for calculating the Net Present Value, Internal Rate of Return, etc of specific investment proposals or projects and methods and tools for establishing Corporate Level Financial Impacts such as Return on Assets, Return on Equity, Net Income impacts, etc.
- Methods and models for establishing systematic condition ratings for all the key equipment categories. The development of Asset Health Indices which formalize the condition ratings based on critical wear-out factors and condition readings such as, number and magnitude of short circuits a transformer has been subject to and particulate in oil tests, etc.
- Probabilistic methods and models, which can calculate system level reliability impacts associated with equipment wear-out and system growth. Probabilistic methods and models for quantifying the level of Safety risk for utility staff or the public. Methods and models to establish Customer Service Level risks associated with computer system and / or employee performance.
- Methods and models for establishing the criticality of the large array of assets that make-up the system. The availability of a commonly used Asset Criticality product, which prioritizes the reliability value of the major asset groups, is very useful in initially structuring the Investment Plan and to identify where maintenance is most important.

10 Examples of investment criteria and business values

The Working Group has examined different case studies on investment decision processes and investment selection criteria. One of the observations is that there are many values and criteria for investment decisions such as:

- Performance;
- Safety;
- Reliability;
- Flexibility;
- Capacity;
- Customer importance;
- Environmental pressure;
- Legal implications;
- Integration;
- Maintainability;
- Quality of supply;
- Importance of plant;
- Risk and consequences;
- Physical condition;
- Return on capital employed;
- Life cycle cost;
- Operational costs;
- Capital costs;
- Obsolescence;
- Corporate image; and
- Sociological impact.

It can be concluded that when comparing the case studies there is a common top six business values for investment decisions:

- Finance;
- Customer;
- Quality of supply (transmission service);
- Safety;
- Environment; and
- Corporate image.

11 Lessons Learnt

Establishing a good relationship between the Asset Manager and the Service Provider(s) is key to the achievement of a successful and lasting result. This relationship must go deeper than simply a contract or service level agreement. For example, since the Asset Manager is taking the key business decisions the Service Provider needs to be able to demonstrate that he is also creating value for the business. From the "people perspective" attention is required to staff motivation and providing balanced job satisfaction, whilst ensuring, for example, that employees feel part of an integrated organisation rather than under threat of "being outsourced".

There is strong potential for the Service Provider to become a separate part of the business, and indeed ultimately ring-fenced or hived off from the parent. Such arrangements can lead to duplicate development of self-supporting infrastructures (e.g. Legal, HR, Finance, etc.) with increase in overheads unnecessarily. The risk of complex cost transfers across the business interfaces also needs to be carefully controlled or better still

viewed from a company perspective rather than from an individual Asset Management / Service Provider profitability perspective.

With the worldwide reduction in the availability of skilled resource, a planned approach to specialist engineering must be adopted and any inherent trend for duplication in each organisation strictly avoided. Bearing in mind, that it is not a static model on paper and as indicated above, people will make difference. The creation of an encouraging and inspiring professional environment will retain and attract competent people who like to take up this challenge.

Developing a very high level of trust across the organisation is absolutely vital whilst at board/director level greater management attention may be needed to avoid conflict. Potentially, the management of the company becomes more complex and risks major failure, loss of supply, fraud, regulatory or license compliance, etc. Equally important, for external parties, is the need to ensure there is a consistent "message" and a common interface avoiding the potential for an external party playing off the Asset Manager against the Service Provider to gain commercial advantage. Company reputation and identity is reliant upon all the business units and not the Asset Manager or Service Provider alone.

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Appendix 2: Asset Risk Management Example

Example of Risk Management Implemented by Nuon Asset Management

Introduction:

Nuon is a Dutch multi-utility company with the focus on power generation, including sustainable energy, energy trading, energy supply and related business as public lighting, consultancy/engineering for third parties, district heating, transmission and distribution of gas and electricity, related services, etc. Nuon owns gas grids (up to and including 8 bar) and electricity grids (up to 240 kV) for about one third of the Netherlands. A wholly owned subsidiary, Continuon, has the licenses to operate the networks (up to and including 170 kV). The asset management for these networks is performed by Nuon Asset Management (Nuon AM), while Continuon more or less plays the role of the asset owner. In this appendix, the vision of Nuon Asset Management on risk management and the experiences with implementing risk management in the decision processes are described.

The objective of asset managers is to improve return on assets of the asset owner. Return on assets is generally seen as only a financial parameter. In the vision of Nuon AM the return on assets should comprise all business values of Continuon. When all business values are taken into account a more holistic and long term approach for improvement of the return on assets will take place.

One of the tasks of asset managers is to make decisions for improving the return on assets. This means in practice that asset managers should decide what investment projects or maintenance activities should be performed by service providers. This decision making should be done according to a transparent and objective process that involves the interests of all stakeholders. To achieve this, a distinction shall be made in identifying risks (problems in the network or with certain assets) and selecting solutions (maintenance activities or investments).

The risks shall be identified, evaluated and treated according to the IAM-manual [A2-1]. To identify the risks a framework of objectives, stakeholders and criteria needs to be developed. Maintaining this risk model is an on-going process. The risks shall be monitored and reviewed on a periodic basis. Nuon AM likes to think of the on-going risk monitoring process as the Risk Management Cycle.

The idea behind the risk management cycle is that once the objectives of a grid company are clear, the risks involving the grid and assets for the company's objectives are also clear. The network performance is measured in KPI's related to the objectives and the identified risks. When the KPI's are not up to the desired level action should be taken to reduce the risk.

The risk management cycle is an idealistic approach but forms a clear vision of what Nuon AM wants to strive for. Nuon AM has identified several milestones to work towards this vision:

1. establish the business value model
2. derive norms from the business values and express them in desired performance levels for KPI's
3. develop standardized quantification of risk effects on the business values to be able to quantify risk effects for individual risks
4. implement risk oriented problem definition in investment proposals
5. set up a database comprising all risks evaluated
6. when enough experience is obtained and the database contains enough data, a risk register can be derived from the database.

Nuon AM has taken the steps 1 to 5 and is now collecting data to establish the risk register. In this paper, the steps taken to date and future developments are described. One of the future developments is to derive the risk register. Another development of interest is to express every risk for every business value in financial terms. This means that the total risk level and risk reduction for the company can be established. Then it can easily be seen what the added value is of the activities done or the activities proposed. The financial term under consideration has to cover the stochastic characteristic of the risk assessment. A separate paragraph is devoted to uncertainty in risk assessment and in decision making.

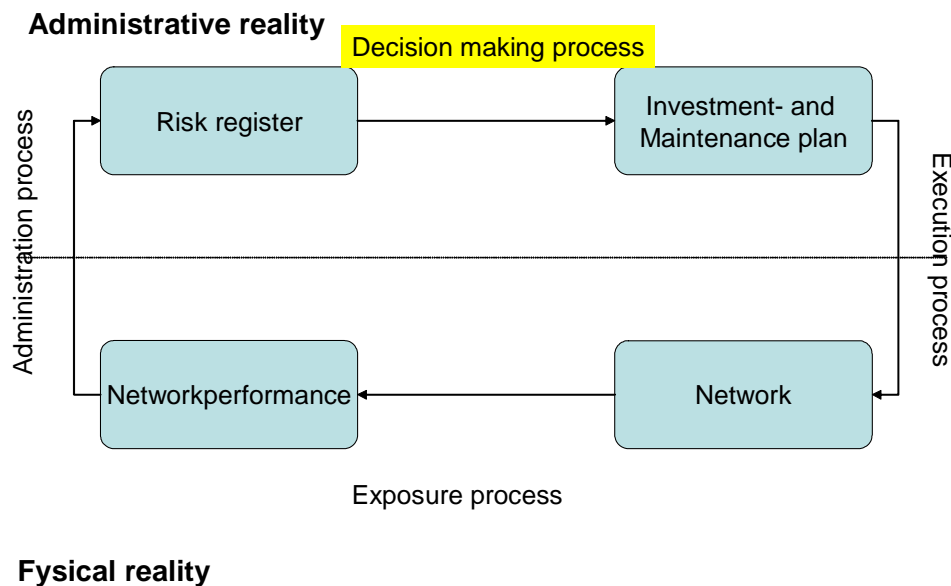


Figure A2.1 Risk Management Cycle

Developing the Business Value Model

In order to get a better understanding of the network business and its interaction with its stakeholders, Nuon and Continuon have developed a model for its business values. Apart from a qualitative model, that is already valuable, the structure for quantitative values (KPI's: key performance indicators) is still under discussion, to define high level but clear KPI's. The selected business values are: financial, quality of supply, (quality of service), safety, legal, image, regulator and environment.

These business values are the relevant aspects to be taken into account when considering business risks and when making decisions on certain activities in the networks. The business value "quality of service" is put between brackets, as this value has to do with the administrative processes for customers (billing, corrections, house-moving, etc.), which is not generally included in the accountabilities of asset management.

Defining whether a field of interest for the management level is to be regarded as a normal condition for doing business (law, client satisfaction, employee satisfaction, shareholder value) or is relevant for making decisions on network risks is often difficult. In order to be able to give the asset managers guidance for day-to-day prioritization and ranking actions, general management problems are not included in the risk model (age of the experts, mergers between utilities, cross-border lease issues, new accounting rules, shareholder value, etc). Also not included is the company's risk policy with respect to societal or natural disasters like large scale inundation, terror attacks, plane crashes. Both, managerial risks and societal risks, are considered separately from the normal network business, as described in the next sections.

Of course there is a relation between shareholder value and the business value "financial", as there is a relation between the company's attitude to the law (e.g. not to take illegal actions) and the business value "legal" (e.g. how fast to react on new or expected laws). However, for the asset manager it is important to know which business values are relevant and how the risks can be determined.

Developing Risk Matrices

Given the Continuon business values for the network business, one practical parameter is defined per value to assess the related risks. This requires a close and precise inspection of each value. One has to be aware of the fact that the risk model of a particular utility is described and that only general conclusions for other business or other utilities can be drawn. Furthermore, risk models are just a tool to help the asset manager to rank the risks and investments; but they are not a business statement on the value of, for instance, a human life. People without knowledge and experience with the risk assessment process may draw the wrong conclusions from risk matrices. Therefore, to prevent confusion and abuse, release of risk-based information must be considered carefully.

Business values have been split into two groups: those values that can be quantified, and those values with a more soft quantification. To the first group belong for example

“financial” and “quality of supply”, which are per incident given in MEuro (million Euro) and million customer minutes lost (calculated with the formula $1.5 \cdot kW \cdot \text{min}$, to generate a figure for the average number of non-supplied customers). (In the Netherlands the quality of supply for gas is so high that customer average interruption index is not a relevant KPI). A sample risk matrix for “hard” value consequences is given in figure A2.2.

Per incident	Financial “Damage”	Quality “ $1.5 \cdot kW \cdot \text{min}$ ”	Safety “victims”	Legal “penalty”
Fatal	> 10 M€	> 10 Mmin	several deaths	loss of licence
Severe	1- 10 M€	1- 10 Mmin	1 death/heavy handicap	imprisonment
Serious	0,1- 1 M€	0,1- 1 Mmin	1 disabled	heavy fine
Moderate	< 100 k€	< 100 kmin	longlasting absenteeism	condemnation

Figure A2.2 Example of a Risk Consequence Matrix: Hard Values

It should be noted that the progression is logarithmic, meaning that the risk consequences are ranked in steps of 10. Experience so far shows that with this approach it is relatively easy to assess the risk consequence. As long as the incidents can be subdivided in fatal, severe, serious and moderate, a coarse scale such as this will suffice. Using these steps it is also quite clear how the consequences of a certain incident can be assessed, both at a first premature assessment to get some feeling for the problem, and at a later stage after collecting and calculating more precise information. Another advantage of such coarse steps is that for an incident that affects several business values, the risk consequence that is one step higher will dominate clearly the other business values (a factor 10) and can therefore be treated essentially as a single risk consequence.

In Figure A2.2 only four steps are used with the idea that incidents with much larger consequences most probably will be considered to be societal disasters that are outside the scope of this risk assessment method, or that they are just one step above the given matrix and can, for this seldom case, be extrapolated from it. Incidents with a lower consequence are either not of interest or belong to a type of incident that individually is too small; but collected together may give a risk consequence that fits into the matrix and is important enough to be taken into account.

Risk consequences are given per anticipated or experienced incident, but not per year or as a KPI for the whole business. The aspects (the columns) are taken from the corporate business values; but the scale per business value is an asset manager’s tool for ranking

risk consequences. In the event that the asset owner decides to drop business values, add business values or change business values, the matrices need to be adapted accordingly.

And again, (only applicable for this utility) the consequences are weighted horizontally to the internal utility's policy. A change in policy will force the asset manager to immediately adapt the weighting; for instance when casualties are weighted more severely than shown above. For instance, from the sample matrix it can be deduced that each kWh not delivered is weighed as 90 Euro (1 Meuro ↔ 1Mmin ↔ 16667 customer*hr ↔ 11111 kWh).

As these matrices are just an example and very specific to a specific company situation, great care must be used in their interpretation or adaptation for other circumstances. The column "safety" is very important for the gas infrastructure and can in that sense be compared with the role of "quality of supply" for electricity. A last remark is that, as can be seen, for each business value the most important parameter has been chosen, thus confining, for instance, "quality of supply" to customer minutes lost only.

Per incident	Image "attention in press"	Regulator "corrections"	Environment "clean-up-costs"	Image "authorities"
Catastrophic	> 1 month national	structural clashes	> 10 M€	structural clashes
Severe	week national, month regional	single conflict	1 – 10 M€	single conflict
Serious	TV-program, national article, week regional	dozens of corrections	0.1 – 1 M€	dozens of corrections
Moderate	regional article, complaint in newspaper	< 10 corrections	< 100 k€	< 10 corrections

Figure A2.1 Example of a Risk Consequence Matrix: Soft Values

The following remarks can be offered for the other business values. The third column shows the environmental impact of an incident, but in order to compare several environmental issues (e.g. oil leakage, noise, SF6-gas leakage, natural gas leakage, losses, contamination) and to combine them in one parameter, the clean-up costs have been chosen as the most relevant indicator, despite the fact that a severe impact on the environment could lead to relatively low clean-up costs. For the sake of simplicity, Nuon AM applies "clean-up costs". With respect to the company's image, it has been felt necessary to split the image between the public image resulting from negative messages in the press/media from a negative image for influential decision makers such as politicians, public authorities, and important organisations. Where the public image in a negative sense can be measured by the attention shown by the press/media, the conflict with authorities has an escalating structure similar to that of the business value "regulator".

Risk evaluation matrix: After assessing the risk consequence to the two risk-consequence matrices with a total of 8 columns, the frequency of occurrence of an incident needs to be calculated or estimated. Another matrix is applied, termed the risk evaluation matrix.

Probability/effect	# per year	Catastrophic	Severe	Serious	Moderate
Permanent	>1000	VH	VH	VH	H
Daily	>100	VH	VH	H	M
Monthly	>10	VH	VH	H	M
Yearly	>1	VH	H	M	L
Frequently	>0,1	VH	H	M	L
Probable	>0,01	H	M	L	N
Possible	>0,001	H	M	L	N
Not likely	>0,0001	M	L	N	N
Almost impossible	<0,0001	L	L	N	N

Figure A2.4 Risk Evaluation Matrix

In the case of Nuon AM, the same risk evaluation matrix is used for all business values, but one can also choose different risk evaluation matrices, thus adding another degree of freedom to compare the business values. The matrix is again intended to be applied per incident. For each risk consequence, a column is available where in principle a logarithmic differentiation has been applied (steps of 10). Also the frequency is distributed on a logarithmic scale, thus facilitating an easy ranking. The frequency is also described in words, but at the lower end, one has to be careful as the steps of 10 are not very well reflected in words as probable, possible, not likely etc.

The meaning of the abbreviations in the matrix is:

- VH very high risk, immediate decision/action necessary
- H high risk, to be treated to the normal procedure for taking decisions/actions
- M medium risk, can be put as a point of attention for the coming years °
- L low risk, at this moment it can be put aside
- N negligible risk, can be neglected.

° may evaluate to a high risk

To illustrate how the risk assessment works an example is given of a Dutch city (from the MW-consumption it can be concluded by the formula mentioned that there are 40,000 customers), supplied through a 50/10 kV substation, that is fed by two paper/oil cables, one of which is a cold standby. The failure rate of the feeding cable is once per year and

the time to switch over is estimated to be 20 minutes. A cable failure is an incident with 0.8 Mmin, thus with a serious consequence. Once per year gives a risk that is assessed as medium, which may motivate a decision to reduce the risk in the coming years. But, given the fact that this incident, which indeed is not regarded as being a high or very high risk, occurs every year in the same city, another business value has to be considered as well: image to the authorities. Interruptions of the power supply every year will lead to an escalation level that within a couple of years (if nothing is done to mitigate the situation) will likely result in conflict with the local authorities. Risk consequence: severe, risk frequency < 10 years, risk assessment: H. Therefore, the normal procedure leads to a proposal for mitigations being written and to recommend the decisions that have to be taken.

Other risk assessment matrices

For process-industries specifically, one typically treats risks for safety, health and the environment differently from risks that are related to the commercial/financial/technical aspects of outages. Risk levels for plant outages in this industry are usually much higher than those in the power industry, (at least in the network business).

The risk consequence matrices are comparable with the above matrices, but the risk frequency and its consequences are different. The consequences are normally very sharply defined, the actions are clear and no further considerations or decisions are needed to implement mitigations. This resolute attitude is compensated by the frequency evaluation, where only incidents that have actually occurred are taken into account (while in the power industry foreseen risks are taken into account as well). The frequency in that sense is given as follows, for example:

- High occurs several times a year in this plant
- ... occurred the last years once in this plant
- ... occurred the last 10 years in one of our plants in the Netherlands
- ... occurred the last 10 years in one of our plants worldwide
- Low occurred the last 10 years in the industry worldwide.

Implementing Risk management approach

Risk attitude: One of the most important, but also difficult parts of risk management is to change the mindset of the technical experts involved. They have to learn to see the infrastructure not as the object of their work, but as the tool to serve the stakeholders. They have to learn to approach the network and its components from the perspective of the outside world. They are facilitated in this way of thinking by the consideration of business values and by the assessment of risk matrices.

Advantages: By forcing experts to focus at first not on technical solutions, but rather on risk description, risk assessment and methods for risk reduction, they will identify other problems, they will accept that certain problems are need not be solved immediately and they will come with other solutions for the important problems. By clearly formulating what the present risk is and the future risk will be, in case that no mitigation is implemented; the experts will get a good overview of the more important and the less

important issues. Since asset management has a holistic approach and since utilities tend to become larger and larger, forcing such an overview has become necessary, as few develop such an overview instinctively. Moreover, a method to collect all risks and risk assessments in a systematic way will improve risk control and risk documentation for the company. Automatically all risks are collected, thus forming a risk databank, while the risk management will be confined to the deviations from the “normal” risks.

Setting up a database of Evaluated Risks

Risk ranking tools: An overview of risks and risk assessments is not only helpful to allocate financial means and other restricted resources (e.g. expertise, materials available, information), but may also help to focus the asset managers themselves on the most urgent jobs (risks). The next figures show a tool designed by Nuon AM to collect risks from all sorts of information sources (service providers, failure data, load and capacity data, maintenance data, governmental plans, legal end regulator developments, specialized studies, consultants, company staff, operators, etc.), to give a first risk ranking, to communicate and discuss this provisional ranking, to set priorities for the asset managers and to develop plans for the coming years. In a second step the risks with the highest priority have been assessed more accurately, giving detailed information to identify which risks have to be reduced with a very high priority (i.e. immediately) or with a high priority, thus leading to investment proposals (the first part of which is based on this accurate risk assessment).

The screenshot shows a web-based form for risk intake. At the top, there are fields for 'Knelpunt ID', 'Beoordelingsstatus' (Oplossen), 'Voortgangstatus' (Ingeschaald), and 'Document' (PCCN-voorstel 1-11-2005). Below this is a text area for 'Knelpuntomschrijving' containing a description of a cable issue in a bridge deck. Further down are fields for 'Datum registratie' (1-11-05), 'Aanleiding' (melding Tecno Beheer), 'Problemeigenaar' (A. Bun), 'Belanghebbenden' (n.v.t.), 'Bedrijfsmiddelsoort' (Verbinding), and 'Bedrijfsmiddelnaam (ID)' (Leiden-Leimuiden).

The main part of the form is a 'Risico Matrix' table. The table has columns for 'Risicovolle Gebeurtenis', 'Gebeurtenis omschrijving', 'Bedrijfswaarde', 'Bedr.waarde Kwantiteit', 'Risico kans', 'Risico effect', and 'Risico ernst'. The 'Knelpunt Risico' is noted as 'zeer hoog'.

Risicovolle Gebeurtenis	Gebeurtenis omschrijving	Bedrijfswaarde	Bedr.waarde Kwantiteit	Risico kans	Risico effect	Risico ernst
kortsluiting in de stalen koker in het brugdek	het onderstation Leimuiden is gedurende de reparatietijd spanningstoos	Financiële prestatie	0,1- 1 M€	Geregeld	Hevig	Matig
		Bedr.waarde weging	1			
		Weging toelichting				
		Service kwaliteit	> 10 Mmin	Geregeld	Rampzalig	Zeer hoog
		Bedr.waarde weging	1			
		Weging toelichting				
		Duurzaamheid	< 100 k€/jr	Geregeld	Matig	Laag
		Bedr.waarde weging	1			
		Weging toelichting				
*		Bedrijfswaarde				
		Bedr.waarde weging	1			
		Weging toelichting				

At the bottom, there is a 'Record:' indicator showing '1 of 2'.

Figure A2.5 Example of a Risk Intake Form

Knelpunt_ID	KP_boordeingsstatus	KP_voortgangstatus	KP_naam	KP_omschrijving	KP_datum_registratie	KP_aanleiding	KP_probleemeigenaar	KP_belanghebbenden	KP_risico	KP_document	KP_bedrijfsmiddel_soort	KP_bedrijfsmiddel_id
5	Oplossen	Ingeschaald	50 kV verbinding Leiden Leimuiden	Ter hoogte van Rijpwetering ligt OD kabel in stalen koker in brugdek. Hierdoor ontstaat er een grote trekkracht op de kabel.	1-11-05	melding Tecno Beheer	A. Bun	n.v.t.	zeer hoog	PCCN-voorstel 1-11-2005	Verbinding	Leiden-Leimuiden
6	Pro memorie	Gewogen	een fase kortsluitstromen 10 kV-netten Noord Holland	Enkele 10 kV-netten Noord Holland zijn star geaard via sterpunten 50/10 kV-transf. De eenfase kortsluitstroom kan tot ca. 10 kA bedragen waardoor knelpunten optreden: kabelmantels niet kortsluitvast gevaar voor LS-gebruikers via doorverbonden MS- en L	9-11-05	diverse studies CN en Tecno	J. Smit	n.v.t.		probleemanalyse eenfase kortsluitstroom	Deelnet	
7	Beoordeeld		Probleem Bommel/Elst - Land van Nederrijn & Waal (MPA 1471)	Elst: trafovermogen tekort, Bommel: Trafo+ lijncapaciteit tekort. Redenen: Normale groei, grootschalige woningbouw KAN-gebied, 40MVA-aanvraag (opwek en belasting) in gebied Bommel/Huissen.	18-11-05	NSP KAN-gebied	Nico				Deelnet	Bommel-Elst
8	Beoordeeld		Knelpunt Deelnet Krommenie/Zaanstreek-West (MPA 3161)	De belasting groeit voor onderstation Krommenie is zodanig dat we vanaf 2008 het bedrijfszeker stationsvermogen ruim gaan overschrijden. Tevens levert de verbinding WIJW-KRN problemen op met de betrouwbaarheid.	18-11-05	NSP Zaanstreek	Jurriaan				Station	KRN

Figure A2.6 Example of a First Risk Assessment

Future developments: Putting risk reduction in financial terms for all business values

Investment decisions: After the assessment of the risk level and the decision to take action, a proposal for the mitigations measures has to be written. The risk reduction of the proposed mitigations has to be assessed by means of the same risk matrices, taking into account the financial and other aspects of the measures to be taken.

At Nuon an investment proposal is required to show a detailed risk assessment of the anticipated incident, quantified as much as possible with reference material. In addition the foreseen risk reduction has to be quantified as much as possible. As an example, the next figure shows, for one investment proposal, the added value per business value.

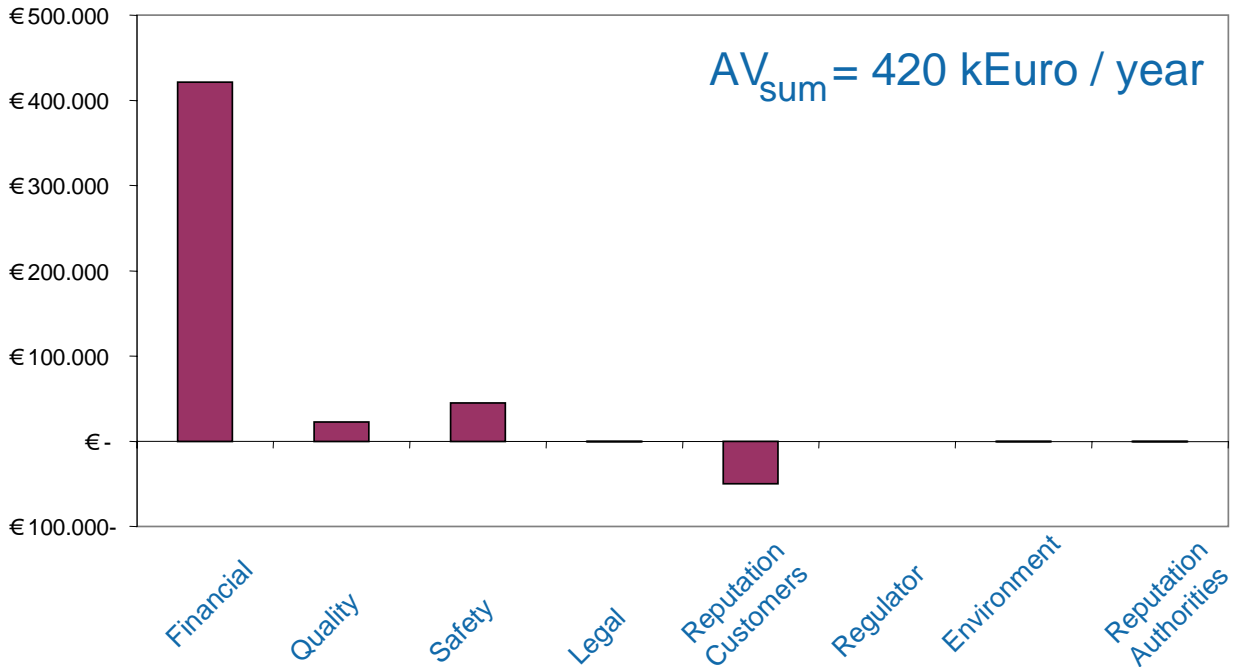


Figure A2.7 Example of the Added Value of a Single Investment Proposal

The total added value of the project is defined as the sum of the added value per business value. Depending on the required investment, a decision can be made “to invest” or “not to invest”. This will be discussed later in the text.

For every project proposed within the Nuon organisation, which exceeds 250 kEuro a calculation of the added value, is performed. Adding the projects together provides insight into the value added to the grid. And it provides insight into where to invest the money see Figure A2.8.

A review of these results shows that the dominating values were “Financial”, “Quality” and “Reputation” within the presented quarter of a year. Strategic management now has direct insight of the value added.

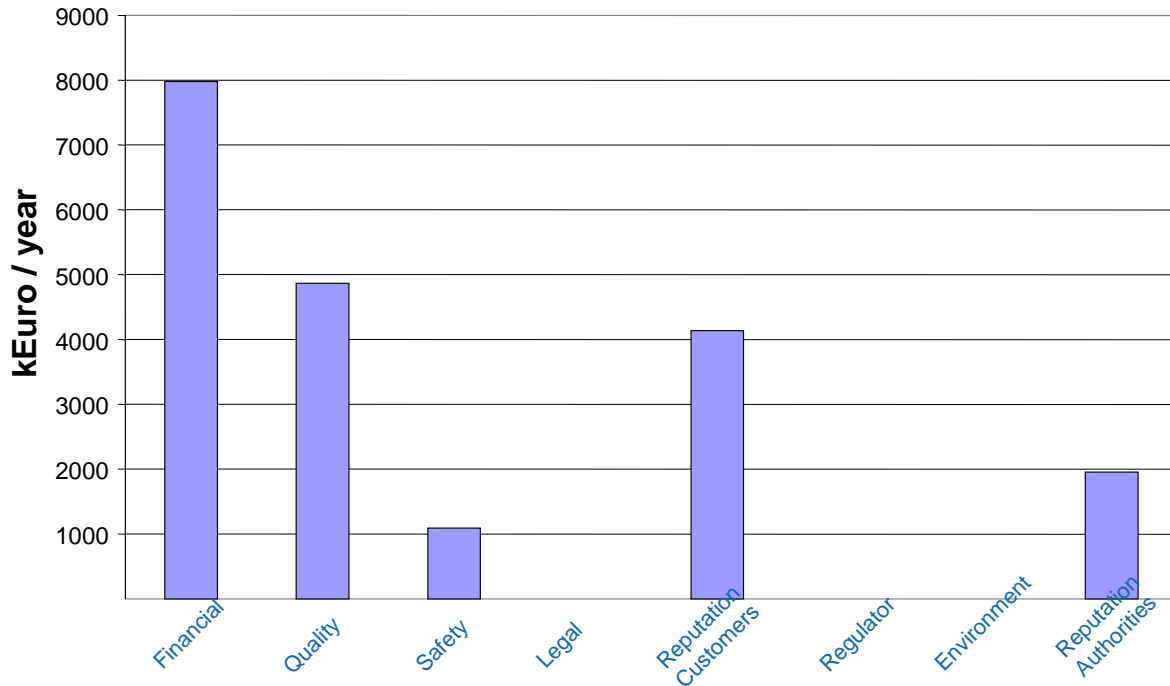


Figure A2.8 Total Added Value of the Proposed Projects

Added Value: For a network with all its rules and obligations, its societal role and the far reaching consequences of AM decisions, it is not easy to formulate the total added value of each decision. In commercial terms the added value of the total of investment decisions for the whole network can be assessed and afterwards evaluated, but for each individual problem in the network another approach will be necessary. Therefore, the added value of each investment decision is brought back to the rules, obligations, societal role and future consequences. Here the model of business values is needed to define which consequences for the network are relevant for the stake-holders as a whole. It is a delicate task to find a sustainable equilibrium between all stakeholders' fields of interest. It is also a delicate task, not to be underestimated, to tune the weights of the different business values to satisfy the stakeholders' wishes.

Given the business values, it is the asset manager's postulation that other values are not relevant to be considered. Each problem, each risk for the network, an asset manager becomes aware of, will be assessed by means of the business values given. The assessed risk is the outcome for all weighted business values. And each investment or activity to reduce such an assessed risk can be regarded as generating added value for the network. Added value is therefore defined as the reduction of risk, see equation (1).

$$AV = Risk_{before} - Risk_{after} \quad (1)$$

In this equation AV is the "added value" of a project defined by the Risk in quantitative numbers before and after the (imaginary) completion of the project: $Risk_{before}$ and $Risk_{after}$. The investment costs are not treated as a risk; but are balanced against the

“added value”. Also the risks involved with performing the project itself are not considered in this evaluation model.

Care has to be taken that added value is generated only by means of reduction of risks of a lower importance, as risks with the highest importance may not be neglected. However, in reality most risk reduction can normally be gained with the highest risks. Besides, the highest risks will normally be emphasised.

Another point of interest, not yet solved for Nuon, is how to express the added value or risk reduction: in absolute terms or in relatively terms. This may have an impact on the ranking of the investments (i.e. which investments can be seen as the most promising).

Risk appetite: A closer look into the risk evaluation matrix illustrates something about the risk appetite of the company. As shown in the figure below, by taking the business value “finance” and by taking the logarithmic average of each step in the risk consequence matrix, the risk appetite can be revealed.

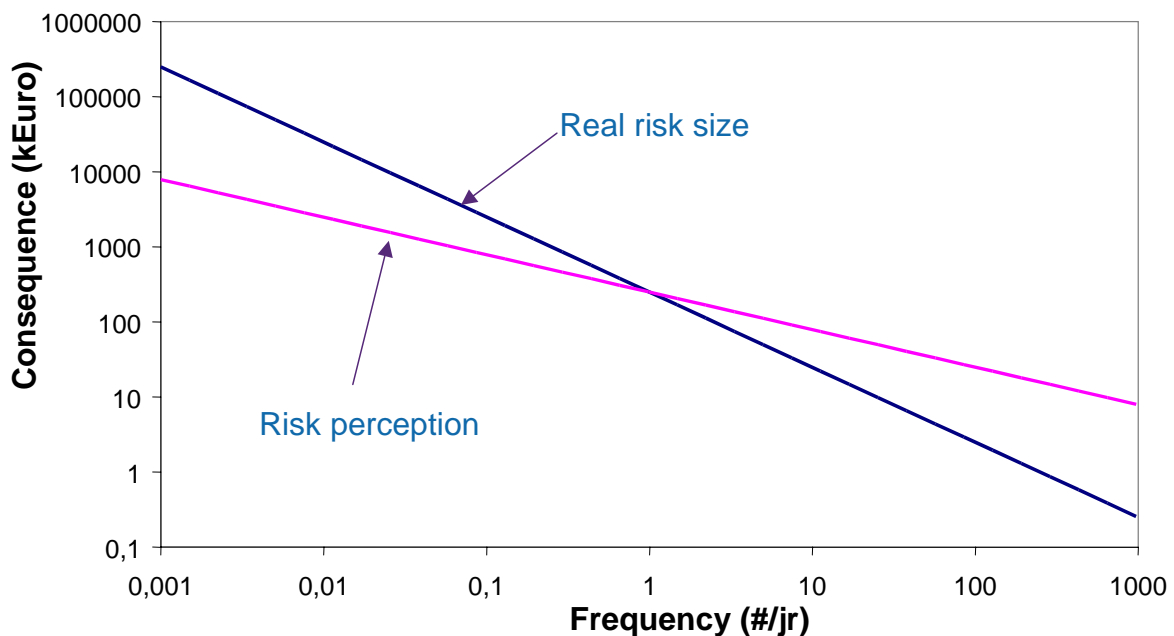


Figure A2.9 *The real risk size (risk = frequency x consequences) is not equal to the perception of risk by an organization*

The perception of risk was deduced from the risk evaluation matrix, Figure A2.5, which resulted in a relationship between risk, consequence and frequency:

$$Risk = Frequency^{0.5} * Consequence = \sqrt{(Frequency) * Consequence} \quad (2).$$

Usually risk is given by a linear relationship: Risk = Frequency * Consequence (dark blue line, here called “real risk size”). The purple risk perception line is a measure for the risk appetite and the purple curve is typical for utilities, that accept a larger risk for the incidents that occur often (more than once a year) but with small consequences and that fear the risk of rare incidents with large consequences. It is just a matter of

definition, but risks with a frequency larger than once a year are regarded as cost drivers and risks with a frequency lower than once a year as performance killers. The right hand deviation between purple and blue line can be seen as a risk attitude resulting in “accepted inefficiency”. The left hand side shows the risk attitude to avoid large performance consequences: the so called “no-surprise zone”. A simple commercial activity, like selling snacks, will show a completely different risk appetite, accepting large risks with a low frequency and avoiding the day-to-day small risks (focus on the short term instead of long term risks).

This is illustrated in Figure A2.10, where the risk appetite is translated into the regular profits. Shareholders, especially those of utilities, most probably prefer the graph that shows profits more to be “in control”. Business that is strong in looking for opportunities will most probably prefer the steeper graph.

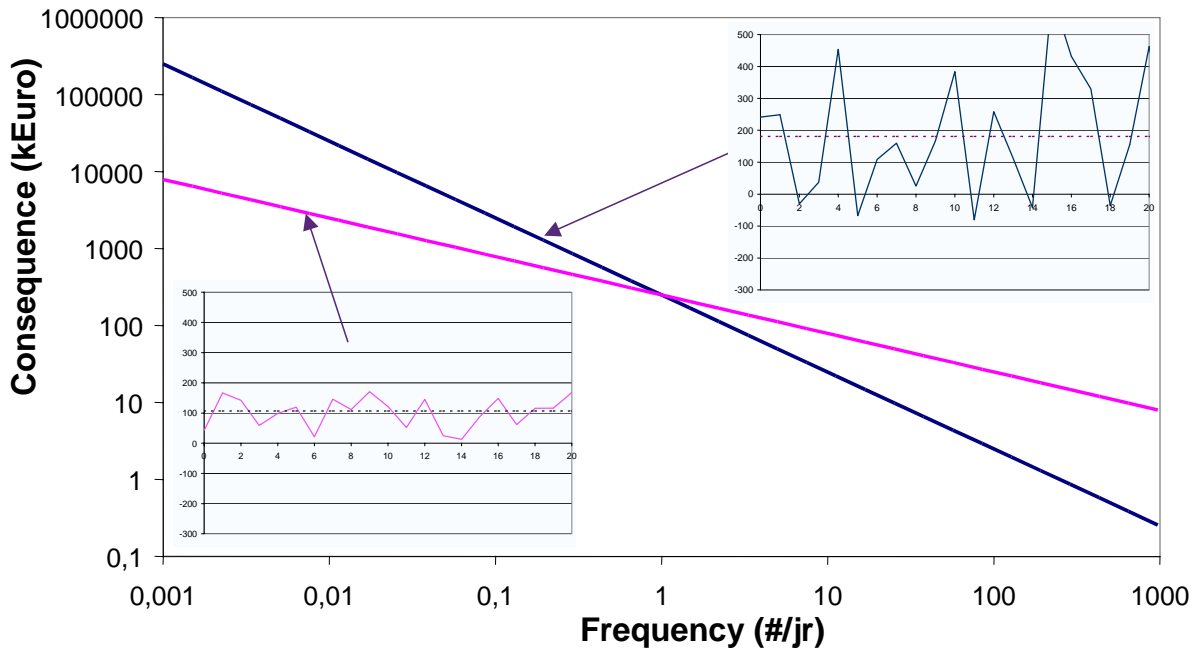


Figure A2.10 *EBIT of a Company following Investments along the Lines of “Risk Perception” and “Real Risk Size”*

In Figure A2.11 a number of projects have been plotted; the round dots show approved projects, the diamond dots are for projects not yet decided and the square dots for the not accepted projects.

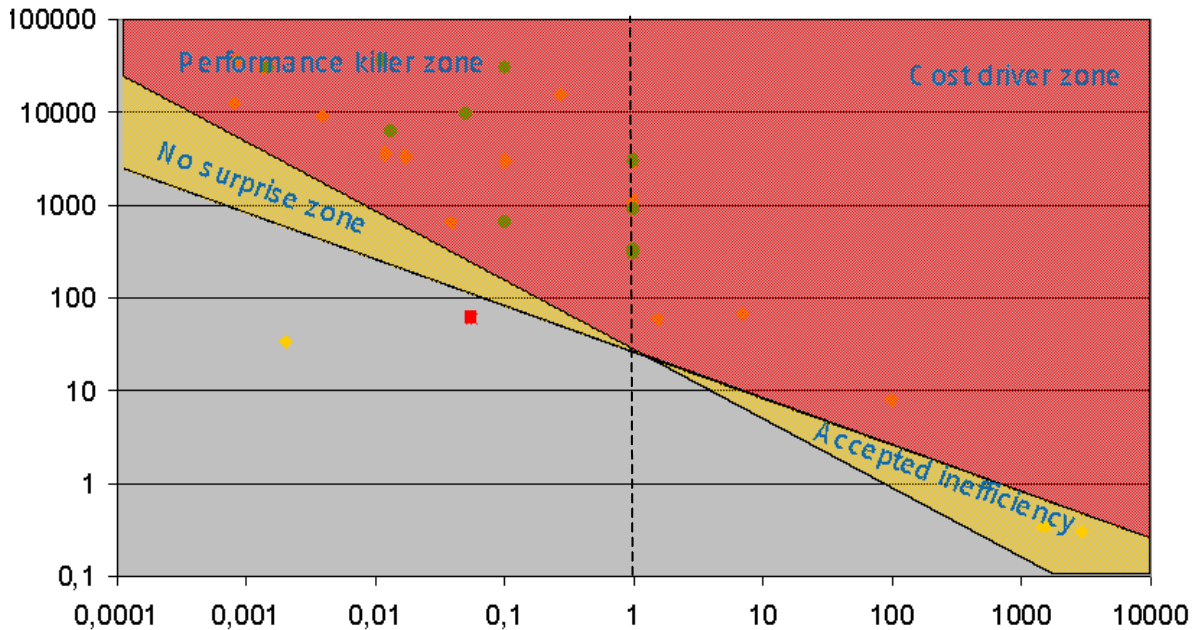


Figure A2.11 *Project Classification by means of Frequency and Consequences*

Adding risks: It may be difficult to estimate beforehand which business value or risk scenario leads to the dominant risk; for instance compare an incident with a high probability of injuries and a low probability of deaths with an incident with a high probability of financial damage and a low probability of a death. In such a case, the risk can be estimated by multiplying each consequence with its frequency (probability) and adding the results. Risk management is sometimes based upon the “gut” feeling or expert opinion of individuals within a company. For difficult decisions, he or she may not be 100% sure of the decision that should be taken. The uncertainty differs per individual, risk and business value. In recent years, quantifying uncertainty regarding decision making has taken flight, e.g.: last year the US Office of Management and Budget (OMB) imposed such a requirement on US legislation: “for regulatory rules that exceed \$1 billion annual threshold, formal quantitative analysis of uncertainty is required.” [A2-2].

From a risk management perspective, the uncertainty can be used to set general guidelines on “when to invest” and “when not to invest”. If guidelines are to be actively used within an organization, they should be easy to use and intuitive.

To illustrate the application of setting investment boundaries the risk model (described before) is used. The investment boundary settings will be discussed in the following order:

- Uncertainty in frequency and consequence estimation
- Uncertainty in risk estimation
- Setting investment boundaries
- Example application

Uncertainty in consequence and frequency estimation: A human being tends to think in orders of magnitude rather than on a linear scale. Therefore, the lognormal frequency distribution function (3) is used for the uncertainty of human estimations.

$$f(x; \mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-(\ln x - \mu)^2 / 2\sigma^2} \quad (3)$$

In this equation μ represents the order of magnitude of the estimation and σ its standard deviation. On a linear scale, $\exp(\mu)$ represents the median.

The confidence bounds of a lognormal function are defined as a function of μ and σ in Table A2.1.

	Conf.	Lower	Upper
bound 1	68%	$\exp(\mu - \sigma)$	$\exp(\mu + \sigma)$
bound 2	95%	$\exp(\mu - 2\sigma)$	$\exp(\mu + 2\sigma)$
bound 3	99.7 %	$\exp(\mu - 3\sigma)$	$\exp(\mu + 3\sigma)$

Table A2.1 Upper and lower bounds for 68%, 95% and 99.7% confidence interval.

The confidence translation matrix used by NUON is a logarithmic scale. For our model to work, we assume that a person scoring an event will be 70% sure that the correct category is selected. This means that an approximation of a fitted lognormal can be made by using the first confidence bound and the weight as median. An example of the resulting lognormal function for consequence category “serious” is given in Figure A2.12.

Since all categories have the same standard deviation $\sigma = \ln(3)$ the confidence bound of the overall consequence of an event is also $\sigma = \ln(3)$.

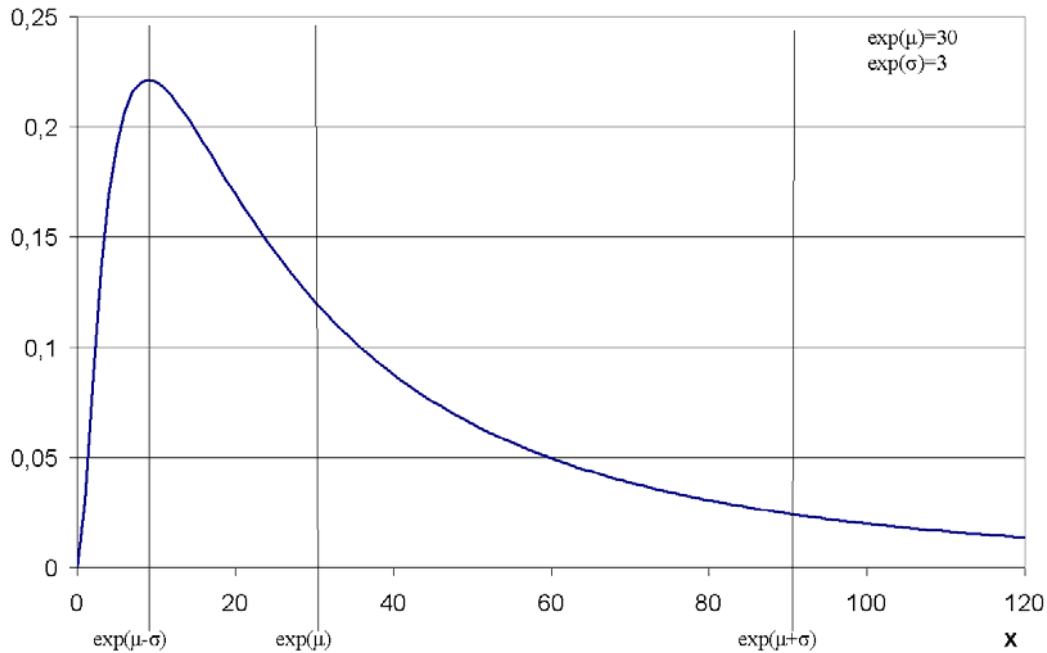


Figure A2.12 The approximated lognormal function inside consequence category “serious” with median 30 and a 68% confidence interval of [10...90].

The categories for the expected number of occurrences per year are also given in orders of 10. Approximation of the category of frequency is similar to the approach for the consequence categories.

Uncertainty in risk estimation: If the goal of an organization is to maximize its earnings, risk is defined as frequency multiplied by the consequences ($R_1=f \times C$). If both f and C are lognormal distributions with $f(\mu_f, \sigma_f)$ and $C(\mu_C, \sigma_C)$ then the resulting risk also has a lognormal distribution defined by equation (4).

$$\begin{aligned} \mu_{R1} &= \mu_f + \mu_C \\ \sigma_{R1} &= \sqrt{\sigma_f^2 + \sigma_C^2} \end{aligned} \quad (4)$$

In organizations, Risk is often acted upon as if were a simple multiplication of frequency and consequence. Within Nuon, risk perception is equal to the square root of frequency multiplied by the consequences: $R_2=\sqrt{f \cdot C}$. This also results in a lognormal function, but than with the characteristics given in equation (5).

$$\begin{aligned} \mu_{R2} &= \frac{1}{2} \mu_f + \mu_C \\ \sigma_{R2} &= \sqrt{\frac{1}{2} \sigma_f^2 + \sigma_C^2} \end{aligned} \quad (5)$$

Setting investment boundaries: Giving a monetary value to a risk can be done by looking at the value “finance” and frequency one per year. How much money are you willing to invest to reduce a yearly expenditure of 1 Euro per year. Logically, the maximum investment would be the same, 1 euro per year. Based on this it is relatively easy to translate the risk number into a monetary value.

Setting boundaries on when to invest and/or when not to invest depends on the certainty one wants to have that it is a wise decision. To set investment boundaries, one is helped with the confidence bounds on the risk. If one wants to have at least a 84%¹ assurance that the decision taken is the best one, the 68% confidence bounds can be used, see Figure A2.13. The same accounts for the 95%, 99.7% and 99.9+ confidence bounds. For investments within the confidence bounds no statement is made.

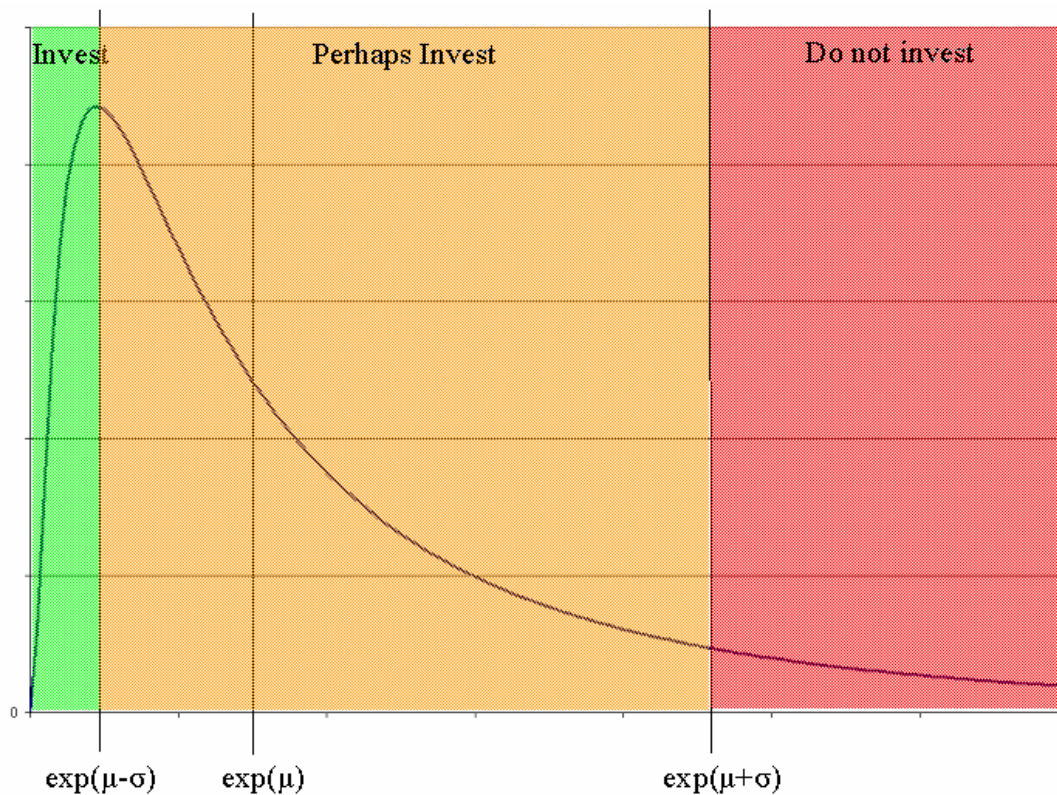


Figure A2.13 Investment Boundaries for a Lognormal Distributed Risk with Median $\text{Exp}(\mu)$ and Standard Deviation σ

¹ $84\% = 100\% - (100\% - 68\%) / 2$

	R=f x C		R = √f · C	
Confidence interval	68%	95%	68%	95%
Invest	< R / 4.7	< R / 22	< R / 3.8	< R / 15
Don't invest	> R · 4.7	> R · 22	> R · 3.8	> R · 15
For an example for a consequence of 30,000 and a frequency of once every 30 years.				
	R=1000		R=5477	
Invest	< 212	< 45	< 1441	< 365
Don't invest	> 4700	> 22000	> 20813	> 82155

Table A2.2 Practical rules for “do invest” and “do not invest”

If an investment proposal is within the confidence intervals a more detailed analyses might be considered taking into account all estimations and their uncertainty.

Example application: The risk evaluation matrix

The Risk Matrix of Figure A2.4 is applied by strategic management for investments exceeding 250 kEuro for at least one year. Calculating the investment bounds for a risk identical to the investment, results in Figure A2.14.

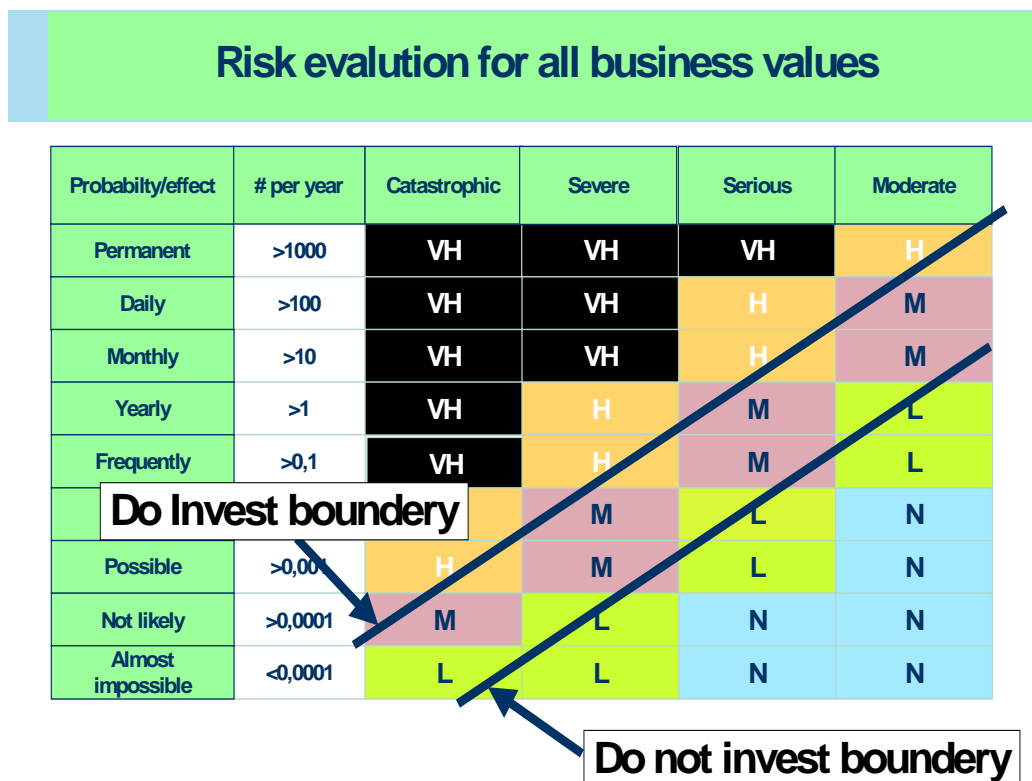


Figure A2.14 Risk Matrix and Investment Boundaries

Observe that the investment boundaries are spot on for an investment of 250 kEuro/year. It is interesting to note that Nuon strategic management created the risk evaluation matrix without calculating the theoretical boundaries. This is a prime example of “practice meets theory”.

Example Overall conclusion

Risk management means decision-making under uncertainty. Working with frequency distribution functions within an organization is complex, difficult to achieve and time consuming to do and to implement. It is imperative that risk management provide tools to support decision making, which are simple and intuitive to use. The model presented in this appendix is such a tool.

Example Literature

[A2-1] International Infrastructure Management Manual
Institute of asset Management, London, ISBN 0-473-09138-0

[A2-2] US Office of Management and Budget “Circular A4”, 2003