Chapter 19
Asset Management Journey for Realising Value from Assets

Gopinath Chattopadhyay

Abstract Assets in line with ISO55000 standard for asset management are items, things and entities which have value or potential value to the organisation. Asset management is for what we do with those assets. The journey begins with understanding the needs of the organisation in line with business objectives to deliver goods and services in a reliable, safe, timely and cost-effective manner. Realising value from assets is a holistic approach addressing complexities of expectations of stakeholder and providing competitive advantage to the business. It starts from the concept of the asset and continues to the design, manufacturing/construction, operations, maintenance and disposal of the asset known as asset life cycle. Focus is on reduced risks, enhanced performance including safety of the operation, environment and the wider communities and achieving reduced Life Cycle Costs. Systematic approach in asset management helps in improving reliability, availability, maintainability, safety and security. Leadership, good organisation culture, alignment with other systems and assurance that assets will perform when needed contributes significantly to the success of any organisation. This chapter covers how to balance cost, risk and performance in informed decision-making for maintaining value of and realising value from assets.

Keywords Asset management · ISO55000 · Life cycle cost · Risks · Performance

19.1 Introduction

The history of asset management goes long back to the days of terotechnology covering installation, commissioning, maintenance, replacement and removal of plants and equipment. It helped in better management of physical assets for reducing life cycle costs through reliability, availability and maintainability. In the past, major focus was on maintenance and managing the assets. In this asset management journey, the focus is now shifted more on what we do with these assets. In addition, there are

G. Chattopadhyay (✉)
Federation University Australia, Gippsland, Australia
e-mail: g.chattopadhyay@federation.edu.au

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other types of assets including financial assets, information asset, human asset and intangible assets including knowledge and goodwill. This journey from maintenance to asset management has therefore taken a holistic approach for balancing costs, risks and enhancing performance (Chattopadhyay [1, 2]).

Assets in line with ISO55000 for asset management are any items, things and entity which has value or potential value to any organisation. Fundamental of asset management is focused on value, leadership and culture, alignment with corporate objectives and other systems and assurance that assets will perform as and when they are needed (ISO [3]). This chapter is mainly on physical assets. However, there are other important assets such as finance, information technology, human assets and nontangible assets such as intellectual property, goodwill, tacit knowledge and know-hows.

Asset management linked to physical assets was first used by Dr. Penny Burns in 1980s (in Asset Management History Project, 1984) (Wikipedia [4]). Infrastructure Asset Management Manual, published in 1996 in New Zealand, on asset management for infrastructure sector became international infrastructure management manual (IIMM) in 2000 (IPWEA [5]).

The professional societies: The Asset Management Council (AMC) in Australia, Institute of Public Works Engineers Australasia (IPWEA) and the Institute of Asset Management (IAM) in the UK along with various professional bodies around the world contributed significantly to the development of body of knowledge in the area of asset management (AMC [6], IAM [7]). Global Forum of Maintenance and Asset Management (GFMAM) provided a platform for better understanding of needs of various countries around the world in asset management and defining and interpreting technical terms in a consistent manner. This helped in developing guidelines for addressing issues and challenges in asset management from global perspective in a coordinated and consistent manner (GFMAM [8]).

Asset management, as per Peterson, covers the following concepts:

- Business goals driving decisions for the use and care of assets,
- Asset strategy determined by operational considerations,
- Maintenance and reliability for a defined goal (not an end in itself),
- Intent for optimising the application of all resources (not just maintenance) (Peterson [9]).

Moore suggested a view of asset management covering

- Incorporation of an understanding and alignment between the business expectations for the assets both currently and into the future;
- An understanding of the assets' current condition and capability today and into the future;
- The centrality of the consideration of how and why the assets are operated;
- A consideration of asset life cycle, e.g. design considerations in terms of capability, reliability and ease of asset management at both initial and rehabilitation phases of an assets' life;
- How asset management needs to be implemented (Moore [10]).

Asset management is expected to provide a strategic platform to connect the physical assets of the business, their utilisation and maintenance along with all the other assets. Woodhouse proposed it as a set of disciplines, methods, procedures and tools aimed at optimising the Whole of Life Business Impact of costs, performance and risk exposures associated with the availability, efficiency, quality, longevity and regulatory, safety and environmental compliance of the company's physical assets (Woodhouse [11]).

International Infrastructure Management Manual (IIMM) proposed how to develop

- Asset Management (AM) policy,
- Organisational structure to deliver AM functions and
- Quality management processes that support the AM functions.

Publicly available specifications on asset management PAS55 (1 and 2 of British Standard Institute, 2008) were developed by industries to cover holistic asset management and paved the way for international standard on asset management ISO55000:2014 series for risk-based and informed decision-making with an aim for reducing cost and risks and enhancing performance over entire life covering various stages of asset life such as acquisition, utilisation and disposal (BSI [12, 13]).

Capital-intensive industries around the world have been facing an ever-increasing pressure of demand growth, geographical locations and ageing assets for doing more with less. There are credit constraints and scarcity of capital. However, showing the board members what is the risk of doing nothing and the actual cost of risk for that option, then one will be surprised to see that there is money available for preventions and continual improvements. What is needed is to show the value of the proposed initiatives and not just limiting the proposition limited to costs and benefits. Asset management journey begins with understanding the needs of the organisation in line with business objectives. The concept of the asset is developed and continues with the design, manufacturing/construction, operations, maintenance and finally, disposal of the asset at the end of the asset life cycle in a cost-effective, reliable, safe, secured and timely manner.

19.2 Overview of Asset Management

ISO standard for asset management which is practically a management standard for asset management consists of three parts:

- ISO 55,000 Asset management—Overview, principles and terminology;
- ISO 55,001 Asset management—Management systems—Requirements;
- ISO 55,002 Asset management—Management systems—Guidelines on the application of ISO 55,001 (ISO [14, 15]).

Asset management in line with this ISO standard is defined as 'coordinated activities of an organisation to realise value from assets' covering the following principles:

- Assets exist to provide value to the organisation and its stakeholders.
- People are key determiners of asset value realisation.
- An asset management organisation is a learning organisation covering.
- Strategic asset management plan.
- AM system.
- Asset management plans.
- Asset management requires understanding of the organisation's operating context and opportunities.
- Asset management decisions consider both short-term and long-term economic, environmental and social impacts.
- Asset management transforms strategic intent into technical, economic and financial decisions and actions (ISO55000) (Fig. 19.1).

ISO55000 series of standards tell what needs to be done and do not tell how it can be done. How the requirements can be addressed by individual organisations needs to be addressed according to the context and expectations of the organisation covering the following:

- Normative reference
- Terms and definitions
- Context of the organisation
  - Understanding the organisation and its context
  - Understanding the needs and expectations of stakeholders
  - Determining the scope of the asset management system
  - Asset management system
- Leadership

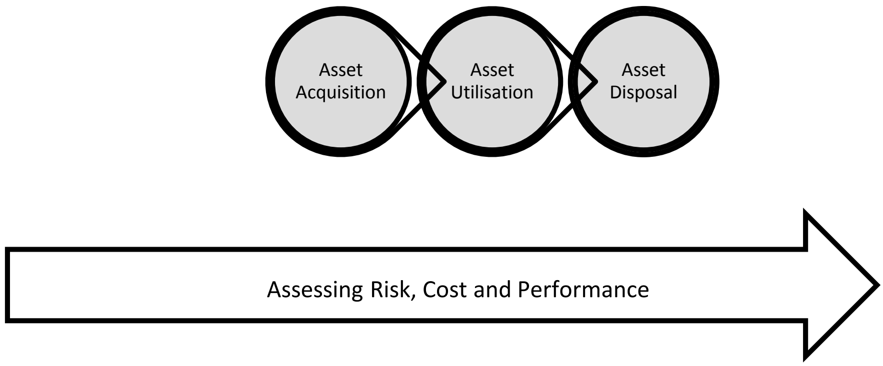

Fig. 19.1 Asset life cycle

  - Leadership and commitment
  - Policy
  - Organisational roles, responsibilities and authorities
  - Planning

- Actions to address risks and opportunities

  - Planning for the asset management system
  - Planning for assets
  - Asset management objectives and planning to achieve them
  - Asset management objectives
  - Asset management planning

- Support

  - Resources
  - Competence
  - Awareness
  - Communication
  - Information system support
  - Documented Information

    General
    Creating and updating
    Control of documented Information

- Operation

  - Operational planning and control
  - Management of change
  - Outsourcing of asset management activities

- Performance evaluation

  - Monitoring, measurement, analysis and evaluation
  - Internal audit
  - Management review

- Improvement

  - Nonconformity and corrective action
  - Continual improvement
  - Preventive and predictive action

The Global Forum on Maintenance and Asset Management (GFMAM) published the Asset Management Landscape, which covers the subject areas for the asset management required to address the knowledge and skills needed for good asset management. These are as follows:

Asset Management Strategy and Planning

- Asset Management Policy

- Asset Management Strategy
- Demand Analysis
- Strategic Planning
- Asset Management Plan

Asset Management Decision-Making

- Whole-life Cost and Value Optimisation
- Operations and Maintenance Decision-Making
- Capital Investment Decision-Making
- Resourcing Strategy and Optimisation
- Shutdowns and Outage Strategy and Optimisation
- Ageing Assets Strategy

Life cycle Delivery Activities

- Technical Standards and Legislation
- Asset Acquisition and Commissioning
- Systems Engineering
- Configuration Management
- Maintenance Delivery
- Reliability Engineering
- Asset Operations
- Resource Management
- Shutdown and Outage Management
- Fault and Incident Response
- Asset Rationalisation and Disposal

Asset Knowledge Enablers

- Asset Information Strategy
- Asset Knowledge Standards
- Asset Information Systems
- Asset Data and Knowledge

Organisation and People Enabler

- Contract and Supplier Management
- Asset Management Leadership
- Organisational Structure & Culture
- Competence and Behaviour

Risk and Review

- Criticality, Risk Assessment and Management
- Contingency Planning and Resilience Analysis
- Sustainable Development
- Weather and Climate Change
- Asset and Systems Change Management
- Assets and Systems Performance and Health Monitoring

- Management Review, Audit and Assurance
- Accounting Practices
- Stakeholder Relations

There is a need to develop tools and techniques along with artefacts for further enhancing capabilities of personnel engaged in asset management and related activities for better managing value from assets in various stages of asset life cycle including procurement, operation and maintenance and disposal of assets for as minimum as possible but as far as practicable life cycle costs (LCC). Organisations need to know about their assets, their conditions, maintenance history, costs and informed risk-based decision for inspections, maintenance and replacements including options for overhaul, major repairs and life extension.

Understanding the condition of assets from failure and maintenance history and estimating the remaining life and option engineering for life enhancement are key steps in life cycle management of capital-intensive assets. Asset management is therefore not treated as a destination. It is like a journey for realising value from assets though appropriate allocation of funds for maintenance and upgrades known as Operational expenditure (opex) and replacements covered in Capital expenditure (capex).

19.3 Understanding the Asset and Its Remaining Life

Estimation of remaining life is a comprehensive and multidisciplinary activity that takes into account a range of factors such as asset life cycle asset management principles, needs of the users of the asset, competing demands of stakeholders, current and future policy and legislative environment, the entity's corporate governance and planning framework, technical adequacy and commercial viability, external or market factors (commercial, technological, environmental or industry implications), the need to rationalise operations to improve service delivery and cost-effectiveness of any life extension. It helps in sound decisions that are appropriate to address the identified risks and the associated impacts on value, carrying out appropriate tasks at the 'right' time and at the right level of expenditure, achieving the right balance between competing factors, such as performance, cost and risk. The starting point of this is understanding the failure mechanism.

Failure is not an easy term to explain to different stakeholders in a consistent way. It is generally accepted as the inability of an item to perform its required function. Causes of failures are mainly the limitations of the system, subsystem or components to perform due to design, manufacture, user and maintenance-related issues resulting in failures. Modes of failures are the resulting effects of failure causes. Mechanisms of failures are physical, chemical or other process causing failures. Analysis of failure needs logical, systematic examination to identify and analyse the probability, causes and consequences of failures and/or potential failures including near hits. In addition, failures can also be due to misuse and/or overloading.

When failure occurs directly and without any influence of any failure of another item, it is termed as primary failure. If failure occurs either direct or indirect failure of another item, then it is termed as secondary failure. Where failure occurs with probability of failure increasing with time such as age and/or usage, it is termed as wear-out failure. If failures do not give any indication or not detected by inspection or monitoring, it is termed as sudden failure. Where failures give some indication or can be detected by prior inspection or monitoring, those are termed as gradual failures. Where loss of functional ability is up to level where it does not stop the item to perform some of the required functions, it is called a partial failure. If the loss of functionality resulting from deviations in characteristic(s) is beyond specified limits causing complete lack ability for required function, it is called a complete failure. When failures are sudden and complete then termed as catastrophic failure. When failures are gradual and partial, then those are termed as degradation.

If failures are likely to cause injury to persons or significant damage to material, then those are considered as critical failures. If failures are other than a critical failure, which is likely to reduce the ability of a more complex item to perform its required function, then those are considered as major failures. Failures not reducing the ability of a more complex item to perform its required function are considered as minor failures.

In the life cycle of any asset, failures can occur due to design, manufacturing, testing and installation-related problems in the early stage, operations and usage-related wear and tears in the middle phase of the life and faster rate in the last phase of the life due to ageing, operation and maintenance-related problems at the end of the life of the asset. This is captured in the bathtub failure curve comprising of decreasing, constant and increasing rates of failures such as.

- Early Failure Period
- Constant Failure Rate Period
- Wear-Out Failure Period

Failure analysis considers life data from maintenance history and mathematical and or statistical modelling for using those life data (age, usage, number of times usage and many other) in prediction and intervention of failures through appropriate inspection, maintenance, repairs and replacements. In the following analysis, life data is taken as time and item is in operation before failure. Let T denote the time to failure, t denote age and $F(t)$ denote the failure distribution function. Then,

$$F(t) = \text{Probability}\,(T \leq t) \tag{19.1}$$

The reliability function corresponds to the probability that an item survives to any given age.

For an item which starts to operate at age $t = 0$, the reliability function, $R(t)$, is the probability that failure does not occur in the interval 0–t. Then,

$$R(t) = \text{Probability}(T > t) \tag{19.2}$$

$$R(t) = 1 - F(t) \tag{19.3}$$

The probability density function (pdf) of the time to failure is a function of age, such that the area under the curve between any two age values gives the probability that a new item will fail in that age interval. The probability density function, $f(t)$, is the differential coefficient of the distribution function $F(t)$. We have the following equations:

$$f(t) = \mathrm{d}F(t)/\mathrm{d}t \tag{19.4}$$

Probability of failure in t to $t + \partial t = f(t)\partial t$

$$F(t) = \int_0^t f(u)\mathrm{d}u \tag{19.5}$$

Note

$$\int_0^\infty f(t)\mathrm{d}t = 1 \tag{19.6}$$

The hazard function $h(t)$ is a function such that the probability that an item which has survived to age t fails in the small interval $t–t + \partial t$ is $h(t)\partial t$.

The hazard function can be related to the reliability function $R(t)$ and the probability density function $f(t)$ as follows. The probability of failure in the interval $t–t + \partial t$ is $R(t)\ h(t)\ \partial t$. Then,

$$f(t)\partial t = (t)h(t)\partial t \tag{19.7}$$

$$f(t) = R(t)h(t) \tag{19.8}$$

and

$$h(t) = f(t)/R(t) = f(t)/(1 - F(t)) \tag{19.9}$$

Probability of failure in the interval

$$t_1 \text{ to } t_2 = \int_{t_1}^{t_1} f(t)\mathrm{d}t \tag{19.10}$$

where

$$\int_0^{\infty} f(t)\,\mathrm{d}t = 1 \qquad (19.11)$$

In industries, some simple terms are used for analysis. These are as follows:

Mean Time to Failure (MTTF), which is average of the observed ages at failure.

Mean Time Between Failures (MTBF), which is the ratio of the component hours of service to the number of failures. In some organisations, this is known as uptime and used as a measure of reliability. The higher the MTBF, the better is the reliability.

Mean Time to Repair (MTTR), which is average of the observed times between failures and back to operation through maintenance actions. In some organisation, this is known as downtime and used as a measure of maintainability. The lower the MTTR, the better is the maintainability.

Availability, which is measured as a ratio of uptime to uptime plus downtime.

Analysis of remaining life is critical to decision-making for future operation and maintenance of plant. It includes how much longer the plant can operate safely in its current condition, what components should be replaced to keep the plant operating, what design life to be considered for replacement components, the cost of future replacements and the cost of planned operating modes. Remaining life can be estimated using life consumed to date, and future operating modes and maintenance plans.

Understanding the asset and its remaining life helps in analysing costs for life enhancements based on degradation, target performance and residual risks. Cost-effectiveness of any capacity and capability gains through upgrade is analysed using revised life cycle costs. Any capital injection and/or reducing inspection and maintenance intervals are worthwhile if the value realised through these activities for reducing cost of operations, risks and associated safety outweighs the total cost for life enhancement activities over the revised remaining life.

19.4 Life Cycle Costing

Life cycle cost considers total cost for the asset over the entire life of the asset. Life cycle costs (LCC) considers all expenses for

- deciding what is needed
- acquisition
- installation
- utilisation (operation) and maintenance
- refurbishment or replacement
- discarding and disposal costs (ISO [16]).

ISO 15,686–5: 2017 (ISO, 2017) suggests whole of life costs and LCC and is given by

$$\begin{aligned}\text{Life cycle costs (LCC)} &= \text{Capital cost } (C) + \text{lifetime operating costs } (O)\\ &+ \text{lifetime maintenance costs}\\ &+ \text{lifetime maintenance costs (M)}\\ &+ \text{lifetime plant losses } (L) + \text{plant disposal cost } (D)\end{aligned} \tag{19.12}$$

Analysis of life cycle costing (LCC) considers

- Service life, life cycle and design life
- period of analysis
- costs covering
- acquisition
- maintenance, operation and management
- residual values/disposal
- discounting
- inflation
- taxes
- utility costs including energy
- risks.

Some of the costs in different phases of life of any asset need to be considered covering:

Cost of planning and acquisition covering:

- need study,
- design and development,
- construction,
- installation,
- testing and commissioning,
- modification and fixing teething problems,
- spare parts,
- training of people, and
- operations and maintenance manuals and relevant drawings.

Operating costs covering:

- labour,
- power,
- consumables,
- equipment and
- overhead charges.

Maintenance costs covering:

- labour,
- parts,
- materials,

- consumables,
- equipment and
- overhead charges.

Life Cycle Cost

- Inflation rate constant at $i \times 100\%$ pa.
- Discount rate $r \times 100\%$ pa.
- Annual operating costs, maintenance costs and plant losses are incurred at the end of the year; we have

$$\mathrm{LCC} = C + \sum_{1}^{N} \mathrm{On}\frac{(1+i)^n}{(1+r)^n} + \sum_{1}^{N} \mathrm{Mn}\frac{(1+i)^n}{(1+r)^n} + \sum_{1}^{N} \mathrm{Ln}\frac{(1+i)^n}{(1+r)^n} + \mathrm{Dn}\frac{(1+i)^n}{(1+r)^n} \tag{19.13}$$

In any real-life capital-intensive assets, life consumption and maintenance costs add complexity to LCC modelling. For example, for rail network, rail life ends due to two major failure modes. First one is Rolling Contact Fatigue (RCF)-initiated cracks and undetected propagations resulting in rail breaks and derailments. Second one is rail–wheel friction-initiated wear resulting in early replacement decisions when it reaches wear limit sooner. Failure to replace might lead to wheel rollover and derailment. There are decision variables such as inspection intervals and grinding intervals for rail surface for controlling crack propagation. In the same manner, there is decision variable for placement of lubricators and choice of lubricants for providing lubricants at the gauge face for reducing wear and therefore further enhancing asset life. All these have an impact on replacement intervals of rails and are used for reducing risk cost associated with derailments, early replacement and unplanned maintenance actions (Chattopadhyay et al. [17, 18].).

19.5 Balancing Cost, Risk and Performance Through Asset Management

Balancing cost, risk and performance is both art and science. There are regulatory requirements to comply with and discretionary decisions by organisations over and above the regulatory requirements. Any capital investment in this process needs systematic approach using the following steps:

- Defining the objective/s
- Defining the alternative options
- Estimating the lifetime
- Estimating the benefits and costs

- Specifying the time value for money (discounting rates)
- Developing/defining the performance measures for effectiveness
- Comparing apples to apples for ranking the alternatives
- Analysing sensitivity using what-if scenarios
- Recommending the option based on cost, risk and performance (Parida et. al [19]).

Alternative capital investment options are analysed using several techniques including the following:

- The payback method: the period when return from the investment covers the capital investment. Any investment is ok if payback period is below acceptable limit (say, asset life).
- Present Worth (PW): an amount at some beginning or base time that is equivalent to a schedule of receipts and/or disbursements for any investment option. Any investment is ok if present worth of benefits is more than investment.
- Annual Worth (AW): a uniform series of money for a certain period equivalent in amount to a schedule of receipts and/or disbursements for any investment option.
- Future Worth (FW): an amount at some ending or termination time which is equivalent to a schedule of receipts and/or disbursements for any investment option. Any investment is ok if future worth of benefits is more than the future worth of investment.
- Rate Of Return (ROR): the acceptability of individual investment option. Any option is acceptable if its internal rate of return (IRR) is not less than a predetermined minimum attractive rate of return (MARR). The higher the IRR, the better is the option.
- Benefit–Cost Analysis (BCA): ratio of the equivalent worth of benefits to the equivalent worth of costs and options are accepted for this ratio more than one. The higher the ratio, the better is the option (Canada et al. [20]).

Example of Payback Analysis

A new asset costing $20,000 will cost $1000 to install and $4000 per year to operate, with a useful life estimated at 15 years. The resale value of this existing asset is $5000 and is now costing $8000 per year to operate. Both assets have the same output capacity.

Solution

Purchase price	$20,000
+Installation cost	$ 1,000
−Sale of existing machine	−$ 6,000
Net cost of equipment	$15,000
Old asset operational costs/yr	$ 8,000
New asset operational costs/yr	$ 5,000

(continued)

(continued)

Net additional profit/year	$ 3,000
Payback Period = 15,000/3000 = 5 years	
If assets life [say 10 years] is greater than payback of 5 years, investment option is acceptable	

Example of Present Worth Analysis:

A new production unit is being considered for purchase. The following facts are available:

(a) Installed cost of the equipment = $240,000.
(b) Estimated additional earnings per year = $80,000 (compared to the present process).
(c) Useful life of the equipment = 8 years.
(d) Estimated resale value of new unit in 8 years' time is $15,000. Resale value of the old machine is included in value at (a).
(e) Assume depreciation is straight line over 8 years and that tax on income is at 50% (Table 19.1).

Annual cash inflow		
Additional earnings/year	$80,000	$80,000
Less depreciation 24,000/8	−$30,000	
Taxable income	$50,000	
Less tax at 50%	−$25,000	−$25,000
Annual profit after tax	$25,000	
Annual cash inflow after tax		$65,000
Total cash outflow		
Installed cost	$240,000	
Resale value in 8 years	$15,000	

Example of selecting from alternative options:

MARR = 15%, Life = 5 years, Salvage value is realised at the end of the life (Tables 19.2, 19.3 and 19.4).

From the above analysis, option B is the preferred option.

The true rate of return is the discount value at which the present value outflows equal the present value inflows and can be calculated using Excel for extrapolation.

When internal rate of return is more than MARR, the investment option is acceptable.

Maintainability

It is the ability of the system to be back to operation when maintenance is performed using standard procedure, right spared and trained people. This is shown using 20 data from maintenance history (Table 19.5).

Table 19.1 PW calculation

Discount rate (%)	Present worth (PW) factor for single payment (P/F) (resale value)	Present worth (PW) outflow	Present worth (PW) factor for uniform series (P/F) (annual cash inflow)	Present worth (PW) inflow
16	0.305	$235,425	4.344	$238,920
14	0.351	$234,735	4.639	$255,145
18	0.266	$236,010	4.078	$224,290

Table 19.2 Options A and B

Option	Initial investment(P)	Salvage value (S)	Annual receipts
A	– 7000	1000	2000
B	−10,000	2000	3000

Table 19.3 PW and FW analysis

Option A	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Totals
Initial investment	−7000						
Annual net receipts		2000	2000	2000	2000	2000	
Salvage value						1000	
Net receipts	−7000	2000	2000	2000	2000	3000	
Present worth (PW)	−7000	1739	1512	1315	1144	1492	201
Future worth (FW)	−14,080	3498	3042	2645	2300	3000	405
Option B							
Initial investment	−10,000						
Annual net receipts		3000	3000	3000	3000	3000	
Salvage Value						2000	
Net Value	−10,000	3000	3000	3000	3000	5000	
Present Worth (PW)	−10,000	2609	2268	1973	1715	2486	1051
Future Worth (FW)	−20,114	5247	4563	3968	3450	5000	2114

Table 19.4 Summary of options

Option	Present worth (PW)	Future worth (FW)
A	201	405
B	1051	2114

If the maintainability test fails, then there is need for further enhancing the process, maintenance strategy and/or design of the system.

All decisions need to be prioritised based on risks. One of the tools used in risk assessment is Risk Priority Number (RPN).

Table 19.5 Maintainability test

Data	Observed maintenance time	Deviation from mean	Square of the deviation from mean
1	39	−17.05	290.70
2	57	0.95	0.90
3	70	13.95	194.60
4	51	−5.05	25.50
5	74	17.95	322.20
6	63	6.95	48.30
7	66	9.95	99.00
8	42	−14.05	197.40
9	85	28.95	838.10
10	75	18.95	359.10
11	42	−14.05	197.40
12	43	−13.05	170.30
13	54	−2.05	4.20
14	65	8.95	80.10
15	47	−9.05	81.90
16	40	−16.05	257.60
17	53	−3.05	9.30
18	32	−24.05	578.40
19	50	−6.05	36.60
20	73	16.95	287.30
Total	1121		4,078.95
Mean time	56.05		
Std Dev			14.65
Risk factor	0.1		
Z from table	1.28		
Upper Limit = Mean time + *z**Std Deviation/Sqrt of Number of data	60.24	Less than contracted time, 65 min	
Maintainability is performing			

Risk Prioritisation Number (RPN)

It is given as

RPN = Severity x Likelihood X Detectability

where the severity is ranked (commonly from 1–5) using metrics such as

- Negligible: minor treatment (1).

- Marginal: injury requiring < 10 days hospitalisation/medical leave (2).
- Serious: injury requiring > 10 days hospitalisation/medical leave (3).
- Very Serious: injury requiring > 30 days hospitalisation/medical leave (4).
- Critical: fatality/permanent body injury (5).

The severity ranking can relate to environmental, plant damage and downtime metrics.

Where the detectability is ranked (commonly from 1–5) using metrics such as

- No or Very low detectability: inevitable, potential failure not detectable (5)
- Low detectability: unlikely to detect a potential failure (4).
- Moderate detectability: may be able to detect a potential failure (3).
- High detectability: a good chance to detect a potential failure (2).
- Very high detectability: it is almost certain to detect a potential failure (1).

The likelihood is similarly ranked (say 1–5), e.g.

- Unlikely: might occur once in 10 years (1).
- Remote: might occur once in 5 years (2).
- Occasional: might occur once in 3 years (3).
- Moderate: likely to occur once per year (4).
- Frequency: likely to occur many times per year (5).

Priority is allocated based on RPN. The higher the RPN, the higher the rank in selecting any items for risk mitigation.

In majority of infrastructure sector, a traffic light type approach of green, yellow, orange and red signal is used for flagging actions to be taken for risk mitigation. Red means the highest priority, orange is flagged to be monitored closely or inspections to be tightened and actions to be taken in the nearest future in line with corporate guideline and/or regulatory requirements. And Green means no action is required other than normal inspections and monitoring. Risk matrix in line with ISO31000 can be analysed similar to Table 19.6 (ISO [21]).

Overall Equipment Effectiveness (OEE)

The overall equipment effectiveness (OEE) is used to better understand the performance of the maintenance. It evaluates how effectively a manufacturing operation is utilised and is expressed well in terms of Performance, Availability and Quality. It is measured in terms of whether plant is operated as per expected speed, reduced

Table 19.6 Risk matrix

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	High risk	High risk	Extreme risk	Extreme risk	Extreme risk
Likely	Medium risk	High risk	High risk	Extreme risk	Extreme risk
Possible	Low risk	Medium risk	High risk	Extreme risk	Extreme risk
Unlikely	Low risk	Low risk	Medium risk	High risk	Extreme risk
Rare	Low risk	Low risk	Medium risk	High risk	High risk

speed or with minor stops. Availability is analysed in terms of breakdowns and product changeovers. Quality is analysed in terms of acceptance and rejects in start-up, during production runs and customer returns. Therefore, OEE indicates the health and performance of assets and productivity and considers.

- Breakdowns
- Setup and Adjustment
- Small stops
- Slow running
- Start-up defects
- Production defects

Effectiveness (OEE) is widely expressed as

$$\text{OEE} = A \times P \times Q \tag{19.14}$$

where
A: Availability
P: Performance and
Q: Quality.

Good asset management helps in reducing losses, enhancing availability, performance of the assets and assuring quality of products and services using OEE (Chundhoo et. al [22, 23]).

19.6 Realising Value from Assets

Asset management, if practised well, retains value of assets and realises value from assets. Some of the important factors including value judgement may not be fully quantifiable and are generally analysed by industries using experience (by resolving conflict of brain vs. heart). Decisions are taken based on risks and not just based on costs and benefits. Risk is the 'effect of uncertainty on objectives' where uncertainty is the 'state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood' (ISO [21]). Risk is 'susceptible' to measurement (e.g. we might know the distribution of likelihood or the possible consequences). However, uncertainty reflects that the exact outcome is unpredictable. Global warming and rare events including cycle, tornados, tsunamis, earthquakes and many other similar challenges put additional difficulties in accurately assessing impacts of those events on asset management (Komljenovic [24]).

Risk management is generally limited to what we know about events, probabilities and outcomes (Knight [25]). As per ISO 31,000, risk management—principles and guidelines—the basic steps need to be used are

- Establishing the context
- Identifying the risks

- Analysing the risks
- Assessing the risks
- Treating the risks
- Monitoring and reviewing progress and performance.

Balancing act of cost, risk and performance is a complex process. At a business level, balancing needs to consider context of the organisation in line with ISO55001. Decision-makers need to better understand the needs and expectations of stakeholders.

There are financial, legal, image/reputation, safety, environmental, service delivery and many other risks for any asset management-related decisions. Mandatory levels of performance and risk are generally regulatory driven. Discretionary levels beyond that require a clear understanding of what customers are willing to pay, what competitors are charging and costs associated with providing expected performance and managing risks (Aven [26]).

Historically, cost used to be based on what level of service the customer should have. Organisations used to be conservative and risk-averse. Therefore, the recovery of cost was the criteria for pricing. In today's competitive market, the balancing of discretionary levels requires an iterative step-by-step approach over a period of time. It would be worth looking at what customers are prepared to pay for different levels of service and determine the life cycle costs of the assets for providing the agreed level of service along with the risks associated with each of the options. Balancing at a facility/asset level is dictated by the business requirements covering capex and opex. This means to balance the risk and cost to achieve the specified performance.

Asset management journey for realising value from assets' needs to be an iterative process from time to time over the life cycle of the assets. Options are generated based on asset condition, remaining physical, technical and economic life, operational costs, costs for upgrade and replacements. Intervention actions are justified based on comparing value realisation from assets for 'Doing nothing', 'Minimal repairs', 'Overhauls' and Replacements by 'as is' or capacity and/or capability improved options.

19.7 Conclusions

Asset management decisions are generally taken based on risk appetite of the board. Options include avoiding, treating, transferring, terminating or retaining risk based on decisions from balancing act. A 'desired' option is recommended based on stakeholders' perception of 'value for cost' in line with AS4183 for 'value' in general and 'value for money' in particular. Balancing is proposed in this chapter for distributing weights to important areas of the decision model for enabling someone or something to remain upright and steady in the perspective of the business. It is required to be reviewed from time to time for a long-term sustainability of the business. Asset owner/s can retain and grow the business considering a 'desired balance' in line with

ISO55000 and proposed by Asset Management Council (AMC) for the concept of an 'accepted level' of trade-off in cost, risk and performance (SA [27]).

International standard on asset management provides consistency in the interpretation of principles and the application of asset management across the industries. There is a need for further developing tools and techniques on how to implement and correctly measure success of good asset management supported by continual improvements.

There is huge opportunity for future work for various industry sectors as follows:

- Alignment of ISO55001 with other systems such as ISO9001, 31000, 14001, 45001, Information Technology (IT) and financial standards (ISO [28–30]).
- Further developing and applying asset management standards for other assets including natural, environmental and social assets.
- Assuring that asset management and audit teams have depth and breadth in line with asset management landscape and provide opportunity for building capability for required competency.

Good asset management helps in the journey of any organisation towards excellence for their business through a balancing act for costs, risks and performance for maintaining value of and realising value from assets. It is a journey which requires leadership and a long-term view along with commitment to financial, human and information system-related resources. Good in no good in today's world. What matters is the aspiration from the whole organisation for leading towards excellence.

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Gopinath Chattopadhyay has Ph.D. in Mechanical Engineering (1999, from University of Queensland), Bachelor in Mechanical Engineering (1979, first-class first, Gold Medallist, from the University of Calcutta), Master of Industrial Engineering (1984, first-class first, Gold Medallist, from the University of Calcutta), MBA (1987, first-class second, Silver Medallist, from the University of Calcutta), Graduate certificate in education for higher education (1999 from Queensland University of Technology) and certificate in asset management from Institute of Asset Management, UK (2015). He is Post Graduate Programme Coordinator for Maintenance and

Reliability Engineering in Federation University, Australia. He is Adjunct Professor of Manipal University; Indian Institute of Engineering, Science and Technology and Indian Institute of Social Welfare and Business Management. He has worked in Qld University of Technology as Senior Lecturer and Postgraduate Programme coordinator for Engineering Management, Professor and Head of Post Graduate Programmes in Central Qld University and Visiting Professor in Indian Institute of Technology, Kharagpur, Lulea University of Technology, Sweden and University of Natural Resources and Environment, PNG. He has supervised 18 research higher degree students to successful completion. He has secured over 2.5 Million Australian dollars of funding for research projects and contributed to more than 170 international journal and conference papers including one prizewinning publication in 2008. He is currently Chair of Gippsland and past Chairs of Brisbane and Gladstone of Asset Management Council, Peak Professional body in asset management and a technical society of Engineers Australia. He was President of Australian Society for Operations Research (ASOR. Qld) and Vice President of Maintenance Engineering Society of Australia (MESA, Qld). He was industry reviewer of ISO55000 series of standards for Asset Management and Total Asset Management Plan (TAMP) for Queensland Government.