

Chapter 2

Asset, Risk and Maintenance Management

2.1 Introduction

Nowadays, asset, risk and maintenance management are three types of management that are heavily related to each other. Moreover, all three of them are frequently encountered in electricity network utilities and other asset intensive industries around the world. Therefore, they need to be studied and discussed in an integrated fashion. For instance, the aspects covered by asset management can range from maintenance and renewal of specific assets or asset groups all the way to the management or balancing of financial aspects with engineering and risk aspects for a large population of geographically widespread assets. The aim of this book is to investigate the research objectives as given in Sect. 1.2 for maintenance management in an integrated fashion with asset and risk management. Thus, in this chapter, the literatures covering these aspects are briefly discussed, both separately and in relation to each other.

2.2 Asset Management

2.2.1 *Asset Management as Business Approach*

Asset management is probably one of the most debated topics over the past decade (Lei Lai 2001; Wijnia and Herder 2009; Liyanage n.d.; van der Lei et al. 2012; Amadi-Echendu et al. 2010; Balzer and Schorn 2015; Woodhouse 2014). It has been used to label some very different processes and means different things to different players depending on where they are in the business. Even within the electricity network industry, asset management has been given a wide variety of interpretations. Indeed, within a single electricity network or power company, the interpretation may be different or change over time. Moreover, it has been recorded

(Lei Lai 2001) that the scope of asset management has developed with each stage of the restructuring of the distribution network business environment and is therefore set to do so again. Asset management should not be seen as just a “buzzword” (Brown 2010) management initiative. Throughout the literature, many definitions can be found for asset management. Later in this chapter, some important definitions of asset management are given.

In general, asset management is a business approach designed to align the management of engineering and asset-related financial spending to overall corporate goals. The objective (Brown and Humphrey 2005; CIGRE WG C1.16 2010; The Institute of Asset Management (IAM) 2014) is to make all asset-related decisions according to a single set of stakeholder-driven criteria. The idea of applying asset management to (engineering) asset intensive industries came from the well-developed *financial asset management* community (Brown 2010). Financial asset management is defined as follows: *making financial investments decisions so that returns are maximised while satisfying risk tolerance and other investor requirements*.

In principle, tangible (engineering and infrastructure) assets differ from financial assets in a way that they are susceptible to wear and deteriorate with age and can be impacted by disruptive technology developments (Manyika et al. 2013). Each installed asset is part of a larger power system and cannot be easily taken out and sold. These assets require inspection and maintenance. From this, it is found that asset management of electricity networks is not identical to financial asset management. A detailed description of the differences between financial and infrastructure asset management can be found in Brown (2010).

From a business point of view, asset management has the following goals:

- Balance cost, performance and risk,
- Align capital and operational spending decisions and corporate objectives and
- Make fact-based and asset data-driven decisions.

An organisation’s asset management framework should generally include an asset management policy, an asset management strategy and an asset management plan (The Institute of Asset Management (IAM) 2008; Anon 2014). These different hierarchies come together in an integrated way in an asset management system. Each hierarchy (policy, strategy or plan) has different typical priorities and concerns with different management timescales and levels of decision-making. In Fig. 2.1, a broad outline of the different hierarchies is provided. The accompanying levels of decision-making and timescale of concerned decision are also shown as levels of management, namely strategic, tactical and operational (The Institute of Asset Management (IAM) 2008; The Institute of Asset Management (IAM) 2014; Balzer and Schorn 2015).

At this point, many electricity network utilities have applied or are applying elements and concepts of asset management to target aspects of their business. Amongst these are for instance (Mehairjan et al. 2012, 2014; Coster et al. 2013; Buys et al. 2011; Soemeer 2013) equipment inspections and

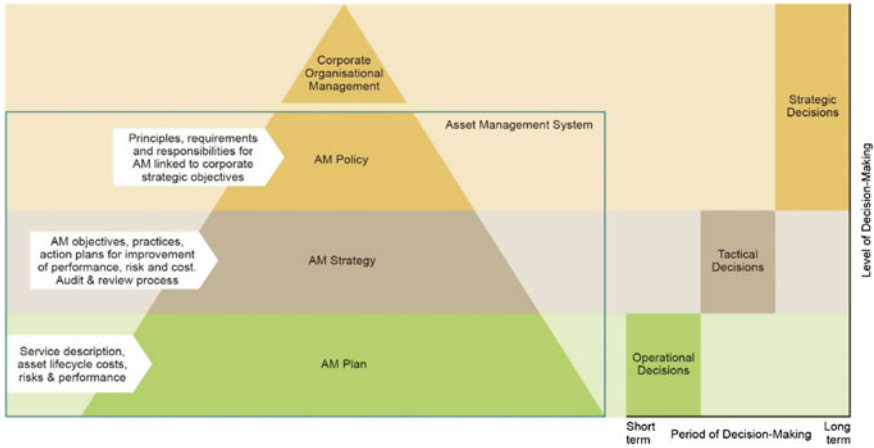


Fig. 2.1 The hierarchy of an asset management framework as an integrated system. The asset management policy, strategy and plan are defined within a corporate organisational management framework. The levels of decision-making and management, strategic, tactical and operational levels are also shown accordingly

maintenance improvement plans, condition monitoring, statistical data analysis, risk-based asset replacement models, etc.

2.2.2 Short History of Asset Management

Although the idea of asset management seems promising for managing electricity network companies in finding the optimal trade-off between cost, performance and risk in a regulatory regime, these companies have only recently started to embrace this concept (Brown 2010). In order to understand this, it is useful to shed some light on the history of asset management. In Table 2.1, a summary of important developments throughout the years is provided.

In the UK, asset management gained interest in the early 1990s during the privatisation period. OFGEM (Office of Electricity Gas and Electricity Markets) initiated an *Asset Risk Management* Survey in 2002. In the period following this survey, OFGEM started requiring the submission of annual asset management plans from its regulated entities. Afterwards, a collaboration of OFGEM, the Institute of Asset Management (IAM) and a review panel, the *Publicly Available Specification 55: Asset Management (PAS-55)* was written. PAS 55 was first published in 2004 and substantially revised in 2008, which is elaborated in Sect. 2.2.3.

The USA has also seen an increased interest in infrastructure asset management, however in a less formal way. Mainly, targeted conference and consulting services have been deployed. Here, the focus has been on the deployment of information systems that enable effective asset management such as maintenance management

Table 2.1 Brief history of important developments in the field of asset management

Type of industry	Element of asset management	Detailed description
US nuclear arsenal (1960)	Analysis of military policy planning in a nuclear age for most efficient allocation of available budgets	
Heavily regulated industries such as petroleum refining and chemical processing	Quantitative risk management	
Manufacturing industries	Focus on optimising process uptime and system availability	Known as <i>physical asset management (PAM)</i>
Public infrastructures such as roadways and water supply systems	Set performance measures and targets Report actual performance against targets and add financial systems and policies	New Zealand Local Government Act (1974) Asset management requirements were expanded in 1996 to require ten-year infrastructure plans that consider the costs and benefits of various infrastructure options. In order to provide consistency, the <i>Infrastructure Asset Management Manual</i> was published in 1996 by the Association of Local Government Engineers of New Zealand

systems, asset databases and project ranking tools. The *Electric Power Research Institute (EPRI)* has reported an organised approach with the Nuclear Asset Management (NAM) programme and the Asset Management Toolkit (AMT). Amongst the publications by EPRI, a widely used one is the *Guidelines for Power Delivery Asset Management* published in 2004, revised in 2005 and rewritten in 2008 to align more with PAS-55.

Given the popularity of PAS-55 and the continuing interest in asset management, and after consultation with industry and professional bodies around the world, this specification was put forward in 2009 to the *International Standards Organization* as the basis for a new ISO standard for asset management (The Institute of Asset Management (IAM) 2008). This was approved, and the resulting *ISO 55000* family of standards has been developed over a period of four years with 31 participating countries and has been published in January 2014 (Anon 2014).

The field of asset management has also conglomerated with the field of engineering. Under the auspices of the *International Society of Engineering Asset Management (ISEAM)*, engineering asset management is focusing on life cycle management of the physical assets required by private and public firms. The purpose is to make products and for providing services in a manner that satisfies various business performance rationales. In a number of reviewed publications and

books (van der Lei et al. 2012; Amadi-Echendu et al. 2010, 2012), this community provides a broad view of the inter- and multidisciplinary approach which combines science, engineering and technology principles with human behaviour and business practice. In the *International Journal of Strategic Engineering Asset Management*, this multidisciplinary practice has been extensively reported on Liyanage n.d.

2.2.3 *Publicly Available Specification 55: Asset Management (PAS-55)*

A brief summary of PAS-55 is given here. As mentioned earlier, in 2004, the British Standards Institution (BSI), together with the IAM released the PAS-55 parts 1 and 2, being the first internationally recognised specification for asset management (The Institute of Asset Management (IAM) 2008). PAS-55 offers guidelines and good practices to enable the optimal management of physical assets and infrastructures over their life cycle. In order to manage the physical assets over their life cycle, the management of other asset types (being non-physical) should also be considered within the asset management system. This way of thinking is incorporated in the PAS-55. For instance, for the management of the life cycle of physical assets, a company heavily depends on the information, knowledge and financial resources. This specification provides a framework for improving the effectiveness of the lifecycle management of physical assets, especially in capital intensive environments, such as electricity, gas and water networks, airports, and railways.

In 2008, the specification was substantially revised and updated. PAS-55 has received worldwide attention from regulators and other regulated industries as a tool for integrating and improving business practices, raising performances and assuring greater consistency and transparency. Basically, the PAS-55 advocates the removal of “silos” in companies and considers assets in “systems” instead. By doing this, a cross-functional optimisation of the life cycle of assets can be achieved as a core principle of good asset management (van der Lei et al. 2012). In the Netherlands, the Energy Court has even set up a Dutch standard known as *NTA 8120* in 2009 for the management of electricity and gas networks based in PAS-55.

PAS-55 is published in two parts:

- Part 1, PAS-55-1:2008: Specifications for the optimised management of physical assets.
- Part 2, PAS-55-2:2008: Guidelines for the application of PAS-55-1.

The specification provides 28 requirements and guidelines for the application and is structured around the well-known *Plan–Do–Check–Act* cycle for continual improvement.

In [PAS-55-1:2008], asset management is defined as: “*systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets and asset systems, their associated performance, risks*

and expenditures over their life cycles for the purpose of achieving its organisational strategic plan". The organisational strategic plan is defined as: "*overall long-term plan for the organisation that is derived from, and embodies, its vision, mission, values, business policies, stakeholder requirements, objectives and the management of its risks*".

2.2.4 ISO 55000 Series

The *PAS-55* can be seen as a groundwork which was laid in order to develop the *PAS-55* into a standard, and in 2009, this specification was put forward to the International Standards Organization as the basis for a new ISO standard for asset management. In January 2014, the *ISO 55000* family of standards for asset management was published (Anon 2014). In accordance with the *ISO 55000*, the Energy Court in the Netherlands also updated the Dutch standard to *NTA 8120:2014*. The *ISO 55000* is published in three documents:

- *ISO 55000* Asset Management—Overview, principles and terminology,
- *ISO 55001* Asset Management—Management systems—Requirements and
- *ISO 55002* Asset Management—Management systems—Guidelines for the application of *ISO 55000*.

In the *ISO 55000*, the most important features of the *PAS-55* are represented and expanded upon.

The features in the *ISO 55000* series are as follows (Anon 2014):

- The alignment of the organisational objectives to the asset management strategies, objectives, plans and day-to-day operational activities.
- The use of whole lifecycle asset management planning and cross-disciplinary collaboration to achieve the best value.
- The use of more risk management and risk-based decision-making processes.
- The enablers for integration and sustainability especially leadership, consultation, communication, competency development and information management.

As *PAS-55* was primarily focused on physical assets, the *ISO 55000* standard has been extended to apply to any asset type. By doing this, the intention is to make asset management more general for interpretation within different asset management contexts. In *ISO 55000*, asset management is defined as follows: "*a coordinated activity of an organisation to realize value from assets*". Although the detailed description of *ISO 55000* is beyond the scope of this thesis, a number of relevant elements from this standard to the content of this thesis are explained for maintenance management. For instance,

- Regarding decision-making: In *PAS-55*, requirements for optimising decision-making (between cost, performance and risks) were given. In *ISO 55000*, it is explained that clear and documented methods and criteria for

decision-making and prioritising are required to reflect stakeholder needs. This will certainly be a crucial point for maintenance management in electricity distribution networks in future. At this moment, we have seen in many parts of distribution networks and even parts of transmission network that complete documentation is lacking regarding maintenance management spending and strategies.

- Regarding risk management: Risk management and risk-based decision-making in *ISO 55000* are based on the published *ISO 31000* risk management. For maintenance management in general, and for maintenance management of electricity distribution networks in particular, the method of risk-based maintenance is still underdeveloped.

The discipline of asset management has, undoubtedly, shown a growth of interest internationally over last years. It has been reported in the literature (Wijnia et al. 2011) that despite these developments, there is not yet a clear and unified basis available that provides a reference across different industrial sectors (Wijnia and de Croon 2014).

In IEC White Paper (2015), it has even been reported that *“the current lack of international standards or guidelines on asset management for electrical networks will have a significant impact on the reliability and future viability of the electricity sector”*. Electricity network companies regularly adopt different approaches in testing equipment, calculating the lifetime and financial costs of various equipment maintenance options and even reporting on the performance of their system. This is hardly intentional, but rather *“stems from a lack of internationally accepted global standards or guidelines on how to practice asset management in the electricity network sector”*. Moreover, it has been reported that *“whilst standards such as the ISO 55000 series provide general guidance on best-practice asset management procedures, they do not provide the industry-specific guidance that is needed given the operational methods and challenges of the electricity transmission and distribution industry”* (IEC White Paper 2015).

2.3 Risk Management

2.3.1 Risk Management as Decision-Making Method

In a business environment, stakeholders and regulators expect from network companies that information is presented in an understandable way. Risk-based methods, explaining information in terms of risks and probabilities, have increasingly been applied in asset management (CIGRE WG C1.16 2010; Rijks et al. 2010; CIGRE WG C1.25 2013). These methods help in expressing and presenting decisions in financial terms related to risks. As a consequence, this has forced electricity network companies to record, document and analyse data and practices in a structured way and to use a consistent and transparent method for analysis. In this

context, risk management is seen as a mainstream regime to enable the asset managers to translate corporate business values and requirements into a comparable, measurable and management dimension, namely *risk* (CIGRE WG B3.06 2014). Risk management can be subject to great misunderstanding, as has been reported in Balzer and Schorn (2015) because risk management does not that risks are deliberately accepted to meet the business objectives. The task is to identify risks within the entire business process to initiate subsequently and implement appropriate measures to manage (control) these risks.

Risk is defined as the product of the *probability* of an event and its *consequences* (ISO 31000:2009 2009). Generally speaking, the existence of risks implies that there is at least the possibility of negative consequences or deviations from expected values when an event has a probability to occur. Essential for risk management is that it is not just limited to solely technical risks of the network utility, but also extends to the management of risks involving the analysis of events for a complete system (i.e. organisation, network and asset) that might have a negative impact (Jones 1995). Moreover, the management of risk involves the decision-making process of measures to assess risks and the evaluation of these measures (CIGRE WG C1.16 2010).

In such a socio-technical business model, the corporate mission, vision and strategy are connected to overall corporate business values. Although every network utility may develop unique business values, some generic, and widely adopted, business values are as follows:

- Quality (customer minutes lost/worst-served customer),
- Safety (injuries to personal and third parties),
- Finance (financial consequences),
- Image (reputation) and
- Compliancy (regulations and legislations).

Basically, in order to pose a certain risk, this issue should have an influence on the business values of the network company (Beukers et al. 2014). Depending on the organisation management, it is often useful in practice to focus on a number of these business values. For example, it is reported in Balzer and Schorn (2015) that risks in area of safety will not be accepted due to laws (i.e. in Germany). In Appendix A, an overview of different business values applicable to risk management is provided. In Fig. 2.2, the business values, as part of a risk management methodology, for a typical electricity distribution network company, are shown (Beukers et al. 2014).

A risk is assessed in a way that the effect on a business value and the probability of occurrence of the effect can be scored. To ensure objectivity of the risk analysis, the probability and consequences are first assessed separately and afterwards combined to form an assessment of the risk. In order to score risks, a set of possible effects is added to each business value (Beukers et al. 2014). The effects relating to safety, quality of supply and finance are shown in Fig. 2.3.

BUSINESS VALUES	
A	SAFETY Minimisation of risks to company personnel and third parties due to the presence of infrastructure and work done on it.
B	QUALITY Quality and availability of goods and services in accordance with stakeholders views.
C	FINANCIAL Financial performance according to the asset owner's requirements.
D	LAW AND REGULATION Operation within the boundaries posed by * the licence to DSOs and the regulation by governmental and legislative bodies, * other agreements
E	IMAGE The extend to which support is given to a desirable image of Stedin at stakeholders influenced by Stedin or influencing Stedin.

Fig. 2.2 Corporate business values for risk management methodology at a Dutch electricity and gas distribution company

	Safety	Quality of Supply		Financial performance
		Worst served customer	Average	
Very Serious	≥1 dead or permanently disabled; >1 heavy injury; >10 medium injuries; >100 light injuries;	over 9 interruptions/year	ΔSAIDI over 20%* regulatory target	Damage, fines or avoided costs over € 1,000,000
Serious	1 heavy injury; 2-10 medium injuries; 11-100 light injuries;	5-8 interruptions/year	ΔSAIDI between 2% and 20% of regulatory target	Damage, fines or avoided costs between € 100,000 and € 1,000,000
Small	1 medium injury; 2-10 light injuries;	3-4 interruptions/year	ΔSAIDI between 0.2% and 2% of regulatory target	Damage, fines or avoided costs between € 10,000 and € 100,000
Minimal	1 light injury	2 interruptions/year	ΔSAIDI between 0.02% and 0.2% of regulatory target	Damage, fines or avoided costs between € 1,000 and € 10,000

*Regulatory system average interruption duration index (SAIDI) target 2010-2016: 25 minutes/year per customer.

Fig. 2.3 Effect evaluation matrix for business values safety, quality of supply and finance for a Dutch electricity and gas distribution company

After the effect has been scored, the probability of the occurrence is scored. The probability of the effects can be scored on a multicategory scale, ranging from almost impossible (e.g. less than once in a thousand years) to daily (e.g. more than 100 times a year). When the effect scales are combined scales with the probability scales, a typical two-dimensional risk assessment matrix can be used to categorise the rank of each evaluated risk as shown in Fig. 2.4.

After the risk assessment, the next step is the treatment of the risk, namely the determination of alternative solutions to deal with the risk. Dealing with the assessed risk can include decisions such as accepting the current risk, taking an action and investing in capacity expansions, maintenance, refurbishment,

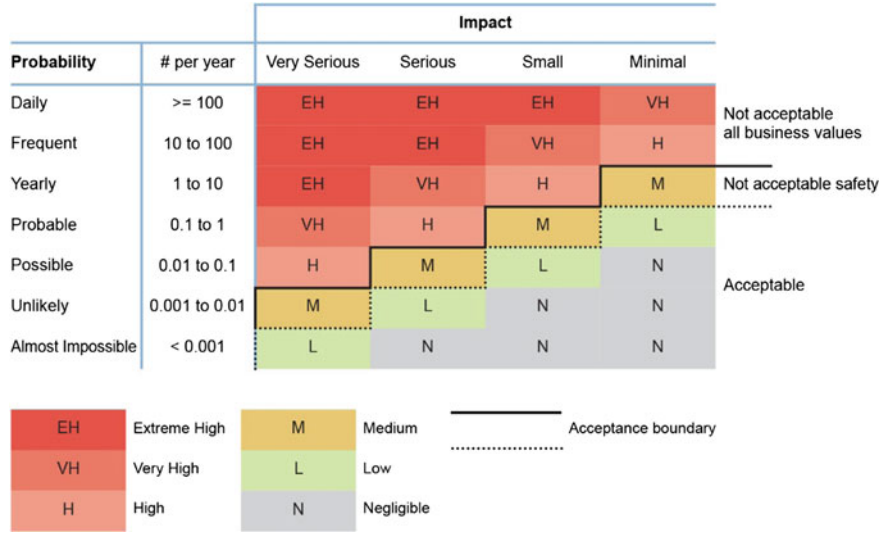


Fig. 2.4 Risk acceptance matrix, which represents the risk values, from negligible to extremely high. The *blue lines* mark the acceptance boundaries. Risks below and to the right of the lines are acceptable, and risks above and to the left of the lines are not acceptable. Unacceptable risks must be mitigated to an acceptable level

replacement or other operational procedures (i.e. restoration of outages, improved business processes, information system and data quality improvements).

Overall, risk management, as a regular business process, provides a method to identify, assess and treat an organisation risk to account for future events with a negative impact on the organisation. Furthermore, it creates an awareness of socio-technical assessed risks and possibilities to treat them. Added to this, the application of an objective risk management approach enables network utilities to have control over risks and have a common language for sharing and discussing risks between management and engineers. It is also used to quantify and support arguments for budgets and portfolio planning. Network utilities use risk management for several aspects, for example, new investment projects and expansion investments.

2.3.2 Risk Management Standards

General risk management standards that are published are as follows (ISO 31000:2009 2009):

- ISO 31000:2009—Risk Management: provides generic guidelines on risk management,

- *ISO Guide 73*—Risk management vocabulary and
- *ISO 31010:2009*—Risk assessment techniques.

In the *ISO 31000:2009*, an overview of a general risk management decision-making process is given as shown in Fig. 2.5 (ISO 31000:2009 2009).

In ISO 31000:2009 (2009), risk management is described as an assessment that provides decision-makers and responsible parties with an improved understanding of risks that could affect achievement of objectives and the adequacy and effectiveness of controls already in place. This provides a basis for decisions about the most appropriate approach to be used to treat the risks. The output of risk assessment is an input to the decision-making processes of the organisation. Risk assessment is the overall process of risk identification, risk analysis and risk evaluation (see Fig. 2.5). The manner in which this process is applied is dependent not only on the context of the risk management process but also on the methods and techniques used to carry out the risk assessment.

In the Dutch extract of PAS-55, namely NTA 8120:2009, risk management for gas and electricity network asset management is described on the basis of the ISO 33000 guidelines. More specific industry (electricity network)-related information regarding risk management can be found in CIGRE WG C1.16 (2010), CIGRE WG B3.06 (2014), CIGRE WG C1.1 (2006), and Rijks et al. (2010).

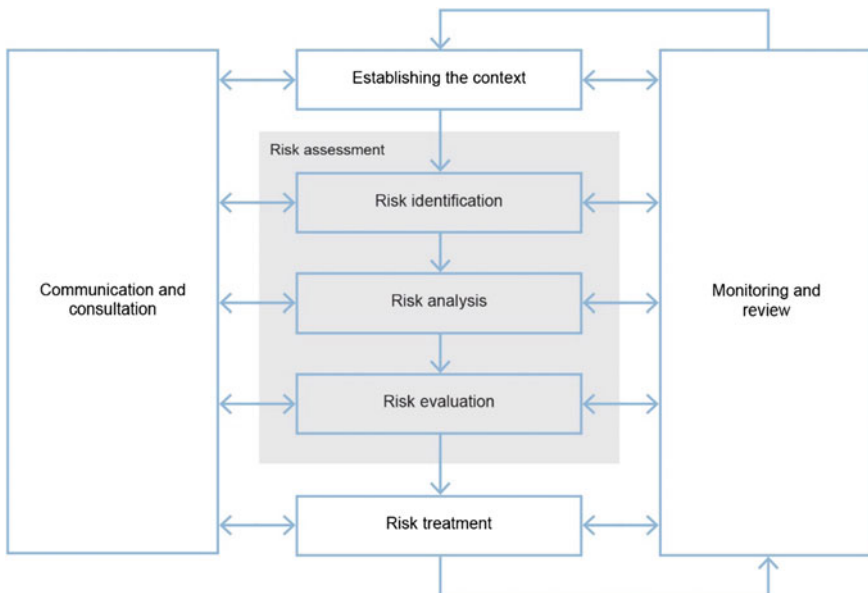


Fig. 2.5 ISO 31000:2009 risk management decision-making general process (ISO 31000:2009 2009)

2.4 Maintenance Management

2.4.1 Definitions

A substantial amount of the literature is available from various resources and industries in the field of maintenance management. A comprehensive overview can be found in Garg and Deshmukh (2006) and Fernandez and Marquez (2012). There are a lot of terms used interchangeably and mixed in available literature and across the industry. Therefore, in this section, common terminology and definitions are set out which are relevant and applicable to this thesis.

In IEC 60300-3-14 of 2004 (IEC-60300-3-14:2004 2004), application guide-maintenance and maintenance support, maintenance is defined as follows: *“the combination of all technical, administrative and managerial actions during the lifecycle of an item intended to retain it in, or restore it to a state in which it can perform the required function”*.

Maintenance management is defined as follows: *“all the activities of management that determine the maintenance objectives or priorities, strategies and responsibilities and implement them by means such as maintenance planning, maintenance control and supervision, and several improving methods including economical aspects”*.

From these definitions, it can be found that in the current business environment, maintenance and maintenance management are considered as highly complex fields involving many disciplines within a company such as operations, information technology, economics, safety, risk, analytics, and accounting (Fernandez and Marquez 2012).

Maintenance action/maintenance task is defined (IEC-60300-3-14:2004 2004; Pintelon and van Puyvelde 2013) as follows: *“basic maintenance intervention or sequence of elementary maintenance activities carried out by a technician for a given purpose”*.

Maintenance policy is defined (IEC-60300-3-14:2004 2004; Pintelon and van Puyvelde 2013) as follows: *“rule or set of rules describing the triggering mechanisms for the different maintenance actions”*.

Maintenance concept is defined (IEC-60300-3-14:2004 2004; Pintelon and van Puyvelde 2013) as follows: *“set of maintenance policies and actions of various types and the general decision structure in which these are planned and supported”*.

Maintenance support is defined (IEC-60300-3-14:2004 2004; Pintelon and van Puyvelde 2013) as follows: *“resources required to maintain an item under a given maintenance concept and guided by a maintenance policy”*.

2.4.2 Maintenance Action, Policy and Concept

In principle, two types of maintenance actions or tasks can be found. It can be either *corrective* or *preventive* (Zaal 2011; Smith 1992; Moubray 1997; Nowland and

Heap 1987; Wilson 1999). A brief description of each of these maintenance actions is given below:

- *Corrective Maintenance*: Corrective maintenance is essentially leaving all assets running until failure and then replacing part of the assets that have failed. During the time, corrective maintenance is being scheduled and performed (usually referred to “break-in”, because they “break-in” to the schedule prepared), the asset is inactive. As a general rule, a breakdown is often ten times more expensive compared to the situation that the failure can be identified and corrected (or prevented) in a planned and scheduled manner. Until now, the majority of components in distribution networks remain correctively maintained. However, with the adoption of AM, utilities are becoming aware of the changing requirements for maintenance (Mehairjan et al. 2014). Corrective actions are difficult to predict because failure behaviour is stochastic and outages in a network causing interruptions are usually unforeseen.
- *Preventive Maintenance*: The primary upgrade from corrective maintenance to preventive maintenance is by means of maintenance plans and schedules. Broadly speaking, preventive maintenance plans describe the methods of inspections and maintenance tasks which can efficiently improve the reliability of physical assets. A shift from corrective to preventive maintenance will, inevitably, require some initial investment; however, it will eventually result in moderation of the total volume of planned work and will allow for control of maintenance hours and workload. When preventive maintenance is applied on an asset item, it is called a preventive task. Subsequently, the timeline of the preventive task in an asset population is called the preventive schedule. This is why preventive scheduling will, eventually, result in arranging maintenance resources in advance, which, in turn, will considerably accelerate maintenance delivery and reduce operational costs (note, however, that an initial, increased investment in the transition period is possible, but will decrease once in a controlled period) (Mehairjan et al. 2014).

The European Standard EN 13306:2010 shows this graphically (Fig. 2.6):

Moreover, each of these maintenance actions or task categories can be triggered by a mechanism, which is usually denoted as a maintenance policy. Examples of maintenance policies are as follows: *failure-based maintenance (FBM)*, *time-based maintenance (TBM)*, *condition-based maintenance (CBM)*, and *risk-based maintenance (RBM)*. A maintenance policy, on the basis of a trigger, determines why a maintenance task (corrective or preventive) is assigned (Pintelon and van Puyvelde 2013). A brief description of the earlier mentioned maintenance policies is given here:

- *Failure-Based Maintenance (FBM)*: A maintenance action is carried out only after a breakdown. The trigger is therefore purely reactive, and with FBM, no planning is possible. In this context, FBM requires a sound spare part policy.
- *Time-Based Maintenance (TBM)*: A policy in which precautionary maintenance actions are carried out triggered by a predetermined scheduled interval. This is a

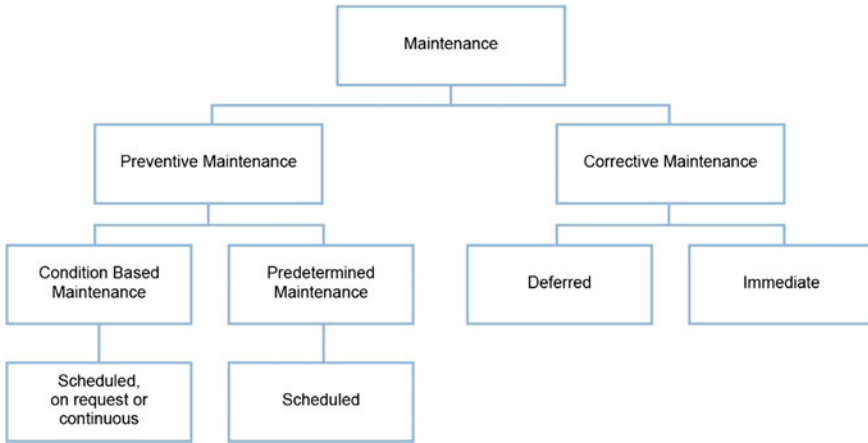


Fig. 2.6 Maintenance methods' breakdown according to EN 13306:2010

periodic policy. The time intervals are decided according to asset type and fixed for the whole life cycle (usually with reference to manufacturer's instructions and updated with historic operational and failure behaviour). In the literature, this policy is commonly denoted as a preventive policy (Pintelon and van Puyvelde 2013). The periodic policy can also be triggered by the use of the component, such as number of switching actions or operating hours. In general, the preventive action coming from this policy may constitute of component replacements or may also be cleaning, lubricating, adjusting, etc.

- *Condition-Based Maintenance (CBM)*: Basically, condition-based maintenance differs from time-based maintenance in the sense that a shift is made in scheduling methods, namely from a periodic method to a “fully” predictive method. Therefore, CBM is a predictive policy. Being predictive refers to estimating the probability of failures on assets. With condition-based maintenance, an early indication of an impending failure (by applying condition monitoring, diagnostics or inspection methods) can be detected and the consequences of an unexpected failure can be avoided. CBM can use fairly low-level methods such as human senses for inspections (denoted as detective-based maintenance) or deploy sophisticated monitoring and diagnostic tools (denoted as predictive-based maintenance). More advanced is the use of various monitoring parameters and network condition to predict remaining lifetimes of component (denoted as prognostics or health-based maintenance) (Bajracharya 2014).
- *Risk-Based Maintenance*: The state-of-the-art maintenance policy is the risk-based version, which is guided by the principles of risk management. A risk is composed of a stimulus (i.e. the root cause) and its consequences. The risk-based approach refers to the quantitative assessments of (1) the probability of stimulus (event) and (2) on business values [key performance indicators

(KPIs)] evaluated consequences. In the planning of maintenance, the stimuli are the failure modes for risk-based maintenance, which brings the term failure mode and effect analysis (FMEA). In scheduling risk-based maintenance, the potential failures on asset items are the stimuli. The probabilities of these stimuli are highly recommended to be derived from condition diagnosis (hence the importance of the upcoming role of condition monitoring in a risk-based management regime). However, in practice, FMEA is mainly based on failure statistics if not expert judgements. The consequences of failure modes and potential failures are, if at all possible, measured with a number of KPIs, such as customer minute loss, financial loss and safety. These KPIs connect the operational-level maintenance tasks with high-level corporate business values. In practice, this link of consequences and failure modes through a certain KPI framework is not yet applied and most of the time not straightforwardly implementable for distribution companies. This will be discussed in Chap. 3 of this thesis. Decisions on preventive maintenance plans or schedules are based on the risk register of failure modes or potential failures. Risk register is a process to rank the expected value of risks, while the expected value is the multiplying product of probability and consequence.

In the literature, more variations of maintenance policies can be found such as *design-out maintenance* (a proactive policy). More literature on this can be found in Fernandez and Marquez (2012), Pintelon and van Puyvelde (2013), Smith (1992).

In practice, a set of maintenance policies and actions of various types exists and requires a general decision-making structure for selecting amongst them. This is known in the literature (Pintelon and van Puyvelde 2013) as maintenance concepts. The literature provides a wide range of maintenance concepts that have been developed through a combination of theoretical knowledge and practical experience. In Pintelon and van Puyvelde (2013), a summary of the most popular maintenance concepts and their characteristics is given and illustrated here (Table 2.2).

In Fig. 2.7, maintenance actions, policies and concept as related to each other are shown (Pintelon and van Puyvelde 2013). It is not always clear from the literature whether for example a RCM-related maintenance concept is a concept or a policy. There are literature sources available that state that RCM can be seen as a priority-oriented policy for instance (Balzer and Schorn 2015).

2.5 Developments and Supporting Pillars of Maintenance Management

2.5.1 *State-of-the-Art Maintenance Management Developments*

In the overview and description of maintenance tasks, policies and concepts given in the previous section, it has been shown that there is a rich amount of literature on

Table 2.2 Summary of popular reported maintenance concepts and their characteristics (Pintelon and van Puyvelde 2013; Balzer and Schorn 2015)

Maintenance concept	Description
Quick and dirty (Q&D)	A decision chart with a number of questions on failure behaviour of assets is made taking into account the business context, maintenance capabilities and cost structure. By following the chart and answering the questions, a number of recommendations for an appropriate policy are found. Usually, companies develop tailor-made Q&D decision charts. No in-depth analyses are used in this method. It is seen as a quick method to set some priorities
Lifecycle cost (LCC)	This is a methodology to calculate and to follow up on the whole cost of a system from inception to disposal. All expenses for purchase, operation and disposal of an investment, including project costs, are taken into account. This method originates from the 1960s and is gaining interest again, perhaps due to the focus on life cycles in PAS-55 and ISO 55000. The method follows a number of steps according to a detailed breakdown structure of the cost of the system under investigation over the lifetime. This method is based on a sound philosophy; however, it is both resource and data intensive. Another approach commonly used is the total cost of ownership (TCO) method, which can be seen as an expansion of the LCC. In TCO calculations, expenses or indirect cost elements are added such as unproductive use of equipment and entire supply chain costs for the business
Total productive maintenance (TPM)	TPM aims at getting the most efficient/effective use of equipment (overall equipment effectiveness (OEE)). In this method, total participation (organisation-wide) is needed. TPM mainly promotes the implementation of preventive maintenance tasks based on small group tasks. This method has been successful in the manufacturing industry. It considered human and technical aspects; however, it is time-consuming to implement
Reliability-centred maintenance (RCM)	RCM is a structured approach focused on the reliability and was initially developed for high-technology and high-risk component of systems (environments). It is a powerful approach based on a step-by-step procedure; however, it is resource intensive and time-consuming. RCM will be discussed in more detail later on in this chapter as it forms an important focus area in this thesis
RCM-based	In the literature, various methods/concepts inspired by RCM principles can be found. For instance, Gits developed an RCM-like concept where the focus is on technical and organisational aspects rather than on economic aspects. Coetzee states that RCM is a core methodology to ensure that an organisation can achieve world-class results. However, a new RCM is proposed in this concept where quality improvement tasks, focus on most important failure modes in the company and the elaboration of task packaging are new features. Also, the incorporation of sound management principles is introduced in the implementation of RCM. Risk-based maintenance (RBM) (Jones 1995) is basically RCM, however, with a strong statistical background. In doing this, the drawbacks from ad hoc FMEA in

(continued)

Table 2.2 (continued)

Maintenance concept	Description
	traditional RCM and too much of experience knowledge based on gut feelings are reduced. In the literature, RBM is sometimes seen as a maintenance policy or maintenance concept, as mentioned earlier in this section. Streamlined RCM is seen as a simplified or abbreviated version of the traditional demanding RCM method, usually promoted by industrial leaders. Nevertheless, streamlined RCM should be carefully applied in order not to lose the RCM benefits
Customised	These concepts are usually in-house-developed using the benefits of existing concepts. Examples are value-driven maintenance (VDM) in which the management of shareholder values are linked to traditional maintenance philosophies. Companies usually have their own, unique, prioritised method and would like to use the benefits of multiple existing maintenance concepts
Lean maintenance	Lean maintenance comes from the idea of lean manufacturing. Lean means reassigning resources to more value-added work, eliminating all waste of work, effort and material. Lean maintenance uses tools from the quality management field. Lean maintenance is a proven concept in, for example, Toyota

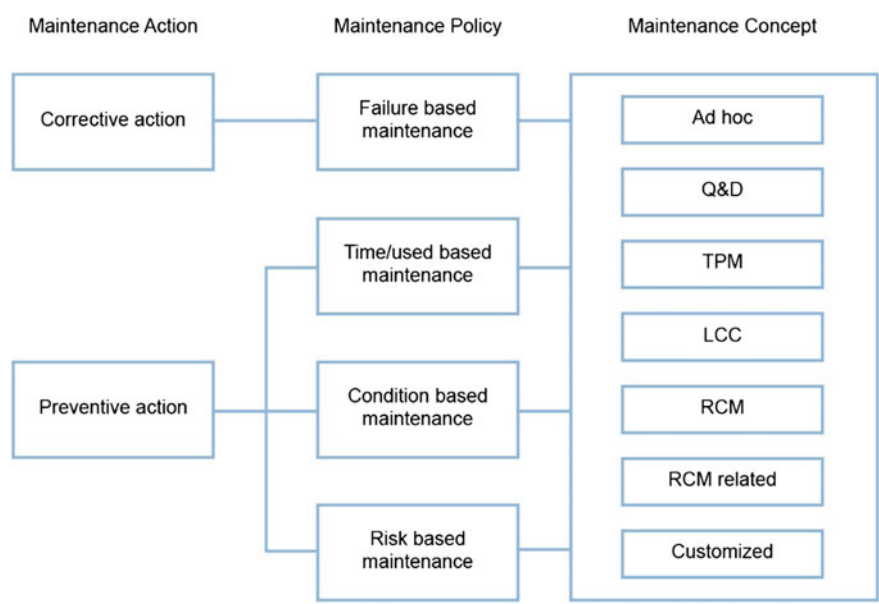


Fig. 2.7 Interrelationship of the different definitions of maintenance action, policy and concept with each other. Two fundamental maintenance actions exist, e.g. corrective and preventive. Maintenance policies are the mechanism that triggers a maintenance task, such as a calendar plan, a condition state or a certain risk level. Maintenance concepts are the previously conducted decision-making procedures or analyses that are necessary for selecting amongst a maintenance policy

aspects of maintenance management available. In this context, we have found that maintenance management has changed drastically over the past decades. In the electricity network sector, similar developments have taken place as a result of the changing maintenance environment. Nowadays, there are different degrees of mixed maintenance tasks, policies and concept implemented in transmission and distribution electricity networks.

Although maintenance management is evolving from reactive (corrective) to more and more preventive and proactive maintenance regimes, a complete migration to a single task, policy or concept is unlikely. In Fig. 2.8, the development in maintenance management as evolved over the past is shown (Moubray 1997; Jones 1995; Pharmatrisanti 2012; Zhuang 2015). This is, however, a general representation of maintenance management regimes and not necessarily reflects the situation for electricity networks. The developments have followed a slower pace in this sector. Mainly, as result of the long lifetimes of power system assets in relationship to the redundantly design networks and stations. Maintenance could in this sense be postponed for longer periods compared to other sectors. Due to the fact that these assets are gradually coming to the end of their technical lifetimes, maintenance management and replacement strategies are crucial aspects in managing the populations of assets. Nevertheless, these trends are happening as well for transmission (started earlier) networks and more recently at a faster pace in distribution networks. The evolution in maintenance management, according to the majority of literature review, can be summarised and depicted as shown in Fig. 2.8.

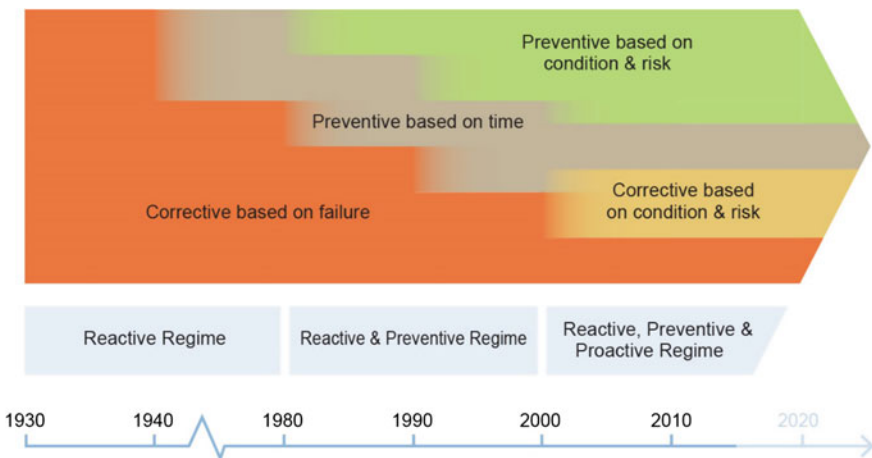


Fig. 2.8 Maintenance evolution in policy implementation

2.5.2 *Supporting Pillars for Maintenance Management*

Obviously, maintenance management has evolved, based not on solely technical grounds, but rather on techno-socio-economic considerations. Therefore, it becomes clear that maintenance cannot be managed as a purely technical and technological function only (Pintelon and van Puyvelde 2013). Maintenance management has to take into account and deal with aspects such as financial insights, the management of maintenance budgets, the management of resources and skills, adopting maintenance processes for effective measurement of the contribution of maintenance to the overall business, data and data quality and computerised maintenance management systems (CMMSs) (Fernandez and Marquez 2012). Thus, maintenance management has to take into account a myriad of considerations. Having said this, the literature, however, reports (Fernandez and Marquez 2012) that many utility network companies have difficulties in practice with enabling an integrated view for maintenance management. According to Fernandez and Marquez (2012), this is mainly due to the lack of essential supporting pillars for maintenance management from an organisation-wide (business) point of view. For network utilities, the essential supporting pillars to enable a foundation for sound maintenance management are Fernandez and Marquez (2012), Jardine and Tsang (2013):

- *Process management*: Maintenance management based on the process management is according to a reasonable strategy. It is required to have methodologies which allow clear definition of the processes, their execution and data requirements. The aim of having maintenance management processes is to improve the efficiency through the management of business processes that are modelled, automatised, integrated, controlled and continuously optimised.
- *Quality management*: In network utilities, the management of quality is concerned with the quality of the service provided through the network. In general, it can be said that the performance of the quality of the service that is delivered is determined by the design, operational status or condition, proper operation and proper maintenance of the network. The level of performance to ensure proper service is achieved by having processes of continuous improvement, incorporation of diagnostic and monitoring tools, analytical methodologies and new technologies.
- *ICT management*: Because maintenance management is considering more and more information from the business environment, information and communications technology (ICT) is beneficial for the optimisation of maintenance management due to the proper exchange of updated information and coordination of automated procedures. The proper exchange of information and the coordination is important for maintenance management; however, interoperability amongst different systems (and vendors) is required to ensure this.

- *Knowledge management*: Knowledge management is the key for proper maintenance. Maintenance requires up-to-date data, information and knowledge about assets. Basically, this is needed for the planning, scheduling and execution of maintenance and the continual improvement of this process. Most of the time in electricity networks, there is a large amount of dispersed knowledge available amongst technical workers, specialists and managers. However, due to the dispersions or lack of methodologies that extract this knowledge, it remains unprofitable and inaccessible.

More general details of these supporting pillars can be found in Fernandez and Marquez (2012). In Chap. 3, the implications of supporting pillars with similar characteristics in practice on the improvement of a maintenance organisation will be discussed in more detail together with a case study of its applications.

2.6 Conclusions and Outlook

2.6.1 Conclusions

In this chapter, a brief overview was given and an investigation of the relevant literature on the underlying arguments for asset management, risk management and maintenance management was performed. Asset management is widely argued in the literature as an *umbrella* subject which can encompass many aspects for the management of asset intensive industries. In this book, asset management is described in the context of infrastructures or physical asset management. The history and development of asset management and the coming into being of PAS-55 specification were provided. Since 2014, asset management has been adopted in the ISO 55,000 series as an international standard. This illustrates the rather recent (at the moment of writing) history of asset management and therefore an interesting field and subject for many asset intensive companies worldwide.

Moreover, the principles of risk management within an asset management-oriented environment were discussed. In general, risk can be seen as a dimension which makes it possible to have a measureable, comparable and management entity, which, at the same time, is understandable and communicable to management layers for making decisions.

Subsequently, maintenance management, as the main focus area of this book, has been described. In line with available standards, a number of important definitions for maintenance management terminology have been given. More importantly, the context of maintenance tasks, policies and concepts was provided in detail in this chapter. Additionally, the relationships of these terms with each other were given. This chapter comes to a close with a brief review of developments in the field of maintenance management. Because maintenance management is evolving into an increasingly complex context within the business environment of electricity network companies, as suggested in the literature, it is essential to build

maintenance improvements on at least the mentioned essential supporting pillars for maintenance management.

2.6.2 Outlook

In the next chapter, an organisation-wide maintenance improvement plan will be addressed with the focus on the establishment of an organisation for maintenance improvement within an electricity distribution network company on the basis of the supporting pillars for maintenance management as discussed in this chapter. Furthermore, Chap. 3 will also discuss the developments, on a maturity model for maintenance management and a framework for maintenance of *key performance indicators* (KPIs).

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Risk-Based Maintenance for Electricity Network
Organizations

Mehairjan, R.P.Y.

2017, XXI, 155 p. 64 illus., 62 illus. in color., Hardcover

ISBN: 978-3-319-49234-6