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Physical Asset Management

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Dr. Nicholas A. J. Hastings
Queensland University of Technology
Centre for Integrated Engineering Asset Management (CIEAM)
Gardens Point Campus, Level 7, O Block
Brisbane QLD 4001
Australia

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About this Book

Physical asset management is the management of fixed or non-current assets such as equipment, plant, buildings and infrastructure. This book presents a systematic approach to the management of these assets from concept to disposal. It introduces the general principles of physical asset management, so as to make these accessible to a wide audience, and covers all stages of the asset management process, including initial business appraisal, identification of fixed asset needs, capability gap analysis, financial evaluation, logistic support analysis, life cycle costing, management of in-service assets, maintenance strategy, outsourcing, cost-benfit analysis, disposal and renewal. Industries to which this is applicable include: electricity generation and supply; oil and gas; water; roads; railways; mining; aviation; shipping; hospitals; retail centres; manufacturing; distribution; defence facilities and defence materiel; recreation and sporting facilities and local government.

The book addresses the needs of existing and potential asset managers and provides an introduction to asset management for professionals in related disciplines, including finance. It provides both an introduction and a convenient reference work, covering the main areas of physical asset management.

This book is based on my involvement in asset management in a range of industries and organizations over a period of many years, in the course of which I have absorbed material from many sources. Thanks are due to staff members present and past at the Centre for Integrated Engineering Asset Management, Queensland University of Technology, Mount Isa Mines, Powerlink, Rio Tinto and the Defence Materiel Organization. Particular thanks are due to Andrew Jardine, Joesph Mathew, Melinda Hodkiewicz, Peter Knights, Tony Healy and Brian Jenney. Special thanks are due to my wife Tina, who developed a wonderful family and garden while I was stuck in the study or away on site.

There is a substantial amount of organizational documentation in this field, but relatively few conventional books. I wish particularly to acknowledge the following key references. These and others are included in the bibliography.

PAS 55 Asset Management Specification, British Standards Institution 2008;
International Infrastructure Management Manual, www.ingenium.org nz;
IEC 60300 series of standards;
Benjamin S. Blanchard, books on logistics and related topics;
Defence Capability Development Manual, and DMO Acquisition and Sustainment Manual, Australian Defence Publishing Service, Canberra;
A.S. Goodman and M. Hastak, Infrastructure Planning Handbook, Mcgraw-Hill 2006.

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About the Author

Nicholas Anthony John Hastings is the training coordinator for the Cooperative Research Centre in Integrated Engineering Asset Management, and an Adjunct Professor at the Queensland University of Technology, Brisbane.

His early career was in the British Army and he attended the Royal Military Academy Sandhurst and the University of Cambridge where he graduated in engineering. He served in the Royal Electrical and Mechanical Engineers, initially working in maintenance management, and later in asset management policy. From 1968 he lectured in Operations Research at universities in Britain and Australia. He was Professor of Operations Research at Monash University, Melbourne, from 1977–93.

In 1994 he took up the Mount Isa Mines Chair in Maintenance Engineering at Queensland University of Technology, Brisbane, and was involved in work on projects in mining, electricity transmission and other asset intensive industries. He is the developer of RelCode software for the analysis of reliability data which is widely used in industry. In 2006 he was awarded the Medal of the Maintenance Engineering Society of Australia for contributions to reliability and engineering asset management.

He is a director of Albany Interactive Pty. Ltd., a consultancy firm in engineering asset management. He enjoys country walks and watching local sport.

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3. From Concept to Project Approval
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Chapter 1
Introduction to Asset Management

Chapter Aim: To introduce to the main concepts of Asset Management.

Chapter Outcomes: After reading this chapter you will know:

- The broad types of assets which organizations have;
- The types of industry to which asset management is particularly important;
- Definitions of assets, liabilities and related terms from an accounting viewpoint;
- Definition of asset management;
- An outline of the asset management life cycle;
- The place of asset management within and throughout an organizational structure;
- Awareness of the dangers of the asset death spiral.

Chapter topics:

- Background
- What is an asset – an accountant's view
- What is asset management
- Asset management basic questions
- The asset life cycle
- Business organization and asset management
- Business planning and asset management
- Dangers of the asset death spiral
- Exercise

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1.1 Background

The asset management specification PAS55 identifies the following types of asset within organizations,

- Financial Assets
- Physical Assets
- Human Assets
- Information Assets
- Intangible Assets

This book presents a systematic approach to the management of physical assets from concept to disposal. The aim is to develop the general principles of asset management in order to make them accessible to a wide audience. Organizations in which physical asset management is of particular importance include all those involving extensive use of plant, machinery and infrastructure. In particular this includes electricity and water utilities; transport industries; oil and gas; mining and minerals processing; manufacturing and distribution; aviation; defence and civil works.

Historically, asset management has not been a well identified activity. The general pattern of educational and professional specializations results in a silo effect in the areas surrounding asset management. Probably the best managed area is the development of building and construction assets, once the outline planning and financial decisions have been made. The most difficult areas involve software and systems, and particularly systems integration. Mechanical, electrical and transport areas lie between these extremes.

In terms of professions, engineers have skills in design, in technical development, and in the solution of technical problems, but this requires a focus which can limit awareness of business issues. Finance and accounting specialists are aware of fixed assets as a balance sheet entry whose technical depths are unplumbed, although their worth be taken. Engineering and maintenance are often viewed as costs, to be minimized, and activities to be outsourced. Information technologists are skilled in establishing data management and communication systems, but the structure, content and use of the information lie elsewhere. Senior managers from political, legal, financial or marketing backgrounds often have priorities and short term imperatives which result in them paying insufficient heed to asset decisions which run to longer planning horizons. And lobbyists for particular solutions put forward unbalanced views of asset development options.

To the public, debate may rage over the provision of, or lack of facilities, or issues such as environmental impact, but this rarely leads to an appreciation of what is involved in planning, financing, creating, operating and maintaining assets. Vocalized or politicized fads and fancies can overwhelm the realities of asset management. The broader, holistic view of asset management has been a relatively neglected area in terms of general education and training.

1.2 What is an Asset? – An Accountant's View

Assets of the type which we are considering here are physical items such as plant, machinery, buildings, vehicles, pipes and wires, and associated information and technical control and software systems that are used to serve a business or organizational function. At the outset, and given that asset management links closely with financial management, it is important to recognize the accounting definition of assets, and in particular the split between fixed and current assets.

A fixed asset (also called a *non-current asset*) is a physical item which has value over a period exceeding one year, for example, land, buildings, plant and machinery. When fixed assets are acquired, their cost cannot be counted as an expense for tax purposes in the year of acquisition. When we buy or sell fixed assets we are regarded as having swapped one asset – money – for another asset, a machine, for example. Only the depreciation of the machine in any given year is considered to be an expense in the year. This is important as far as tax treatment is concerned.

Faster moving assets such as: cash; accounts receivable; inventory (materials, work in process, finished goods, consumables) are referred to as *current assets*. Slow moving spares which are normally held for longer than a year should be regarded as fixed assets.

Expense is money or assets consumed in generating sales or service in the current year. This typically includes wages, materials and overhead costs. In manufacturing it will comprise the materials and labour that go into making the goods sold in the year, plus administrative costs. It also includes depreciation, which is the proportion of the fixed assets "consumed" in the year.

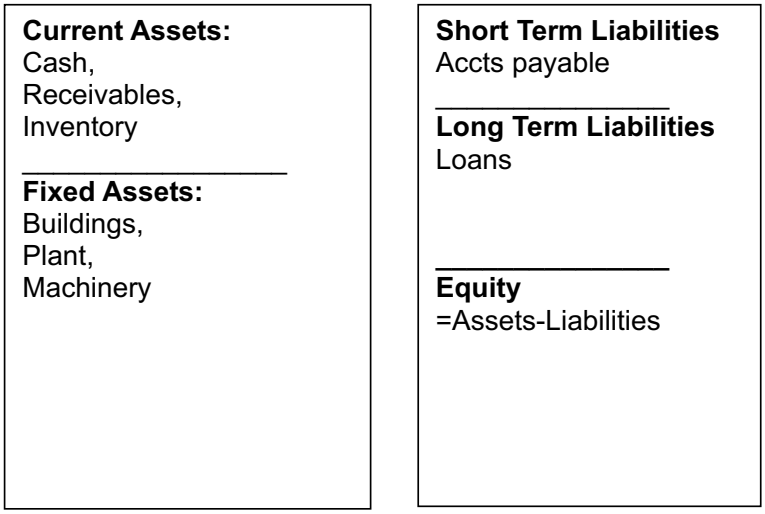


Fig. 1.1 Balance sheet

Liabilities are money that we owe. Amounts that we will need to pay in the immediate future, such as bills for recent purchases, are short-term liabilities, whereas loans which we will repay in future years are long term liabilities.

Equity means the net value of the company after the liabilities are subtracted from the assets. If the result is not a positive number, the company has gone broke.

The assets, liabilities and equity feature in the company balance sheet. Figure 1.1 illustrates this.

1.3 What Is Asset Management?

1.3.1 Definition

Given a business or organisational objective, Asset Management is the set of activities associated with:

- identifying what assets are needed,
- identifying funding requirements,
- acquiring assets,
- providing logistic and maintenance support systems for assets,
- disposing or renewing assets

so as to effectively and efficiently meet the desired objective.

From this definition we see that asset management encompasses a broader and quite different set of activities from "maintenance", which is primarily concerned with keeping existing equipment in operating condition.

1.3.2 Alternative Definitions of Asset Management

The following definition is given by the Asset Management Council of Australia:

"The life cycle management of physical assets to achieve the stated outputs of the enterprise."

PAS 55, the Publicly Available Specification on Asset Management published by the British Standards Institute, gives the following definition of Asset Management:

"… 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 lifecycles for the purpose of achieving its organisational strategic plan."

These various definitions say the same kinds of things; that asset management is concerned with applying technical and financial judgement and sound management practices to deciding what assets we need to meet our business aims, and then

to acquiring and logistically sustaining the assets over their whole life, through to disposal.

1.3.3 Why Do We Need Asset Management?

The asset management function is needed to provide asset knowledge and the capacity for related management and decision support activities within the context of our business. In the area of capital planning and budgeting, or CAPEX, this involves:

- Asset (and associated capability) development planning and implementation
- Asset continuity planning and implementation
- Logistic support facilities development and management

In the area of operating budget or OPEX it involves:

- Procurement planning and management, e. g. for consumables and spares
- Organization wide, asset related systems and procedures, e. g. computer systems applications in asset management and maintenance, shutdown / turnaround planning,
- Development and management of maintenance outsourcing,
- Awareness and management of regulatory compliance

1.4 Asset Management Basic Questions

Asset management has the aim of continuously providing answers to basic questions about any asset, such as:

- Does it work?
- Is it safe?
- Does it support the business aim?

In relation to our business aims have we got the right:

- Equipment by type and location
- Support facilities, buildings, logistics and services by type and location
- Support personnel by quantity and skills

If not, what should we be doing about it, for example,

- Buildings, plant, machinery, equipment: buy or sell, lease or terminate lease,
- Asset support facilities expand, contract, consolidate, re-locate,
- Asset support personnel, recruit, reduce, train, outsource, in-source.

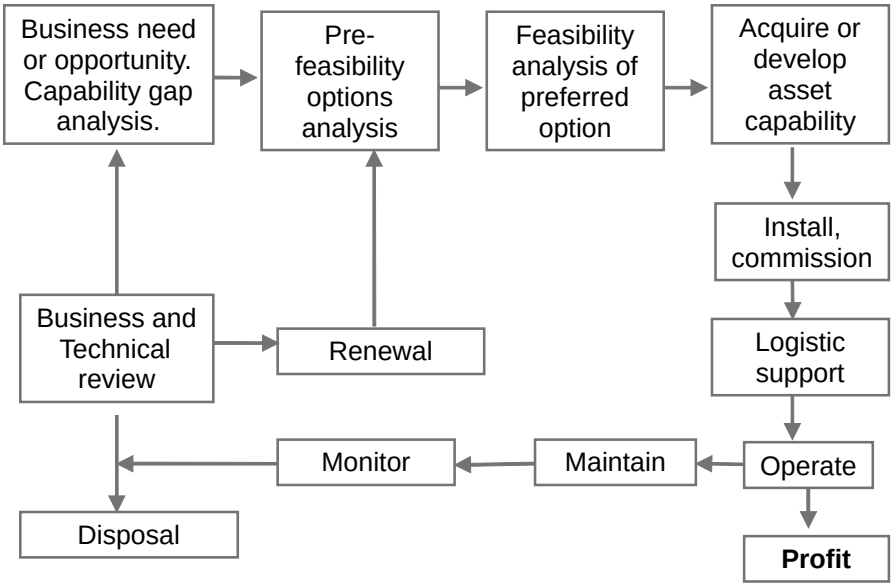


Fig. 1.2 The asset life cycle

1.5 The Asset Life Cycle

Figure 1.2 illustrates the life cycle of a physical asset in outline. The main stages in the life cycle are:

- Identification of business opportunities or needs.
- Asset capability gap analysis and requirements analysis
- Pre-feasibility analysis, physical and financial – options selection
- Feasibility planning, physical and financial – for selected option
- Acquisition, development and implementation
- Operation, logistic support and maintenance
- Monitor and review
- Disposal

1.6 Business Organization and Asset Management

In asset intensive businesses it is essential to structure the organization so that the development, acquisition and operation of the assets are carried out effectively. Business functions, such as Sales, Operations, Finance and Human Resource Management may be clearly represented in the business structure, whereas asset management can be a “grey area”, beneath the purview of senior management, but above the level of maintenance. Figure 1.3 illustrates this.

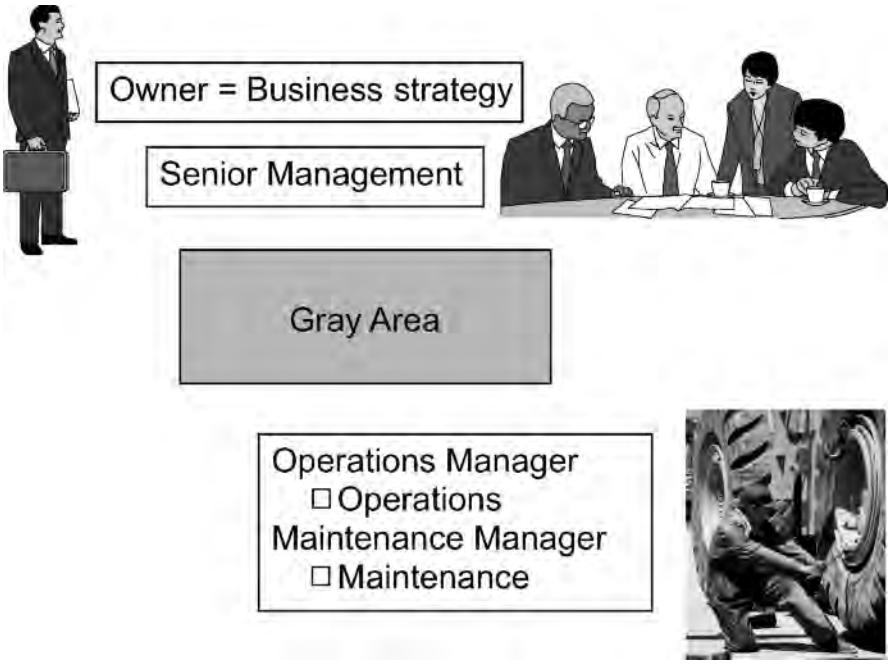


Fig. 1.3 Asset management – a gray area

Successful asset management requires recognition and effective implementation of the functions indicated in the definition of asset management in paragraph 1.3. The "grey area" of Fig. 1.3 needs to be replaced by the functions shown in Fig. 1.4.

An essential step is to recognize asset management as an activity which requires representation at the Vice President or Chief Officer level. This is illustrated in Fig. 1.5. The precise title may vary, and what we have referred to here as a Chief Asset Management Officer may have a title which refers to or includes engineering, planning or logistics. Representation at the Chief level allows asset management to play its role in key asset related decisions and activities affecting the business. If asset management decisions fall between, on the one hand, senior managers whose background gives them little appreciation of the physical state of the company's assets in relation to needs, and, on the other hand, maintenance or engineering personnel who are too junior or too inarticulate in business terms to state their case, then financial and operational disasters can follow.

1.6.1 Asset Management a Matrix Activity

The existence of a Chief Asset Management Officer does not mean that all asset management activity must be concentrated at the top level. Operating divisions

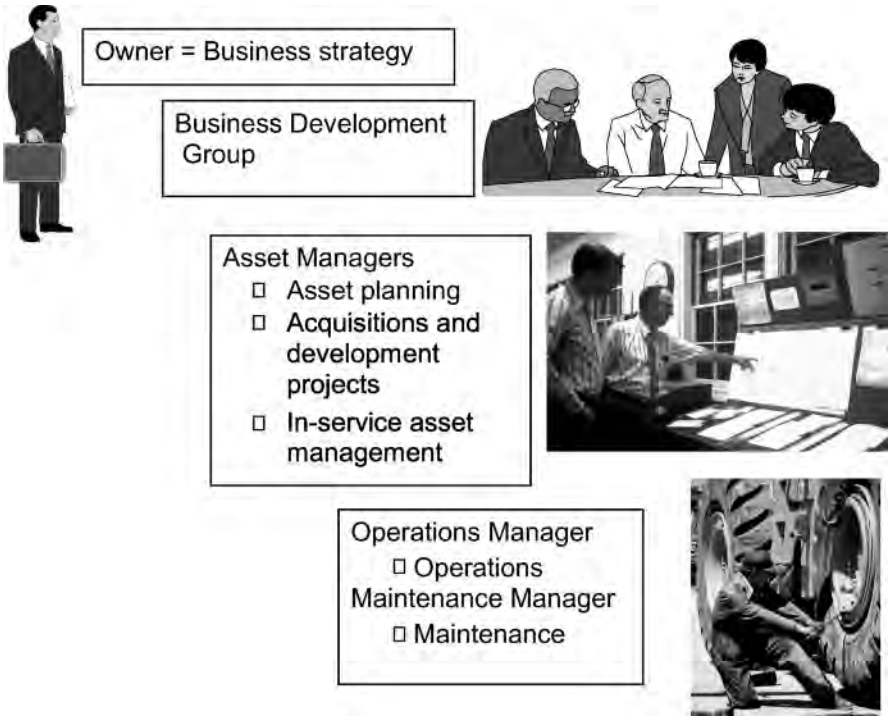
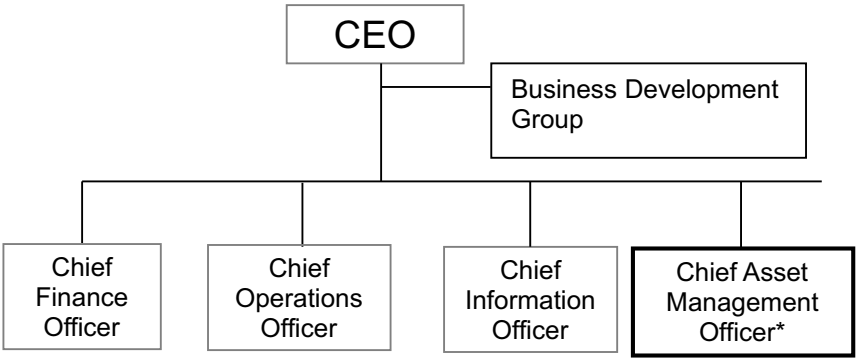


Fig. 1.4 Business activities and asset management



* Title may vary to cover the Asset Management / Engineering / Logistics / Planning functions but representation at 'Chief' level is important.

Fig. 1.5 Asset management in the organization

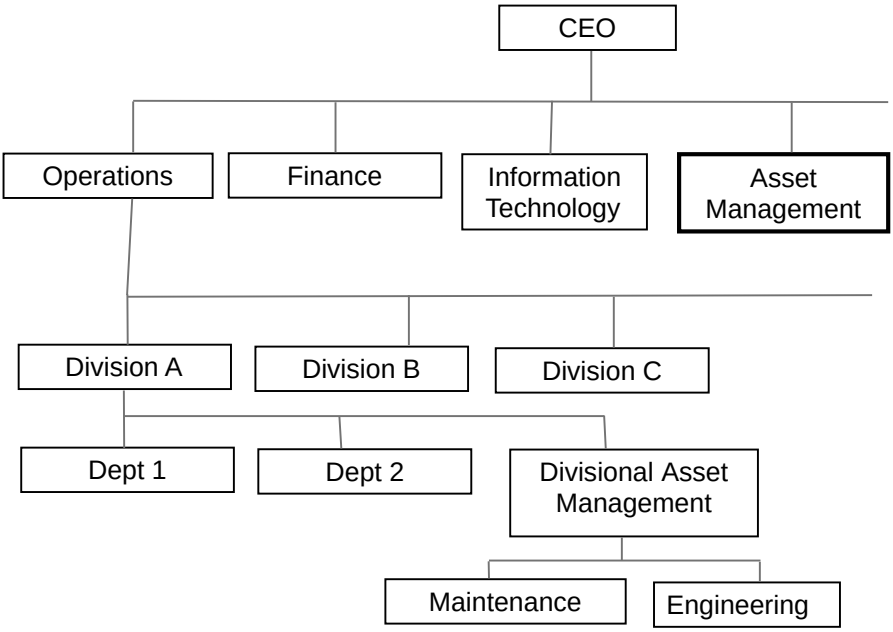


Fig. 1.6 Asset management in the organization (2)

may have asset managers looking after their own assets, just as they have information technology and accounting staff looking after their own divisional activities in those areas. Also, asset management is a functional activity which pervades many areas of the business. Asset management skills and awareness are needed in many roles, and not just by persons who are labelled "Asset Manager". At the risk of some ambiguity, we shall use the term Asset Manager to cover both a person employed *primarily* in asset management activities and a person who needs to use an asset management approach in tackling issues which are only part of their overall job. However, company wide issues, policies, strategies systems and procedures need to be coordinated from the higher level, and we shall assume the existence of a group which we shall refer to as the asset management group, recognising that other names may be used in various organizations. Figure 1.6 illustrates how asset management at the divisional level can combine with asset management at the chief officer level.

1.7 Business Planning and Asset Management

We conclude this chapter by listing in Fig. 1.7 some of the important factors in business planning which influence asset management. In subsequent chapters we shall elaborate on how these factors are involved in decisions and procedures, but for the moment it is sufficient to be aware of these issues as fundamental importance to the asset management role.

a. Trends and forecasts of demand for the product or service
b. Forecasts of revenue and costs; profitability, payback period, return on investment.
c. Capital Budget – how much, where from
d. Opportunities – for new business and/or business development
e. Technological developments
f. Asset capability gaps – gaps in capacity and/or ability in delivering all aspects of the required asset role.
g. Timing – when the assets are required and what lead times are involved
h. Acquisition strategies, supplier options
i. Age and remaining life – replacement provision.
j. Obsolescence – when is existing equipment out of date?
k. Condition – providing adequate reliability, availability?
l. Criticality – in relation to business need.
m. Risk – assess possibilities for loss of market, availability, capacity,
n. Health, safety and environment issues.
o. Strengths, Weaknesses, Opportunities, Threats

Fig. 1.7 Business factors in asset management

1.8 The Asset Death Spiral

Classic situations have arisen where a plant is central to business profitability, but it is ageing – in other words it is an ageing cash cow. Senior managers see no glory in it and the engineers have been redeployed to projects elsewhere. Capital funding is cut and the maintenance budget is cut. Spending on simple problems falls, and in time, simple problems become big problems. Eventually a major accident occurs resulting in fatalities, financial loss and ignominy for those unfortunate enough to be involved. The situation is known as the Asset Death Spiral and is illustrated in Fig. 1.8.

Fig. 1.8, initially the plant is running with an appropriate level of budget, which we have shown schematically as being divided between Non-Routine Maintenance, Routine Maintenance and Renewal. The total budget is then cut, reflecting a perceived reduced importance of the plant. Breakdowns still occur, so Non-Routine Maintenance work must be carried out, but this now requires resources funded from a reduction in expenditure on Routine Maintenance and/or Renewal. This reduction exacerbates the situation, causing more breakdowns, which in turns further reduces the Routine and Renewal budgets, so that the plant spirals down into a situation where all of the budget is being spent on breakdowns. Eventually the maintenance department is overwhelmed and the plant dies.

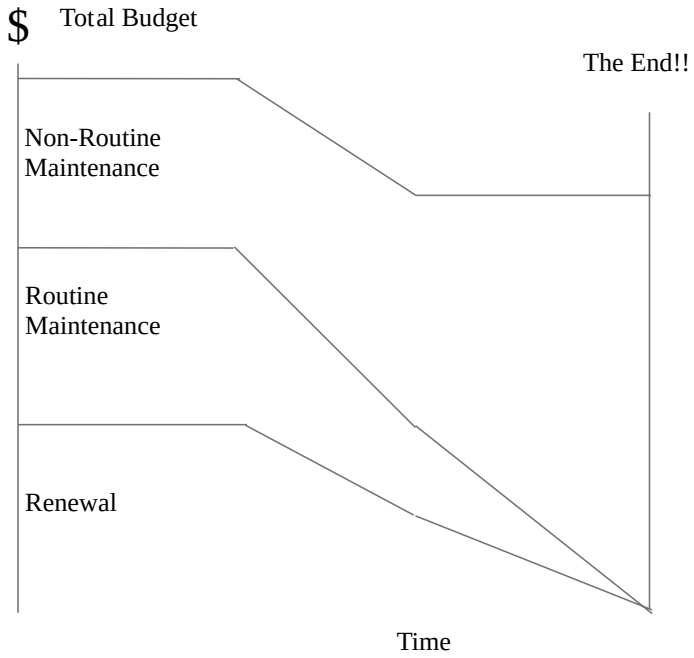


Fig. 1.8 The asset death spiral

1.9 Exercises

1.9.1 Holiday Resort Exercise

The owners of a holiday resort have had a good year, but at times the resort was overcrowded. There are opportunities to develop additional areas for leisure activities and accommodation. Write down half a dozen dot points of factors that they should consider in making plans for the future.

Alternatively, make a similar analysis related to an organization in a field with which you are familiar.

1.9.2 Pacific Earth Moving Part 1

Pacific Earth Moving is a medium sized company which sells, maintains, and hires out excavators, bulldozers, graders, trucks and other earth moving equipment. Increased demand is occurring for the company's services and the company needs to develop proposals which will enable it to fund and implement expansion. The existing senior mangers have grown with the business but are mostly close to retire-

ment and a new organizational approach is needed to plan and implement developments.

You have been hired to advise Pacific Earth Moving on establishing a systematic approach to its future. What factors should the organization consider in deciding on the overall direction and pace of development. What analysis should be undertaken prior to commencing equipment acquisition. Give your answers in dot point form.

1.10 A Top Level Decision

Jock and Sheila were lying in bed one Sunday morning when Jock reached for an envelope that had been lying on the bedside table for a couple of days. He knew what it contained.

"We need to renew the lease on this place", he said. Sheila said nothing, which Jock realized was an ominous sign.

"We have to live somewhere", he ventured, but the silence continued. She must be ahead of him on some other track.

"I'm going to go off the pill next month", Sheila said.

Jock and Sheila had discussed having a family and had agreed that it was what they both wanted. Obviously, going off the pill was a necessary start, but why bring it up now? And what did it have to do with the lease on the flat? Then Jock had a blinding insight.

At the beginning of the year he had moved out of the maintenance department of the industrial conglomerate where he worked, and got a job in Asset Management. He didn't know what asset management was, but he liked the sound of it, and more importantly, the job offered a rise in his pay.

It was the asset management perspective which made him realize that his and Sheila's Sunday morning sports session had morphed into a Business Development Meeting.

"There are some house blocks just released in Mullum Gully", said Sheila.

"We could go and look at them this afternoon", said Jock. Sheila smiled.

Chapter 2
The Asset Management Function

Chapter Aim: To describe the aim, structure and activities of asset management. To indicate the competencies needed by people who work in asset management.

Chapter Outcomes: After reading this chapter you will know:

- Why asset management is needed and what it's main activities are
- How the asset management function should be structured
- The need for personnel working in particular technical asset areas
- The need for financial, legal and engineering support
- The basic knowledge required by asset managers
- The personnel roles required in asset management and the competencies required for those roles
- What is meant by asset management policy
- What is meant by asset management strategy

Chapter Topics:

- The asset management function
- Structure
- Asset management groups
- Knowledge required for effective asset management
- Asset management activities
- Asset management policy
- Policy statement
- Asset strategy factors and model
- Personnel roles
- Personnel competencies
- Personnel development

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2.1 The Asset Management Function

Asset management activities permeate to many levels of an organization, and are not confined to a central group. For this reason we shall use the term Asset Management Function as a flexible descriptor for the activities involved, and apply the term Asset Manager to those involved significantly, but not necessarily exclusively, in asset management activities.

The purpose of the Asset Management Function is to provide resources and expertise to support the acquisition, in-service support and disposal of the physical assets required by the organization. A central asset management function will be needed at company level, providing inputs to asset planning, taking a role in major acquisitions and developments and providing the systems and facilities needed to support assets throughout their life. Asset management is distinct from operations, and does not usually involve the direct design or building of the assets themselves. It is also normally distinct from maintenance, but the technical services functions which support maintenance are part of asset management. The exact terminology and reporting structures may vary from organization to organization.

2.2 Structure

Asset management activities and responsibilities impact on a wide range of roles within an organization are not confined to a specific department. However, in a large organization, effective asset management will benefit from the existence of recognized asset management personnel with expertise in specific areas. These may be formed into distinct groups, the title of which will depend on company history and structure.

An example in defence is the Defence Materiel Organization, which has divisions managing land, sea and air assets. Within each division are asset management groups referred to as System Program Offices (SPOs). Each SPO manages a particular group of prime assets, such as a type of ship or aircraft and all the associated subsidiary assets. In an airline, groups will correspond to the main aircraft types, with additional groups for ground handling equipment, sales systems and customer support systems. An asset management group consists of asset managers with suitable technical backgrounds, and personnel in accounting and finance, legal, contracting, procurement and engineering roles. The financial, legal and engineering staff will be co-located to asset management groups from their professional area. For particular projects, teams will be formed with personnel numbers and skills dependent on the content and size of the project. The asset management groups form a basis from which these teams can be formed.

The asset management groups have key roles in acquisition and development decisions, acquisition and development projects, and in creating and managing organization-wide systems for equipment support for new and existing assets.

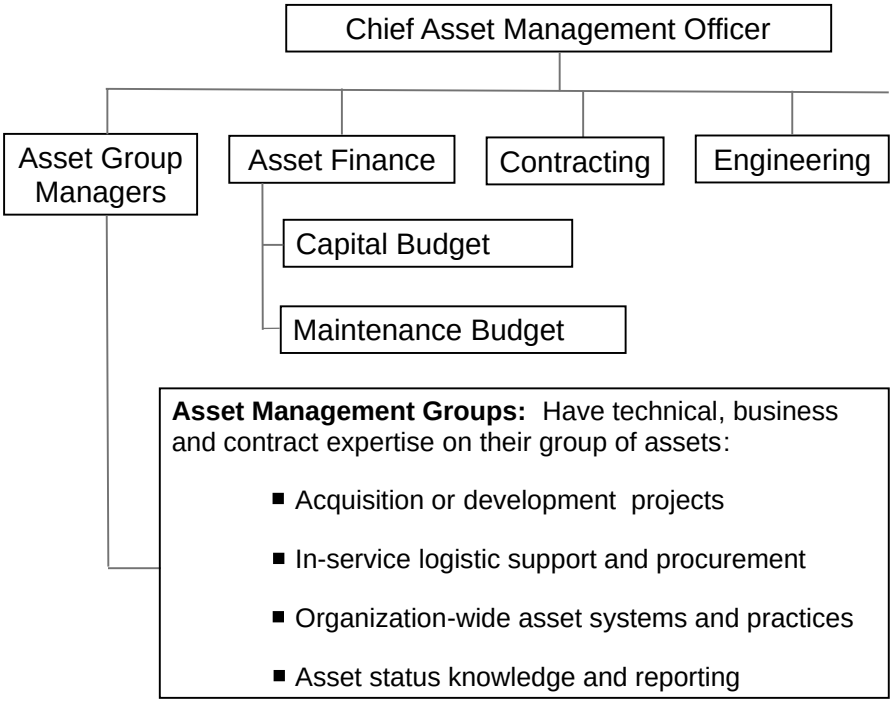

Fig. 2.1 Asset management group structure

Figure 2.1 illustrates this structure. The actual design, building and manufacture of major plant and equipment is generally not part of the asset management role.

The asset management groups just referred to can involve hundreds of personnel in a large organization. In a smaller organization the same types of tasks are undertaken and the same types of decisions are made, so that the logic of the processes carries through, even though the tasks may be handled by, say, a works manager, a works engineer or a maintenance superintendent in among a range of other commitments.

2.2.1 Asset Management Groups Example

Asset management groups are based around the various major equipment areas operated by the company. Figure 2.2 shows an example of the asset management groups for an electricity transmission company. The company installs and operates transmission lines and substations. There are asset management groups for 'substations' and 'field' with sub-groups for switchgear, transformers, transmission lines and so on. Each group is headed by an asset group manager, supported by technical, logistics, financial and commercial staff with competence in the particular field.

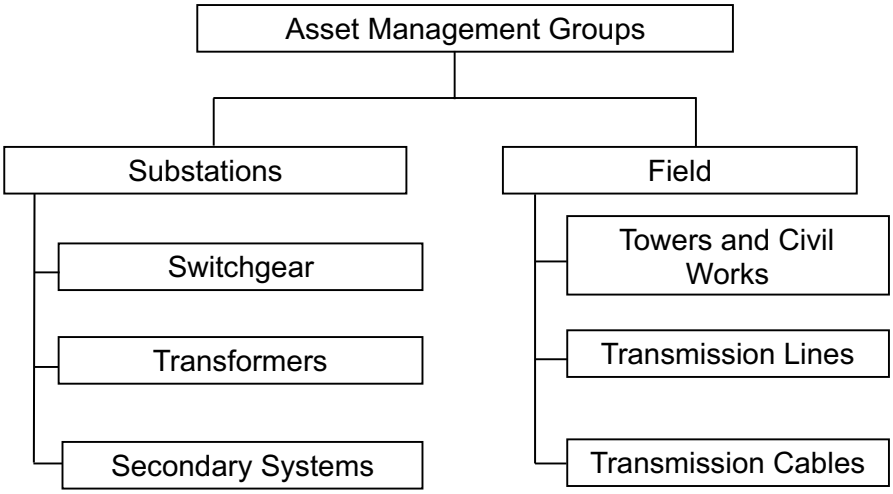

Fig. 2.2 Asset management groups example – electricity transmission

The asset management groups are involved in, and often have primary responsibility for projects of a wide range of types. For any particular project, a project team will be created, drawing on the most closely related asset management group, augmented by financial, contract and engineering specialists as necessary. These specialists may be involved with a particular project team on a full time or part time basis depending on the amount of work required. Project teams may bring in staff members from other asset management groups where multiple technologies are involved. For major projects, an *integrated project team* will be formed, which may be led from the business development group and will includes representatives from key stakeholder groups.

2.3 Asset Knowledge

The management of assets is dependent on knowledge about the organization's assets, in terms of both current equipment, business role of the assets and future prospects. Asset managers need to have a practical working knowledge of the major assets at a management level so as to be able to make sound business decisions. They need to be aware of the assets which constitute elements in any given capability, that is, the array of subsidiary items which are necessary to support particular prime equipment. There is also a requirement for *configuration management* that is, keeping systematic track of changes to equipment configurations, such as technical upgrades and regulatory compatibilities.

For major items for which future capital decisions are required, it is advisable to list the date and type of the decisions that will be needed. For example, for a truck fleet, we need knowledge of the years of remaining effective life of vehicles, and of

Table 2.1 Asset management knowledge

1	What assets have we got
2	Where are they located
3	What is the business significance of our major assets
4	What is the profit and loss position of our major assets
5	What is our asset utilization including peak load and seasonal factors
6	Are there gross imbalances – that is, major shortages, surpluses or misallocations of equipment or personnel
7	What is the condition of each major asset
8	Are reliability or availability issues significant
9	How much longer can specific assets last
10	Are there significant risks
11	Are maintenance costs a significant factor
12	What asset related developments and market opportunities exist
13	What has the market got to offer in terms of assets that we might usefully acquire

the lead time for acquisition of replacements, so that we can plan our replacement strategy sufficiently far in advance. This knowledge, combined with an assessment of the future requirements of the business, and of developments in the types of vehicles available from manufacturers, will enable us to make sound and timely decisions within the constraints of business risk. A summary of points of knowledge which an asset manager may need to have is shown in Table 2.1.

2.3.1 Asset Management Activities

The asset management function has a role to play in relation to a substantial number of activities, as shown in Table 2.2 Asset management activities.

2.4 Asset Management Policy

A policy statement is a statement of the overall aims or principles adopted by an organization. A classic policy statement from history was made by a senator in ancient Rome: “Carthage must be destroyed”. PAS-55, the Asset Management specification, calls for an organization to have an asset management policy. Some suggested general points to be covered in the asset management policy statement are shown in Fig. 2.3 Asset policy statement.

Other aspects of policy may cover the assignment of authority and responsibility for specific areas of asset management to various office holders. For example, the company board to approve and monitor capital asset acquisition plans and to review

Table 2.2 Asset management activities

1	Input to asset related aspects of business development at the concept planning stages
2	Input to pre-feasibility and feasibility analysis for asset developments including requirements analysis, input to financial analysis
3	Preparing business cases for asset related activities, can include preparing proposals, evaluating proposals and advising on the preparation of proposals
4	Development of recommendations for acquisitions, process improvements, replacement, refurbishment
5	Life cycle costing
6	Management of asset acquisition and/or development projects
7	Development and implementation of logistic support policies
8	Management of introduction into service
9	Setting maintenance policy and procedures
10	Applications of asset related technology e. g. new equipment developments, condition monitoring developments
11	Managing asset policies in regard to health, safety, environment, security requirements
12	Managing through life support provision, effectiveness and audit
13	Maintenance facilities and resources planning and provision
14	Maintenance outsourcing strategy and management
15	Configuration management
16	Technical input into computerized asset management systems structure and development
17	Input into the selection, implementation and user support for asset management information systems
18	Asset renewal/replacement/overhaul policy assessment and decisions
19	Arrange and carry out reliability and availability tests and evaluations
20	Equipment redeployment for asset management reasons
21	Equipment disposal
22	Asset related special studies
23	Asset implications of changed operating practices
24	Equipment leasing policy and management
25	Identifying and setting asset related emergency response strategies
26	Introduction and management of organization-wide asset related systems including the Computerized Maintenance Management System, Incident reporting systems, fault and failure reporting systems and responses
27	Spare parts management systems and spares control setting including rotable repair parts policy and management, insurance spares
32	Pilot studies and trials organization and evaluation
33	Liaising with stakeholders on asset related topics

Our organization has significant investment in plant, equipment, buildings, services and skilled and experienced personnel.
Our policy for managing these assets is to pursue optimum sustainable performance in support of the development of shareholder value, whilst complying with requirements for health, safety and the environment.
To achieve this we undertake to:

- Adopt a whole-of-life approach to the acquisition, operation, performance, maintenance and disposal of assets.
- Ensure legislative compliance in acquisition, operation, risk management, maintenance and disposal of assets.
- Proactively pursue world's best performance in all aspects of asset management.
- Ensure that the people involved in management of our assets are appropriately selected, developed and trained.
- Apply continuous improvement to managing our assets, to operational efficiency and to the enhancement of the skills of our people.

Fig. 2.3 Asset policy statement

asset performance records; the Chief Asset Management Officer to be responsible for reporting to the board the requirements for asset replacement, for preparing plans for asset replacement and preparing and monitoring in-service asset support strategies; operations mangers to be responsible for managing risk within their operations areas.

Other policy principles are general in relation to business governance and practice, and may be in the form of references to other relevant documents. An example is procedures for ensuring a transparent choice of suppliers or service providers. However, we may also specify that interests of logistic support allow selection from a limited range of providers. Another example is that work is to be carried out in accordance with relevant legislation, standards and guidelines, including health, safety and environmental protection. Policies in relation to outsourcing and the retention of specific sets of skills within the organization may be established.

2.5 Asset Management Strategy

A strategy is a broad level plan set by senior management as a guide to how an organization intends to achieve its aims. Figure 2.4 illustrates an overall life cycle model and related asset strategy factors.

Under this heading, we set out the procedures, or refer to existing documents which specify procedures to be followed in managing assets. The asset strategy

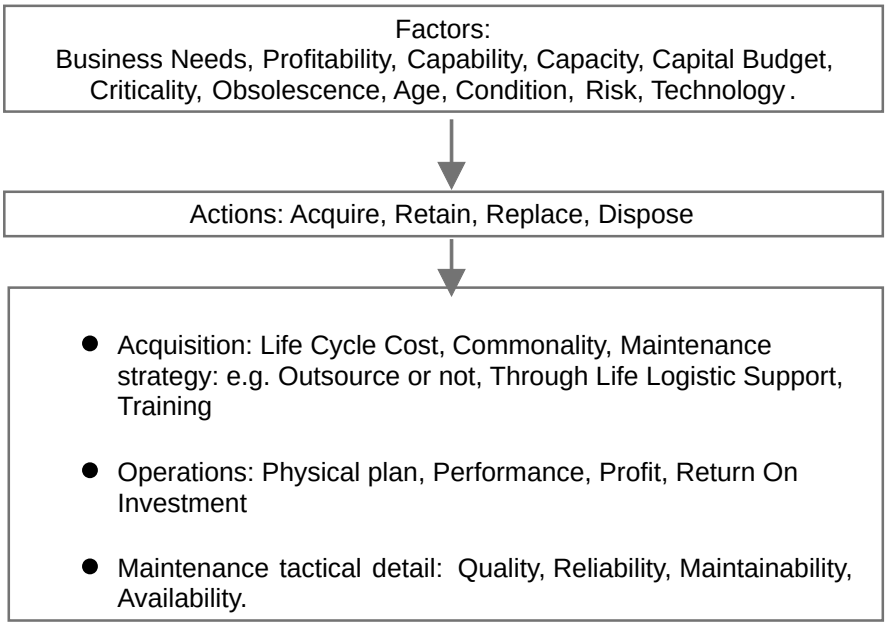

Fig. 2.4 An asset strategy model

will also specify authorities and responsibilities for action in relation to asset management activities. These may be incorporated in more generally based documents such as organization charts and job descriptions, but it is important that the asset management aspects are covered. Some examples are as follows.

2.5.1 Capital Items

Asset replacement plans are to be created and to be reviewed annually, and as required in the event of significant changes.

The age and condition of assets is to be monitored and taken into account in planning, so that issues of reliability and risk, and disruptions to business plans are minimized.

Capital expenditure proposals are to be prepared in accordance with the organizations standard procedures and timings, and will include a financial and/or cost-benefit analysis and a risk analysis.

2.5.2 In-Service Support

A systematic approach to the support of in-service assets is to be established and operated in accordance with the following requirements.

Asset maintenance plans, which may include outsourcing, are to be established and to be documented in the organization's maintenance management computer system.

Plans will be created and maintained, to deliver the required level of service of assets. Asset maintenance plans are to minimize life cycle costs consistent with achieving the outcomes specified.

Risk analysis of asset operations is to be undertaken in accordance with specified procedures. Risk management and mitigation strategies are to be implemented as indicated by the analysis.

The specified information management system is to be used for recording plans, procedures and work management.

Reporting procedures for asset related incidents, failures or defects and procedures for the analysis and response to these are to be established and intelligently followed.

Definitions and reporting procedures for asset performance indicators are to be applied.

Procedures for asset management and maintenance operating budgets are to be established and followed.

2.5.3 Business Strategy and Asset Strategy

The asset strategy must be responsive to and interact with the business strategy. Issues deriving from the business situation which will impact on asset management strategy include the following.

- Changes in demand for product or service.
- Changes in revenue and costs.
- Technological developments.
- New business developments
- Acquisitions
- Divestment, sale or phasing out;
- Redeployment;
- Changed operating practices;
- Equipment replacement/Leasing;
- Outsourcing or In-sourcing of services.

Other factors are the extent to which we plan for long term growth or to just do enough to meet short term requirements; degree of commitment to in-house repair and logistic support as opposed to use of outsourced support facilities; the use of redundancy to achieve system reliability, rather than seeking high reliability of individual items; the degree of co-ordination between related parts of a supply chain, e. g. electricity generation, transmission, and distribution; maintenance and replacement strategy in regard to run-to-failure, age-based, condition-based, spend-limit based replacement decisions.

2.6 Personnel Roles in Asset Management

The asset management function requires persons with business, technical, operations or service experience, who can work effectively with finance, contract and engineering specialists. The following are key personnel roles in asset management. The assignment of persons to these roles will depend on the size and structure of the organization, and the existence of a role does not necessarily imply that that role constitutes a full time job.

Asset Group Manager

An asset group manager is involved with a group of assets of a related type and has asset managers under him or her. In the electricity transmission example there are asset group managers for Substations and for Field Works.

Asset Manager: An asset manager is involved with a particular range of assets. For example, in the electricity transmission organization there are asset managers for Switchgear, Transformers and Secondary Systems within the substation asset group. Asset Managers require knowledge of relevant technologies and their operational context. They provide management and leadership for the group, and also provide input into business development in relation to their technical area.

Asset managers are likely to come from engineering or logistic backgrounds, but they need to be familiar with the business in its broader context, and with general accounting and financial concepts. Whilst the ultimate detail of accounting and finance will remain the province of specialists in those areas, most business decisions are based on estimates or forecasts made from the basis of combined technical and business knowledge. Here, asset managers have a key role to play in providing timely and sound input into business decisions. A company with a strong asset management presence is likely to outperform one where asset management is weak or non-existent, and it is particularly important that asset managers can provide a working link between the technical and the financial elements of the organization.

Project Manager: Acquisition and development projects constitute a major activity of the asset management function and require a high level of training, skill and experience in the project management field. Project managers are typically trained and certified in relation to the requirements of professional organizations such as the Project Management Institute and the Project Management Body of Knowledge (PMBOK).

Finance, accounting and costing: Personnel in these fields play an important role in assessing costs, assessing the financial viability of projects and in managing the finances of projects in progress.

Lawyers: Contracting and contract managers,

Procurement managers and officers:

Engineers: Engineers are required to provide technical knowledge essential to decisions relating to the organization's assets. This includes technical knowledge of

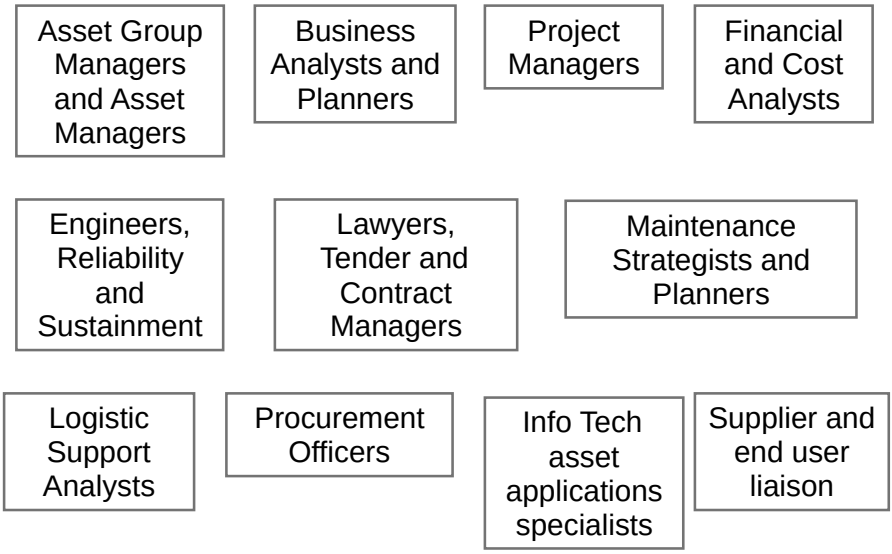

Fig. 2.5 Personnel roles in asset management

design and operation, and engineering and data analysis skills in reliability, maintenance, through life support and replacement decisions. Engineers may take "subject matter expert" roles which run across an organization. For example, an expert on draglines may advise on technical and asset related decisions across a range of sites.

Logisticians: Asset management is a mainstream area for the logistics specialist. The work involves applying such techniques as logistic support analysis and level of repair analysis. This activity area extends into configuration management, cataloguing of spares, identification and coding of maintainable items of equipment, setting inventory control parameters and ensuring that the distribution system for assets, consumables and spare parts is appropriate to needs. A mining company once purchased a vehicle to work underground but then found that it was too big to be taken down the shaft.

General staff: are also required covering human resource management and administrative functions.

Figure 2.5 summarizes the personnel roles which are relevant to the asset management function.

2.6.1 Competencies

Asset management needs competencies suited to the tasks involved, including appropriate knowledge, skills, experience, behaviour, attitudes and attributes.

The required background knowledge will involve an understanding of the technical areas of the business, the commercial needs of the business, skills in bringing together plans and projects and in presenting a balanced view of all aspects of an issue as a basis for business case development and decision making. Unlike many other areas of business, there is not an obvious direct educational feed-in to the asset management area.

The ability to work in a team and to share, mould and integrate opinions with logic and objective data are important. Members of the asset management groups will generally be drawn from technical, operational and service areas and will be people with substantial experience and competence in the relevant roles. Members in specialist roles such as finance, legal and engineering will combine their specialist knowledge with a thorough grounding in the operational and business environment of the organization. It is a staff job.

The asset management project teams will be selected for their combination of equipment knowledge and awareness of business requirements and processes. Equipment knowledge will assist them in identifying developments in their technical field, and assessing their practicality and business value. It is important to recognize and to provide sound responses to both customer pull and technology push. Table 2.1 Asset management knowledge and Table 2.2 Asset management activities provide check lists of areas of knowledge and experience which can be used in checking the competence of asset management personnel.

2.6.2 Personnel Development

Getting the right people into the right positions in asset management involves recognizing the competencies that are needed and recruiting, selecting and developing people to deliver these competencies. For any particular appointment it is useful to identify the main competencies needed and then assess individuals against this. A simple rating system for any competency is:

0 = None,
1 = Low,
2 = Medium,
3 = High.

This approach is illustrated in **Fig. 2.6** which is a spider diagram relating to the position of Asset Group Manager. The spider diagram helps in visualizing and presenting the competencies required for a particular post, and the competency status which has been assessed for a particular candidate. This can assist with decisions on appointments, and also identify where individuals would benefit from additional training and experience.

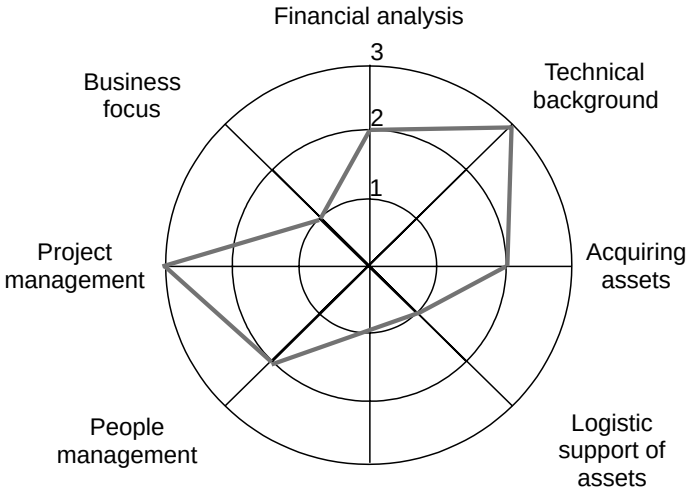

Fig. 2.6 Spider diagram

2.7 Exercise

2.7.1 Pacific Earth Moving Part 2

Pacific Earth Moving is a medium sized company which sells, maintains, and hires out excavators, bulldozers, graders, trucks and other earth moving equipment. Increased demand for the company's services has led to the approval of a proposal to implement a major expansion plan. Several senior mangers who grew up with the business have recently retired and a new organizational approach is needed to implement developments.

You have been assigned to advise Pacific Earth Moving on establishing an organizational structure for asset acquisition and asset management for the future, and indicating what personnel should be recruited. Provide an outline of the proposed organization in the form of an organization chart and an indication of the personnel roles and competencies required by the company.

2.8 Asset Management – Who Needs It?

Every few weeks Jock would call in on his Pop at his old weatherboard house near the Yarra river at Warrandyte. Pop barracked for Richmond, unlike Jock who was a Brisbane Lions supporter. Pop also went along to the local oval every week to watch his youngest great-grandchild play for the Warrandyte Bloods in the local under 12 s league. After the usual football banter, Jock told Pop about his new job.

"What do you mean asset management?", asked Pop. Jock explained.

"We could have done with some of that in the early days of the war", said Pop. Jock liked to hear Pop's stories and waited for him to go on.

"Norway was a disaster", said Pop. "We were supposed to block the German advance but we were landed without any of our stuff. We were sitting on a hillside with just our packs and rifles when an officer told us to start digging in. He didn't stick around so we just took a couple of casual kicks at the rocks and sat down again."

"Then my mate Happy Kershaw noticed a plane in the distance, and said that it was coming our way. Happy stood up and said, 'It's dropping something'.

"We watched idly as the something fell to the ground, and then jumped a mile as it gave an almighty bang. Realization dawned, as the plane veered away and we could see black crosses on its wings. After that we lay flat, and dug furiously with our bayonets and bare hands.

"Later that night we were pulled back and shipped out on a destroyer, but all our gear was lost. Someone must have learnt a lot about logistics from that little episode", said Pop.

Chapter 3
From Concept to Project Approval

"Ideas are two a penny" Bill Gates

Chapter Aim: The aim of this chapter is to describe the asset development process from concept to project approval. This chapter shows how asset management works with other parts of the organization in order to create sound development plans. The focus is on procedures for larger scale developments, such as major acquisitions. The chapter starts at the concept level, goes through the preliminary approval stage, to feasibility planning and on to final project approval.

Chapter Outcomes: After reading this chapter you will know:

- The stages involved in asset development
- The structure and role of development planning teams
- The concept of capability, with examples
- The identification of business needs
- The concept of capability gap analysis and the develop of a capability requirements statement and operational concept
- Pre-feasibility analysis of development options, leading to a proposal at the preliminary approval stage
- Feasibility analysis and the creation of an acquisition or development plan

Chapter Topics:

- Capital project initiation
- The business development group
- Business development planning
- Major and minor projects and development flexibility
- Capability concept
- Development planning teams
- Needs analysis
- Remaining life and retirement schedule

N. A. J. Hastings, *Physical Asset Management*,

- Capability gap analysis
- The capability requirements statement
- Pre-feasibility analysis
- Feasibility analysis
- Development plan topics
- Stakeholders
- Existing process and the status quo
- Lead time activities
- Operational concept
- Function and performance specification
- Level of service
- Financial analysis
- Acquisition Strategy
- Project maturity measures

3.1 Project Initiation

Business development generally involves a senior level group which identifies business development needs, examines options for meeting the needs, establishes priorities, assesses financial returns, sources and constraints and initiates major development projects. The rationale behind asset intensive projects may be one or more of the following:

a. Capacity expansion, reduction or consolidation
b. Renewal or updating of existing capacity
c. New business directions
d. Process improvement
e. De-bottlenecking
f. Protection of assets
g. Technical developments, internally and externally
h. Environmental or safety improvements
i. Response to regulatory changes

Development ideas may have a *top down* or a *bottom up* origin. A top down development will originate with senior management. A bottom up development will start in the operations areas rising through the hierarchy and then feeding in to the business development process. The organization should encourage business development from the bottom up as well as from the top down. Workplace personnel and managers close to the workface are in an excellent position to see how improvements can be made, often on a very cost effective basis. They should be encouraged to develop and bring forward proposals in a spirit of *continuous improvement.*

For a concept to proceed into the mainstream of development planning, the backing of senior management must be achieved. A budget needs to be set aside, and procedures established, for the purpose of getting ideas to ‘square one’ of the development process.

3.2 Types of Project

Several different types of project can be identified as follows:

a. Off-the-shelf acquisition
b. Business development but not primarily acquisition
c. Design incorporating selection of off-the-shelf items
d. Design from the drawing board but standard technology
e. Design with developmental technology
f. Introduction of technical change
g. Research and development

An off-the-shelf acquisition is one where we acquire an existing product, with no design or modification involved. With off-the-shelf acquisitions the logistic support requirements should be readily met and often are available as a standard part of the acquisition package. As we proceed down the above list, the level of complexity increases. Businesses should be wary of projects that involve significant amounts of development work as they often lead to technical problems and delays. In such cases it is best to undertake a pilot project initially to eliminate as many unknown factors as possible.

3.3 Business Development Planning

Business development is a key role of senior management. Development planning requires confidentiality, as plans are discussed which may influence the overall direction of the business, but which are still in a state of flux. A business development group is normally established to generate, assess and monitor major potential developments. In looking to the future, the business development group will need to draw on specific asset knowledge and in this situation the existence of a recognized asset management group with the necessary knowledge and skills is an advantage.

3.3.1 Major Projects

An example of a major strategic development decision is a commitment to develop a new mine. For example, a mining company may be considering developing a mine which will produce particular mineral, say nickel. A decision as to whether to proceed with the development of the mine will depend on an assessment of the current and future demand for nickel, the development cost of the mine, the likely yield and other factors such as transport costs, energy costs and regulatory issues.

Once a concept takes on the aspect of a major project, which usually means exceeding some financial threshold of the order of millions of dollars, a development planning team will be formed. The asset management group, or equivalent,

will play a key role here, particularly in regard to the asset acquisition and sustainment aspects of the project.

The stages of development of a major project are as follows,

- Project initiation
- Capability requirements analysis
- Pre-feasibility analysis – identify options
- Feasibility analysis – detailed plan
- Implementation

Figure 3.15 details the steps involved in a major asset development project, and the subsequent sustainment of the asset in service.

3.3.2 Minor Projects

Minor projects play an important role in supporting and developing business performance. These developments may be handled within operating divisions and often form part of existing job activities rather than giving rise to specially formed teams. The logic of the steps involved in appraisal and implementation is much the same in both major and minor cases, but the volume of work is less in a simple acquisition or a development with modest logistic support needs.

3.3.3 Developmental Flexibility

In this chapter we describe processes for the assessment of business needs and the determination of asset requirements. In practice, our processes must not delay acquisition or development unnecessarily. Where the business justification is clear and the needs can be met by well recognized steps, then our organization should be such that we can proceed without delay.

In a warehousing operation, for example, if additional forklift capacity of a standard type is needed, a rapid and favourable assessment of the factors involved should result in the acquisition of an additional machine within days. On the other hand, the development of a new warehouse site would involve a detailed analysis of issues such as future demand, site availability, site access, materials handling, and personnel requirements for operations and support. The extent of our deliberations, in terms of detail and time, should reflect the level of complexity and degree of urgency of the business need, and the acquisition or development process should adapt accordingly.

3.4 Capability

An important concept in business development planning is *capability*. Capability is the ability of a system to meet a specified need in all its aspects, that is, it covers the combined concepts of capacity and ability, covering all the assets and associated personnel, resources and services which are required to meet the need. It is essential that those involved in business development planning understand the concept of capability, as otherwise they will not take a sufficiently comprehensive view of all aspects of a development.

To illustrate the meaning of "capability" consider the example of a fire station. The primary assets are the fire engine or engines and the building which houses them. However, the total capability required, goes beyond these primary assets. There is a need for provision and storage of a range of fire fighting and fire protection equipment, basic medical equipment and supplies, communications equipment, electricity and water supplies, transport access roads and parking space, short term food supplies, the provision of training rooms and training facilities, the availability of personnel to staff the facility, and planning and training for operations and maintenance. These elements in total comprise the capability which is needed. Figure 3.1 summarises this. In addition to the basic list of items, technical specifications will also be needed, such as the quantity, capacity or level of service. The key point here is to be aware of the extensive range of items which typically constitute a capability.

Figure 3.2 illustrates the types of inputs to asset capability in a general case.

Prime equipment = Fire Engines and Building
Capability includes:
- Water supply
- Vehicle accommodation
- Crew accommodation
- Equipment storage
- Chemicals storage
- Training facilities
- Communications equipment
- Navigation equipment
- First aid equipment
- Vehicle access
- ILS items (Integrated Logistic Support)
- TLS arrangements (Through Life Support)

Risks e.g. Delivery delay, communications compatibility.

Fig. 3.1 Capability example – fire station

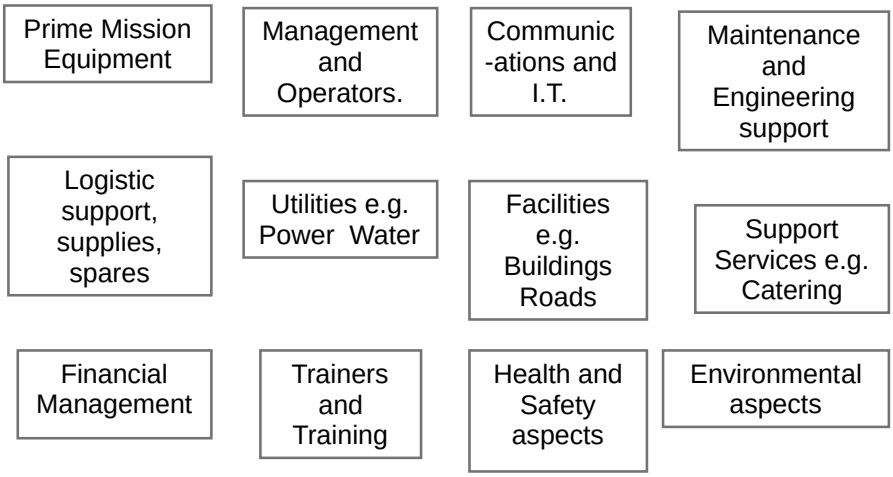

Fig. 3.2 Inputs to capability

3.5 Capability Requirements Planning

Capability Requirements Planning is the determination of the capability requirements needed in order to support a business plan over a planning horizon. **Figure 3.3** indicates the steps in capability requirements planning.

Capability requirements planning starts with a business plan and proceeds into a *needs analysis*. A *needs analysis* is an assessment of the total capability required to support the business plan. An example is where the growth in demand for electricity, leads to a plan to expand the supply, leading to an estimate of the generating capacity, transmission capacity (i. e. high voltage lines) and distribution capacity (i. e. local supply lines) needed at various points over the planning horizon.

The next step is a projection of the *un-augmented asset capability*. This is the available capability, projected over the planning horizon, if no new development is undertaken. To assess this we start from the existing capability and project forward, taking into account all factors which will deplete this capability, such as the retirement of old plant, the impact of technical and regulatory changes and also any augmentation from the coming to fruition of existing committed plans. In this step we do not consider the addition of new capability which has not yet been approved. The result will be a projected available level of generating, transmission and distribution capacity going forward in time.

The next step is *capability gap analysis*, where we identify the gap between the required capability and the projected un-augmented capability. This analysis will indicate a capability gap moving forward in time. In the electricity generating case the gap will be in megawatts of generating capacity and may also reflect legislation on the source of energy.

From the capability gap analysis we construct a *capability requirements statement*, which is a statement of the capability which we need to acquire to fill the gap.

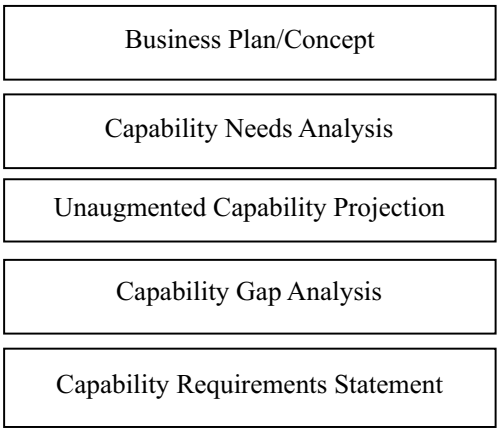

Fig. 3.3 Capability requirements planning

This statement will address both the quantity and type of capability required, the timings required, and issues such as level of service, essential criteria and desirable criteria.

The capability requirements statement will form the starting point for the creation of a development plan which will deliver the capability necessary to support the business plan.

3.5.1 Development Planning Teams

The senior management of the organization will exercise a review function which will include an initial assessment of major development proposals. When a major proposal is seen as having potential it will become part of the *Requirements Portfolio* of projects and a development planning team will be formed.

Development planning teams will appear in the organizational chart as shown in Fig. 3.4 and will report to a development manager. They will draw on personnel from the Business Development Group, on the user area most involved in the development, and on asset management personnel with skills in the development area. Other key stakeholders will be identified and brought in as required. The team will report to the head of business development, and through him, to the board of the company. Figure 3.5 illustrates sources of development team representation.

For large projects, subsidiary working groups may be established to deal with specific issues. If necessary, a separate exploratory or trials stage will be established. It is better to put in the effort at this stage of a development, rather than to enter into a project which later turns out to be technically or financially unsound, though in any case there is always an element of risk remaining.

Some asset based businesses involve a continual succession of projects, such as building projects, and they will be organized to deal with this routinely The organization of each project will depend on its size and complexity. For smaller projects, the development will take place within the relevant operational area.

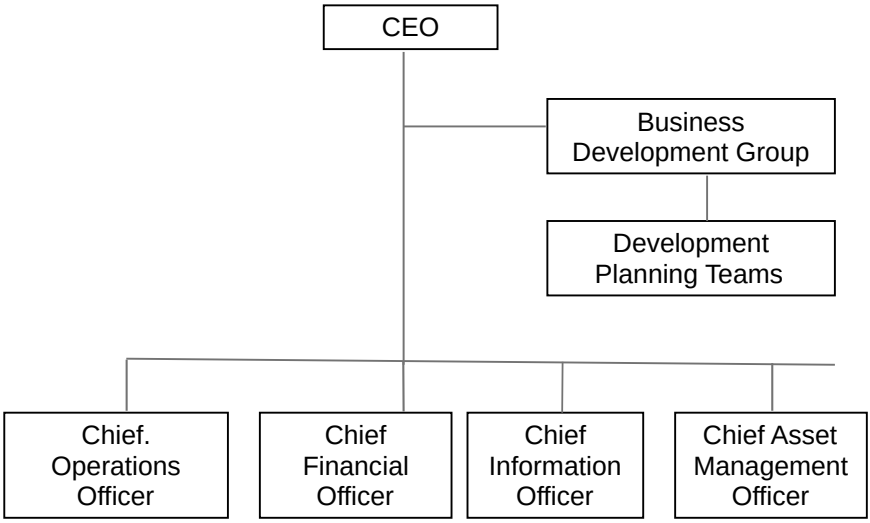

Fig. 3.4 Development planning teams in the organizational structure

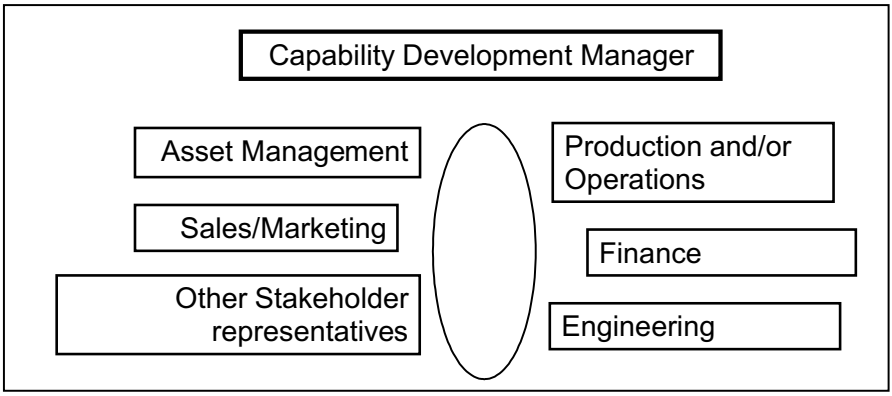

Fig. 3.5 Sources of development team representation

3.5.2 Needs Analysis

Needs analysis is the identification of what the organization needs in terms of asset capability in order to support its business plans. Initially, needs analysis works at the level of prime equipment and takes a broad view of business development. Any actual development requires a more detailed consideration of the factors involved in achieving and delivering a capability.

Needs analysis looks at several time-frames on a rolling basis, such as 0–5 years, 5–10 years, 10–20 years. Analysts consider likely scenarios and responses to those scenarios, and identify the capability needs of the organization over the cor-

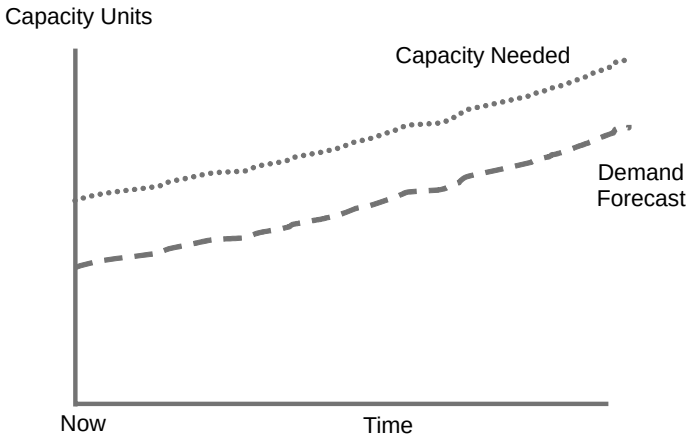

Fig. 3.6 Needs analysis

responding periods. This requires a good understanding of how business functional requirements convert into asset capability requirements. Figure 3.6 schematically illustrates the principles of needs analysis at a simple level. The dashed line shows a projected increase in demand for a product or service. The dotted line shows the projected level of capacity needed in order to meet the demand, allowing for some spare capacity to accommodate variability and risk.

3.5.3 Un-augmented Capability Analysis

The next step in capability requirements planning is to assess what the capability will be over the planning horizon if no augmentation is carried out. We estimate the decrease in our production or service capacity if no acquisitions are made. Primarily, this decrease will be due to older equipment being retired or becoming obsolete. In Fig. 3.9 the light solid line, labelled 'Capacity if no Acquisitions' shows the projection of the un-augmented capacity.

3.5.4 Remaining Life and Retirement Schedule

In assessing the un-augmented capability we consider the retirement of existing assets as they age. For capability requirements planning purposes we also need to consider the lead time required in order to replace them, whether as a direct replacement or as part of an alternative solution.

To assist in this process an analysis in the style indicated by Fig. 3.7 is carried out. This lists the assets by type and age, and shows the *life of type* or planned

effective life of each group. From this the *year of expiry*, that is the year by which replacement is needed, can be calculated. In Fig. 3.7 this is shown in relation to 'Now' but in practice an actual calendar year would be shown. The acquisition lead time is then entered and we then calculate the year of decision. The *year of decision* is the year in which we must make a decision about replacing the assets in order to acquire their replacements by their year of expiry. The year-of-decision calculation gives an indication of the urgency of the development process.

The analysis can also be supported by an asset retirement schedule as illustrated in Fig. 3.8.

Item Type (1)	Qty (2)	Year of Life, (3)	Life of Type, (4)	Year of Expiry, (5)=Now+(4)-(3)	Acquisition Lead Time, years (6)	Year of Decision (7)=(5)-(6)
A	10	13	15	Now+2	2	Now
A	12	11	15	Now+4	2	Now+2
B	30	7	10	Now+3	3	Now
C	24	37	40	Now+3	3	Now
C	30	36	40	Now+4	3	Now+1
D	12	15	15	Now	2	Now-2

Fig. 3.7 Determining year of expiry and year of decision

Item Type	Now	Now+1	Now+2	Now+3	Now+4
A	0	0	10	0	12
B	0	0	0	30	0
C	0	0	0	24	30
D	12	0	0	0	0
E	0	3	15	0	6
F	2	7	3	2	0

Fig. 3.8 Retirement schedule, numbers retiring each year

3.5.5 Capability Gap

The capability gap is the gap, projected forward over the planning horizon, between:

a. The capability that we need.
b. The un-augmented capability.

The gap may be positive or negative, that is to say, there may be a shortage of capability or an oversupply. The gap is the driver for new capability or, in the case of excess, for the disposal or reallocation of resources.

In Fig. 3.9 the light solid line, labelled 'Capacity if no Acquisitions' shows the projection of the un-augmented capacity. The gap between the capacity needed and the un-augmented capacity is the capacity gap. We may also refer to this gap as the pre-plan capacity gap, since it represents the situation before any plans to fill the gap are introduced. For simplicity we focus on some form of prime equipment capacity in this figure, but in practice we would consider a prime equipment capacity gap initially and then follow up with a consideration of the related subsidiary items of the capability. The gap will vary through time, in this case increasing as demand rises and un-augmented capacity falls. It is important to project the gap forward on the basis of the un-augmented capability, otherwise a lack of appreciation of the variations in the gap over the planning horizon can lead to the development of inferior capability plans. In some instances the gap may rise and then fall, suggesting that the company should plan to cope with a temporary rise which is quite different to dealing with a permanent one.

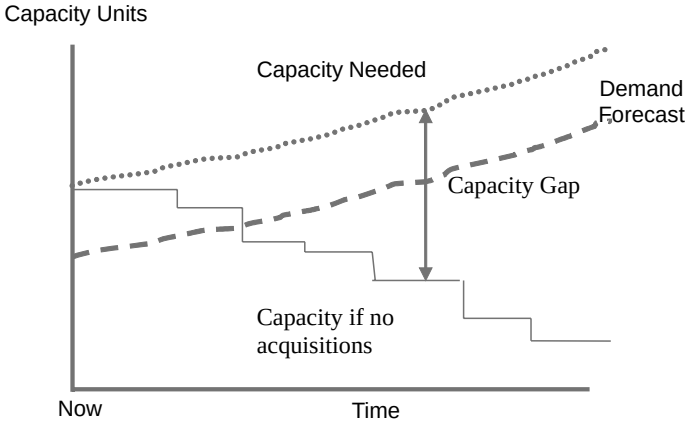

Fig. 3.9 Capacity gap

3.5.6 Capability Requirements Statement

Having completed the capability gap analysis, the development team prepares a *capability requirements statement.* This statement identifies the capabilities which are required to fill the capability gaps. The capability requirements statement forms a basis for further analysis and refinement towards a development plan. The statement must provide sufficient information to act as a starting point for subsequent development analysis, and take account of the financial aspects of the decisions, but great precision is not expected at this stage.

For example, a capability requirements statement may specify that a company will require trucks with sufficient capacity to move a specified volume of goods over specified routes, and logistic support for those trucks. The statement will also specify factors of timing and cost, based on stated market expectations. The capability requirements statement will also specify *decision criteria* that any feasible plan should meet. Some of the criteria will be deemed to be essential, such as the ability to move a given volume of goods, and the ability to meet certain design regulations, whereas other may be desirable, for example a requirement relating to fuel consumption.

3.6 Creating the Development Plan

Management will review the capability requirements statement and decide if the project is to go forward. If so, the project will move out of the requirements portfolio and go into the planning portfolio. The capability requirements statement is the starting point for the creation of plans to fill the capability gap. In the case of a major development, these plans are developed in two stages, referred to as Pre-feasibility Analysis and Feasibility Analysis. If the project proceeds successfully through these stages, this leads on to the acquisition and implementation of the capability. Figure 3.10 shows the steps at the pre-feasibility and feasibility analysis stages. In practice the level of formality in moving through the planning process will depend on the complexity or otherwise of the project and the timing requirements of the development. However, the basic logic of the process is valid, even when some steps are accelerated.

3.7 Pre-feasibility Analysis

Pre-feasibility analysis starts from the requirements determined in the capability requirements analysis stage. The analysis considers the scope of possible responses to the requirements statement and examines options for delivering them. A preferred option or small range of options is selected. It is important not to get emotionally committed to a particular option too early in the analysis. Pre-feasibility analysis

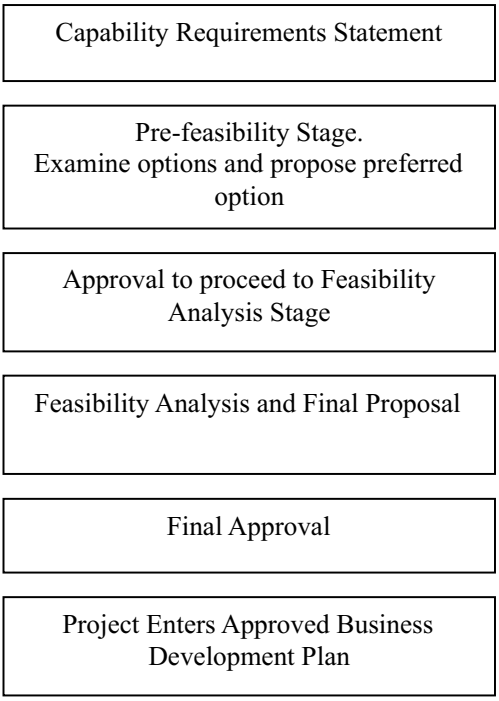

Fig. 3.10 Pre-feasibility and feasibility analysis stages

may indicate that some aspects of the capability requirements statement require review, resulting in reference back to the requirements planning stage.

The result of the analysis is a pre-feasibility plan and an initial business proposal for the project. The proposal seeks approval to proceed to the feasibility analysis stage where a fully detailed and costed plan will be developed. The selection of a specific supplier will normally remain open at this point.

3.7.1 Feasibility Analysis

If the pre-feasibility plan for a project is approved, the project enters the feasibility planning stage. Here the plans for the preferred option from the pre-feasibility stage are subject to detailed analysis and costing. A feasibility planning project team will develop the analysis and there will be a broader stakeholder review which will provide feedback to the project team.

The result of feasibility planning is a development plan and a final business proposal. If this leads to a final decision to proceed, the project then enters the approved business development plan and moves forward to the physical acquisition or implementation phase.

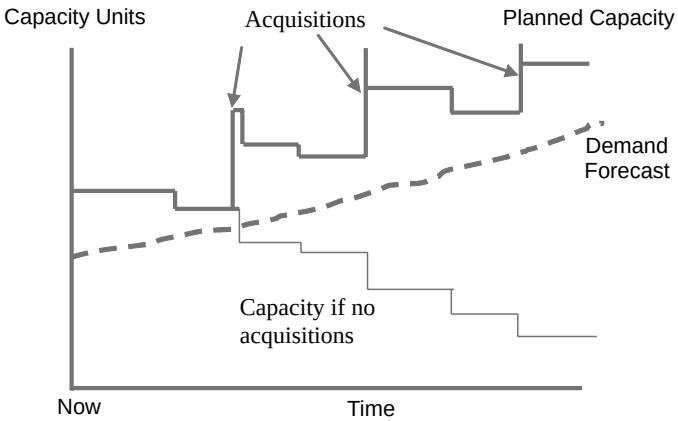

Fig. 3.11 Asset development plan

3.8 Development Plan

The development plan will indicate what assets are planned to be acquired and when. In Fig. 3.11 the heavy line at the top shows a series of planned acquisitions which will be sufficient to keep capacity at a satisfactory level. A significant amount of supporting analysis and detail will normally accompany the plan, and we consider aspects of this in more detail in subsequent sections.

3.9 Development Plan Detailed Topics

The following is a list of topics which are typically covered in the development plan.

General Summary

- Title of plan
- Aims and scope
- Financial returns and costs
- Finance requirements and provision
- Schedule, date of decision
- Acquisition strategy and possible suppliers
- Risks
- Business case

Requirements

- Equipment and facilities
- Capital costs
- Net people requirement – operations and maintenance

- Materials
- Training
- Operating costs

Technical and Logistics

- Test and evaluation
- Project costs
- Maintenance concept
- Logistic support concept
- Life duration estimate
- Life cycle costs

Background

- Stakeholders
- Assumptions
- Data analysis process
- Measure of success

The maturity of the feasibility stage can be assessed with the aid of the table shown in Fig. 3.14.

3.10 Considerations in Development Planning

The issues involved in development planning are considered at length in various parts of this book. Some of the more immediate ones are discussed in this section.

3.10.1 Stakeholders

Identify the stakeholders, that is those people and functions that will be affected by the proposed plan. Survey their opinions and take them into account in developing, or even abandoning the plan. If necessary form a stakeholder committee. It is important to the success of any project that the stakeholders buy in to the plan.

For asset developments, the stakeholders normally include the relevant business, operations and maintenance managers and staff. Where customers and suppliers are affected they will potentially form part of the stakeholder group, subject to business confidentiality. The plan is more likely to succeed if all the relevant groups have contributed to its development. At the same time, some stakeholders may resist the plan, particularly if they see it working against their interest, and it will be necessary to use management judgement and authority to present the rationalisation for the plan from the overall business viewpoint. But suffer fools gladly – they may be right.

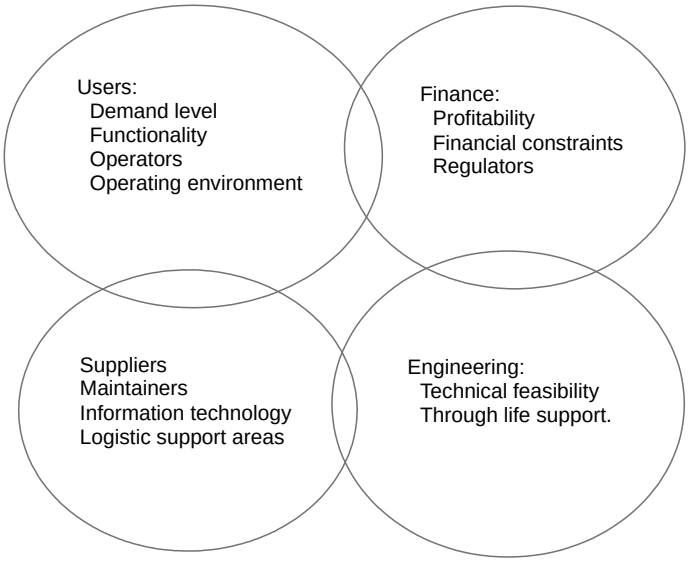

Fig. 3.12 Stakeholder groups

3.10.2 Existing Processes and the Status Quo

In developing any plan it is important to be aware of the existing situation and the existing processes. Be sure to check out the existing situation and consult with stakeholders. Always consider the possibility of retaining the status quo, and use this as a basis for comparison.

3.10.3 Lead Time

An important factor in creating development plans is an appreciation of the amount of lead time required in order to introduce new equipment, and the range of activities which are essential to success. An indication of typical lead time activities is shown in Fig. 3.13.

3.10.4 In Service Date

The Capability Requirements Statement will specify an “In Service Date” as the date when a capability is planned to be available for service. This may be a single date or a range of dates in the case of a phased introduction. For a phased introduction we specify an Initial In-Service date and a Final In-Service date. An implementation timetable may also be needed. At the early stages these dates are preliminary

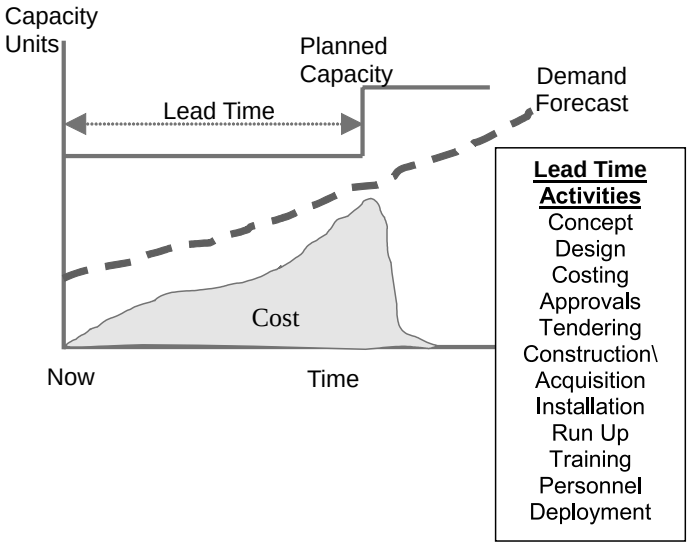

Fig. 3.13 Capital equipment lead time activities

estimates to be firmed up as the acquisition project proceeds. Awareness of the lead time activities and project progress will enable the project team to keep the end user informed of potential changes to in-service dates. Adhering to the planned in-service date is a main target of the development team.

3.10.5 Date of Decision

To ensure an adequate focus on timing, it is desirable to specify a "date of decision" for the final approval of a project whilst it is in the capability requirements analysis and pre-feasibility analysis stages. The many activities involved in an acquisition or development can easily be under estimated and this may result in the development not being completed in time to meet business needs.

3.10.6 Operational Concept

An operational concept document describes the characteristics of the proposed development in end-user terms. The simplest cases are expansions of existing functions. Other types of development may involve responses to new markets, new services, new technologies or developments to existing services or processes. The development of this document will involve the operations group in working out how the new capability will be used and how it will work in with existing capabil-

ity. This can involve market appraisal, technology appraisal, procedural appraisal, evaluation of competition, and financial appraisal in terms of the customer interface.

Project studies may be undertaken to evaluate feasibility and potential profitability of probable options. For example, the organization may require an examination of capacity expansion options in terms of demand, revenue potential, technical options, staffing levels, and considerations of cost and timing, and disposal and redeployment.

The following factors are important in the development of the operational concept:

a. Meet the market need in terms of key outputs, characteristics and features,
b. Profitable,
c. Affordable,
d. Technically feasible,
e. Timing feasible
f. Identify and assess risks.
g. No unsatisfactory risks,
h. Operationally and technically supportable
i. Reliability, availability, maintainability satisfactory
j. Meet design, environmental and safety standards
k. Life adequate
l. Retain some flexibility for revision as the acquisition develops

3.10.7 Function and Performance Specifications

From the operational concept we develop functional and performance specifications for the key assets required to deliver on the operational concept. This about specifying how big, how strong, how many seats, how heavy, what power, what flow rate, how many bedrooms, how many bathrooms, how many garage spaces, what voltage, what noise level, etc. we require in the intended assets. Some features may be *essential* and some merely *desirable.* In developing specifications it is important not to get carried away and set specifications which are unachievable or will imply development work, unless development is a planned part of the project. Refer to existing performance standards and keep to modest variations.

A specification for a new design of rotating turret for a vehicle required a rotational speed which was set to a high level without reference to existing performance standards. At the pre-feasibility stage it became apparent that to achieving this performance would require a radical redesign of the drive system and quite infeasible changes to the vehicle body. Reference back to the capability requirements team showed that, once they related their specification to existing systems, they were quite happy to accept a rotational speed comparable to existing best practice, rather than the wildly optimistic figure originally specified.

3.10.8 Level of Service

Level of service relates to setting standards in such areas as performance, availability, timeliness of response to failures, and provision of information when problems arise. Level of service relates to corresponding performance indicators. As an example, in a railway system, a performance indicator is the proportion of services that are not cancelled, and a corresponding level of service is a specification that this should be, say, 97% or more.

3.10.9 Financial Analysis

Preliminary appraisals of revenue potential, costs and profitability will be carried out and will be refined as the proposal proceeds. Details of financial analysis are considered later. The proposal will be supported by data, analysis and estimates and a statement of assumptions, including the following:

- Demand forecast
- Revenue forecast
- Operational cost forecast including personnel
- Equipment life cycle cost estimate
- Profit and Loss projection
- Cash Flow projection
- Balance Sheet projection
- Sensitivity analysis in regard to assumptions, particularly demand and costs
- Identification of major risks, business, technical and regulatory

3.10.10 Acquisition Strategy

In considering acquisition and development options it is important to ensure that they are feasible from a delivery point of view. A development team may be over-optimistic in assessing what the suppliers can supply and what the developers can develop, within a given time scale and cost envelope.

A danger lies in assuming that an acquisition is of an off-the-shelf nature when in fact it requires adaptation to suit our needs. In this case it is advisable to undertake the adaptation as a separate project, and only to proceed to the main project when we are sure that our needs can be met within desired business parameters.

Another factor is the availability of resources to implement any acquisition or development plan. This includes consideration of the availability of personnel for design and development functions, for equipment specification and evaluation and for cost analysis, legal and financial support and engineering support for acquisition and system implementation. Restrictions in these areas may be critical in reducing the range of projects that can be undertaken.

A summary of points relating to the acquisition strategy is as follows:

a. What potential suppliers are available?
b. How extensively should we canvas for potential suppliers?
c. Should we adopt a preferred supplier list?
d. Should we go to open tender?
e. Should we sole source?
f. Is development work required?
g. Should the acquisition/development be phased?
h. If phased, will changes to the equipment over the phases be a problem?
i. Should the acquisition be evolutionary, allowing for possible equipment improvement over the acquisition process?
j. What major logistic issues are there?

3.11 Project Maturity

At any given point in time a number of projects will be in the feasibility Planning Portfolio. Figure 3.14 shows a scoring system which enables management to track the maturity status of these projects. As a project matures its total maturity score will progress towards 25 and we can monitor progress and manage priorities by reference to the maturity score at any point.

Maturity Score	Business Status	Technical Difficulty	Cost	Schedule	Operations and Support
5	Firm	Minimal	Firm	Confirmed	Planned
4	Understood	Manageable	Estimated	Understood	Known
3	Feasible	Feasible	Contingent	Activities Identified	Understood
2	Plausible	Speculative	Speculative	Speculative	Conceptual
1	Exploratory	Unknown	Unknown	Unknown	Not identified

Fig. 3.14 Feasibility stage maturity status scoring

3.12 Implementation Portfolio

The result of feasibility planning is a development plan and a final business proposal. If this leads to a final decision to proceed, the project then enters the approved business development plan and moves forward to the implementation portfolio. The Implementation Portfolio consists of the set of acquisition or development projects which have been approved for development and are in progress, but not yet handed over to operations. The steps in the journey from initial idea to asset delivery and ultimate disposal are summarized in Fig. 3.15 Steps in the asset management process. The implementation phase of a project is considered in a later chapter.

Development concept and capability requirement perceived
Capability requirements planning project approved, enters Requirements Portfolio
Forecasting, Needs analysis, Un-augmented capability analysis including retirement of older existing facilities, Capability gap analysis
Capability requirements statement established
Pre-feasibility project approved, project enters Pre-Feasibility Portfolio
Pre-feasibility project executed, examine options, initial financial analysis, date of decision
Initial business proposal
Preliminary approval
Feasibility analysis project approved, project enters Feasibility Portfolio
Feasibility analysis of preferred option, test and evaluation work, acquisition strategy, selection criteria, logistic support plan, financial analysis
Final business case
Project approval, project enters Implementation Portfolio
Acquisition/Development project established
Acquisition/Development process, request for tender developed and released, tendering, tender evaluation, equipment trials, supplier selection
Pre-contract negotiation, Contract acceptance
Training developed
Logistic support developed
Commissioning, Equipment pre-acceptance checks
Acceptance
Operational readiness, introduction into service
Hand over to user
Acquisition/Development implementation complete
Sustainment process operational
Operations and sustainment activities on-going
Configuration management, Performance monitoring, Condition monitoring
Defect reporting, analysis and corrective action as determined
Replacement planning
Disposal

Fig. 3.15 Steps in the asset management process

3.13 Capacity Planning Exercise – Generators

3.13.1 Gap Analysis

An electricity generation company is considering developments for power generation over the period from 5 to 8 years ahead. A forecast of demand including reserve capacity indicates that demand will be for 5.2 gigawatts (GW) in year 5, increasing at 10% per annum compound over the remainder of the planning period. A projection of generating capacity available from existing sources is for 4.8 GW to be available in years 5 and 6, decreasing by 0.6 GW per year in years 7 and 8.

Calculate the following for each year of the planning period using a tabular format.

- Year
- Needs
- Un-augmented capacity
- Capacity gap.

3.13.2 Pre-Feasibility Planning and Options

Two options for covering the generating capacity gap are to be considered. These are,

a. adding generator capacity in 600 MW units at the minimal rate to cover the forecast demand, at a cost of $1 billion per unit, with a lead time of 3 years.
b. adding capacity by building 2 GW power stations at a cost of $2.7 billion each with a lead time of 4 years.

Extend your tabular format to develop plans for the two options. Discuss the financial and practical merits of two options and of other possible options. What major elements of capability would be likely to be required besides the generators?

3.14 Bottling Plant Exercise

A bottling plant has four old bottling production lines which need 48 hours a week of scheduled operating time to meet demand. Unscheduled downtime has been eating into planned production time recently. A business development review finds that there is steady demand for the existing product, but that there is growing demand for bottles with a screw top closure. A range of new equipment at various costs and levels of performance is available on the market. At present there are six mechanics, but several are nearing retirement and mechanics with suitable skills are not readily available. What should you do?

3.15 A Business Imperative

Jock and Sheila's trip to look at the blocks of land was not as successful as they had hoped. The prices were much higher than they had anticipated and the best blocks had already gone. They renewed the lease on their apartment and things drifted on for several months. Then one day Jock got in from work to find that Sheila was already home and looking excited.

"You're home early", said Jock.

"Look at me", said Sheila.

As he was already looking at her, this involved no special effort on Jock's part.

"So", he said.

"It's happened", said Sheila.

With no further response from Jock she gave him a "men are so dumb" look and said,

"I'm pregnant!"

Jock picked her up and whirled her around.

"Careful!", she said.

He put her down gently.

"Wow", he said.

A little while later, Sheila said,

"We are going to have to get on with buying a house. We will need three bedrooms, or maybe four – and a new car"

"We won't need so many bedrooms at the start", said Jock, "and why do we need a new car"

"Well we can hardly put a baby seat in that ridiculous two-seater, and we will need room for a pram and baby things. I think we'll have to get a hatch-back"

Jock gave a slight groan.

"Aren't you pleased?", said Sheila looking hurt.

"Of course", said Jock, and he thought about the Capability Development Team that he was involved in for the process plant expansion at work.

His mind turned back to the impending baby. It wasn't the technicalities that worried him. It was the money.

"Maybe I can get the job of Project Leader for the next Feasibility study" he said, half out loud.

"This isn't one of those work projects that you spend all your time thinking about", said Sheila. "It's a baby and it's ours."

He gave her another hug.

Chapter 4
Developing a Business Case

Chapter Aim: The aim of this chapter is to outline the principles and steps involved in developing a business case. Asset managers are frequently involved in developing business cases, which may range from the level of major capital projects to process improvements or systems changes. Business cases are also required for developments such as outsourcing, This chapter is concerned with the overall structure and outline content of business cases, and the details of financial analysis methods are given in later chapters.

Chapter Outcomes: After reading this chapter you will know what steps to take in order to develop a business case. You will have available a list of headings under which a business case can be developed, for both large and small projects. You will have enjoyed reading about the use of business case methods to choose a bottle of wine in a restaurant.

Chapter Topics:

- Business case introduction
- Development plan
- Business case outline
  - Title
  - Executive summary
  - Background
  - Stakeholders
  - Assumptions
  - Options including base case
  - Preferred option
  - Financial analysis
  - Human resources
  - Environment, health and safety
  - Non-financial benefits
  - Risk

N. A. J. Hastings, *Physical Asset Management*,

  - Summary
  - Project management plan
  - Performance monitoring
  - Date of decision
  - In service date
  - Conclusion
- Smaller project business case outline
- Final decision to proceed
- Approved development plan
- Business development process summary
- Wine selection example

4.1 Business Case Introduction

A business case is an argument for taking a particular acquisition or development path. It involves defining the proposed path and stating the reasons for and against pursuing that path, in terms of revenue, costs, discounted cash flow criteria, benefits and risks. Development of a business case is an essential activity which arises at several stages in the asset development process. Asset management personnel need to be familiar with the steps involved in developing a business case, and to be skilled in developing and presenting cases. It is also important to undertake this task objectively, so that the business advantages and disadvantages of any particular case are presented in a balanced way, without undue bias or emotional commitment.

The ability to develop and present a well argued business case is a key attribute of a good asset manager. Lack of ability to develop and present a business case indicates a lack of maturity in the asset management role.

4.2 Development Plan

Before a business case can be developed it is essential to create the plan on which it is to be based. In the case of a major project development based on the procedure outlined in the previous chapter, the pre-feasibility analysis phase will lead to the development of an initial business case. If this is approved the project will enter the feasibility analysis phase which will lead to the development of the final business case, and if this is approved the project will proceed to the acquisition/development stage.

Besides the formal development of business cases for major projects, we will often want to develop business cases in a wide range of situations. The evaluation of options for practically any development can be assisted by the development of an initial business case. For minor projects the two stage process used in major developments may still be followed in principle, but only one actual business case will normally be created, and less detail will be required.

4.3 Business Case Outline

An asset development plan contains information from which we develop a business case. The business case is a summary of the plan, put forward for approval and funding. In outline it covers the following points.

1) Project title, Name of proposing group, Name and details of contact person(s);
2) Executive Summary
   i) Brief statement of problem or opportunity
   ii) Aim of proposal, expected function or effect, main benefits,
   iii) Financial summary, revenue, costs, NPV projected
   iv) Risks
3) Background Situation
   i) An objective statement of current strengths, weaknesses, opportunities and threats.
   ii) Development concept
   iii) Asset needs analysis
   iv) Existing capability, planned capability, capability gap analysis;
   v) Indication of any important relationships to other capabilities or proposals
4) Stakeholders
5) Planning Assumptions such as
   i) Level of service required
   ii) Availability of relevant items, e. g. equipment, land, utilities
   iii) Demand assumptions
   iv) Price assumptions
6) Options Available.
   i) Include “do nothing” or “base case” option.
   ii) For each option summarise relevant concept, data and analysis
   iii) Indication of preferred option with reasons
7) Preferred Option Description
   i) Operational concept, function, effects and net benefits
   ii) Technical feasibility
   iii) Function and performance specifications
   iv) Acquisition strategy
   v) Financial summary
   vi) Consider wider impacts
8) Project financial analysis for preferred option
   i) Added revenue, value and/or cost savings
   ii) Acquisition and development costs
   iii) Net personnel and operating costs
   iv) Logistic support and through life costs, LCC
   v) Project implementation costs
   vi) Required budget
   vii) Investment analysis, NPV, Payback Period, IRR
   viii) Cash flow analysis
9) Human resource factors, availability, net cost, training

10) Environmental assessment
    i) Environmental protection actions required, such as sound barriers, waste disposal facilities
11) Health and safety assessment and requirements or issues
12) Non Financial Benefits
    i) Identify benefits of a non financial nature such as social services, sports ground development, …
13) Summary of Project Activities
    i) Acquisition/Development strategy,
    ii) Scope of Work
    iii) Timings, Project lead time
    iv) Sustainability aspects
14) Risk Analysis
    i) Identify risks of doing nothing
    ii) Identify risks to the project succeeding, solution risk, schedule risk, financial risk. May include high, medium, low analysis;
    iii) Identify risks in the longer term
15) Development Project Management
    i) Indicate the resources and funds required to manage the implementation of the plan
16) Performance Monitoring
    i) Indicate how the intended results will be monitored and reported
17) Proposed date of decision
18) Proposed In-Service date
19) Concluding summary

4.4 Smaller Project Business Case Outline

For a smaller project a briefer case will cover the following points.

1) Name of Proposer
2) Title of Project
3) Executive summary, physical and financial
4) Introduction and background
5) Current situation
6) Forecasts and opportunities
7) Desired future state
8) Outline of options including maintain status quo and potential development paths
9) Proposed development, acquisitions, scope of work
10) Physical/material business benefits, e. g. more production quantity, less losses, staffing or resource savings
11) Estimated value NPV, Payback Period, IRR
12) Risk, environmental and health and safety considerations
13) Proposed timings including in-service date

4.5 The Final Decision to Proceed

The final decision to proceed lies with senior management. It will be based on financial considerations, combined with judgement in relation to forecasts of future developments, consideration of future flexibility and of risks to both the project itself and to the assumptions underlying the business case.

4.6 Approved Development Plan

Once approved, a project becomes part of the organization's approved Business Development Plan. This is a portfolio maintained by the organization, which contains all project plans which have received final approval but are not yet introduced into service.

Projects in the approved Business Development Plan must be taken into account in subsequent planning, and will be regarded as fixed, unless changes are approved at senior level. Such changes should only be made in response to significant changes in the business environment.

4.7 Wine Selection Example

Some fundamentals of the entire business development process can be illustrated by means of the following example relating to the purchase of wine in a restaurant.

Problem Statement
To meet the drinking requirements of the party
Stakeholder group: All members of the party
Options: Beer, Wine (white or red?), Water
Needs analysis: We need 2 bottles of red wine, 1 bottle of white, some water.

Capability Gap Analysis
Needed = 2 red, 1 white, water
Available = 1 bottle of white brought by a member of the party. Water is available in restaurant at no cost.
Gap = 2 bottles of red wine

Capability Requirements Statement
We require 2 bottles of red wine

Decision Criteria
A next step is to establish the criteria on which we are going to make our decision. For wine selection we may decide that our criteria are:

- Produced in South Australia (or other region preferred by top management)
- Made from one grape variety – no cheap blends
- At least two years old – no vintage-Thursday-week stuff
- At least 14% alcohol – we are serious
- Within notional budget – but not rash.

Pre-feasibility analysis
Acquisition strategies were identified as:

- Buy from the restaurant wine list
- Buy from the bottle shop down the road

Check against criteria – was there wine on the list that met them. Answer Yes there were three. Options analysis involved ranking them in order of price. One wine was deemed too expensive and so it was eliminated.

Stakeholder group meeting
No one wanted to go out to the bottle shop.
White wine drinkers now say that one bottle may not be enough.

Pre-feasibility proposal
Buy the middle priced red wine from the restaurant list – the cheapest wine was considered too high a risk. White wine drinkers are to buy extra by the glass if needed. It was noted that this issue should have been identified at the needs analysis stage. A possible issue was whether white wine drinkers should pay separately for extras, but this was countered by the fact that the bottle of white was provided by a member of the party. The pre-feasibility proposal was approved.

Feasibility analysis
Check current availability of selected wine with waiter. Confirm that the price is as on list.

Test and Evaluation
Sample the wine and continue with the current plan only if the wine is satisfactory.

Project approval
Wine approved. Place order for selected wine. Wine ordered.

Implementation
Wine delivered, drunk, empty bottles disposed of thoughtfully.
Note: For the white wine, through life logistic support was required in the form of an ice bucket and ice, or other temperature maintaining device.

4.8 Experience required

Jock applied for the position of Project Manager for the pre-feasibility study for an expansion at the Sandy Point plant. He was doubtful of his chances of getting the job, but was disappointed to find that he wasn't even short-listed. Rumour had it that the front runner was an experienced project manager from Sydney, but a counter rumour said that this guy was fishing for an even bigger job. There were also four or five others who had made the short list.

Jock and Sheila continued house hunting and Jock continued worrying about money. Sheila gave up work.

"I have more important priorities now", she said.

Jock looked out for other job options, but nothing came up. Then out of the blue he had a call from the Human Resource Manager. She said that Ricardo wanted to see him. Ricardo was the CEO and he had only met him once before. That time he had made the mistake of calling him "Mr. Ricardo", not realizing that Ricardo was his first name. Ricardo was only a Divisional Manager then and less well known, but still it was an embarrassing moment.

Jock's meeting with Ricardo went surprisingly well. Ricardo wanted him to run the Sandy Point project!

"Yes Mr. Mello", said Jock.

"Call me Ricardo", said Ricardo and they both laughed.

Jock was mystified how he had got the job, but his friend Declan from corporate legal said it must have been to do with the bitumen plant. It was after a budget meeting at the bitumen plant that Jock had met Ricardo the first time.

"Yes, maybe", said Jock to Declan. "I was lumbered with the job of Acting Operations Manager at the bitumen plant when some guy went sick".

"That was when I realized the meaning of the phrase 'Asset Death Syndrome'. The funny thing was that the plant was running above nameplate output and bitumen was selling like hot bitumen".

"No wonder the financial boys were happy", said Declan, "It was the classic ageing cash cow."

"But nothing happened", said Jock, "My budget was approved".

"I was at that meeting", said Declan, "And it may have seemed like nothing to you but after you left there was a massive argument. The Divisional Financial guy said that your budget proposals for CAPEX and OPEX had no business justification and were just waffly ambit claims. But my boss spoke up for you. It was the first time that I had heard him speak up on anything. It was those photos that you showed at the end of your presentation – the ones with the leaking drums".

"I wasn't sure if I should show those", said Jock, "It could have been a CLM".

"CLM?" said Declan.

"Career Limiting Move. I held back the worst ones just in case", said Jock.

"Well, anyway", said Declan, "My boss said that if any of that stuff leaked into the creek, and it got out that they had knocked back your budget proposal then it would look bad in court. When he said "in court" Ricardo really picked up on it.

The argument went on, but Ricardo eventually said that he took it that nobody was opposed to the budget submission, and by that time, nobody was."

Later Jock caught up with the H.R. manager to fix up some details. He couldn't resist asking how it came about that he got the job when he wasn't short listed. She was cagey – she had done the short-listing.

"Ricardo looked through all the applicants and said he wanted someone with in-plant experience", she said, turning away.

Jock hadn't worked at Sandy Point, but had had three years at Jungalup.

"Those other applicants certainly weren't Desert Rats, more like Gabardine Swine", he mused, with one of his Pop's old phrases coming into play.

That evening Sheila had more news – she had found a house. No, she didn't care about Jock's stupid decision criteria, the point was that she liked it. Jock looked at the Real Estate Agent's brochure and it seemed that it actually met all his stupid criteria except one – it was $150,000 over budget. Jock looked at her.

"Okay", he said. Sheila gave him a hug.

The next day at work Jock worried about what Declan had told him about the inadequacy of his budget proposals at the bitumen plant. If he was going to make a success of the pre-feasibility project he would have to get a grip on the business of creating business cases. And he didn't want to go asking the Gabardine Swine.

"I need to make some notes on business case development", said Jock to himself.

Chapter 5
Implementing Development Plans

"Success has many fathers, failure is an orphan."

Chapter Aim: To present the steps involved in implementing an asset acquisition or development plan from project approval to introduction into service.

Chapter Outcomes: After reading this chapter you will be aware of the steps required in implementing an asset acquisition or development plan. You will gain an overall perspective of the steps and activities involved in the implementation of asset development, from the establishment of a project team, through acquisition to commissioning, introduction into service and change management. This will assist you in managing or participating in asset development.

Chapter Topics:

- Project team and activities
- Team functions
- Project management
- Project milestones
- Evaluation of suppliers
- Equipment selection and trials
- Through life support
- Financial and contract process
- Project maturity status
- Assigning responsibilities, the RACI chart
- Project management reports
- Financial overview report
- Project progress monitoring
- Delays and overruns
- Scope creep
- Project portfolio management
- Commissioning

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- Introduction into service
- Operational readiness
- Training
- Change management

5.1 Project Team and Activities

Business development projects follow on from the stages considered in earlier chapters. The phases of capability requirements analysis, pre-feasibility analysis and feasibility analysis establish the need, the asset requirements, the project plan and the business case covering all aspects of the capability and its logistic support. A project budget will have been prepared and approved. The next step is to carry out the acquisition or development.

5.1.1 Team Functions

For a major development, a development team is established and a development project schedule is prepared. The project team will address the following roles, the number of persons involved being dependent on the size of the project. Some roles may be shared across projects, depending on the volume of work involved.

- Project Manager
- Assistant Project Managers for major subsidiary areas, geographically or technically, e. g. mechanical systems, electrical systems, instrumentation systems, site construction.
- Logistic support manager
- Scheduler
- Commercial manager
- Contracts manager
- Technical and administrative personnel supporting the above as required by the volume of work.

The members of the project team may be sourced from relevant operational areas, from business development or from asset management. In many cases the asset management group will be either in a full project management role, or providing a major part of the development team.

5.1.2 Project Management

The implementation of development plans has three main stages, firstly the creation and letting of contracts for acquisition, development and/or construction, secondly

the implementation of the defined work and thirdly, introduction into service of the new capability. A standard project management software tool should be adopted as an aid to managing any large project. Planning is required for:

- Activities
- Resources
- Resource allocation
- Critical path
- Acquisition procedure standards

5.1.3 Activities

The range of activities will typically include the following.

a. Create a Project Management Plan for the development, including a list of activities and a schedule.
b. Create a functional specification document and selection criteria for tendering against
c. Incorporate through life support requirements
d. Create an Invitation to Register Interest if required
e. Create request for tender document
f. Tender evaluation and supplier selection process
g. Pre-contract testing and evaluation against specifications
h. Contract negotiation and agreement
i. Acquisition
j. Management of assets under construction
k. Quality assurance
l. Implement logistic support plan
m. Installation
n. Commissioning
o. Pre-acceptance checks
p. Equipment acceptance
q. Implement training plan starting with train-the-trainer
r. Operations and maintenance personnel to be trained and deployed
s. Introduction into service
t. Disposal of replaced equipment

5.2 Project Milestones

Stages in a project can be identified by milestones such as the following.

a. Requirements defined
b. Design or acquisition specification complete
c. Tendering complete

d. Pre-contract testing and evaluation complete
e. Contract let
f. Installation complete
g. Commissioning complete
h. Pre-acceptance testing complete
i. Final acceptance
j. Operational

5.3 Evaluation of Suppliers

Before committing to a supplier, assess the potential ability of the supplier to deliver the proposed capability. This will involve assessing technical and managerial competence, financial viability, track record and future potential. There is a tendency to play safe and prefer larger organizations to smaller ones. Look particularly at the competence of a supplier in close relation to the specific capability which is sought. One supplier may match your need well, whereas another supplier may be relying on ambit claims of competence which do not include the specific area required by the current project.

5.4 Equipment Selection and Trials

Figure 5.1 shows a check list of points relating to equipment selection. The selection process will also involve trials of equipment to check their suitability against the function and performance specifications and the selection criteria. The selection and trials considerations will include issues such as reliability, maintainability and logistic support which can affect the delivery of capability over the life cycle of the assets.

5.5 Through Life Support

Through Life Support provision involves implementing the logistic support plan, updated to reflect the actual equipment selection choices made in the acquisition process.

5.6 Financial and Contract Process

Figure 5.2 summarises the steps to be taken.

Criterion	**Option 1** **Equipment Type A**	**Option 2** **Equipment Type B**
Performance in relation to specification		
Acquisition and life cycle cost assessment		
Compatibility with existing equipment and systems		
Operations considerations		
Site preparation, Facilities		
Maintenance considerations		
Documentation provision and standards		
Logistic support		
Overall rating		

Fig. 5.1 Equipment rating and selection summary

Fig. 5.2 Capital project financial and contract stages

Maturity Score	Business Status	Technical Status	Cost	Schedule	Operations and Support
10	Achieved	Proven	Within Budget	Achieved	Operational
9	Demonst-rated	Demonst-rated	Within Contingency	Confident	Transitional
8	Acceptable	Integrated	Exceeds contingency	Acceptable	Developing
7	Contracted	Designed	Contracted	In tolerance	Being procured
6	Negotiating	Planned	Negotiating	Manageable	Defined

Fig. 5.3 Implementation project maturity scores

5.7 Project Maturity Status

At any one time a portfolio of implementation projects will be current. Figure 5.3 shows a scheme for describing the maturity status of these projects.

5.8 Assigning Responsibilities

In any project or operational situation it is important that people understand what their responsibilities are. A convenient way of considering this for any given function is to consider who is *responsible* for carrying out the function, who is *accountable* for the results, who needs to be *consulted* about the activities and who needs to be *informed*. This is referred to as a RACI analysis.

A RACI chart is a chart in which the columns contain personnel functions and the rows contain activities. The cells contain one or more or the letter R,A,C,I indicating:

R = Responsible
A = Accountable
C = Consulted
I = Informed

Only one Responsible and one Accountable entry should appear in any row. Figure 5.4 shows an example relating to an equipment acquisition project.

	Project Manager	Contracts Manager	Logistic Support Manager	Equipment User Support Representative
Meeting schedule and budget	RA	I	I	CI
Acquisition contract	A	R	I	I
Logistic support plan	A	C	R	I
Introduction into service	A	I	C	R

Fig. 5.4 RACI chart for acquisition project

5.9 Project Management Reports

Standard reporting methods must be established for projects. Examples of types of reports are as follows.

5.9.1 Topics

a. Financial overview report
   i. Monthly
   ii. Cumulative
   iii. Forecast
b. Project overview report; progress to date, forecast and risks
c. Recent activities and immediately forthcoming activities
d. Logistic support and sustainment, overview report
e. Capital budget progress reports
f. Project summary report

5.9.2 Financial Overview Report

The financial overview report contains information on the following points.

- Project total budget
- Project financial status in relation to planned milestones
- Actual expenditure to date
- Planned expenditure to date
- Planned future expenditure

- Budget remaining
- Budgetary status of risks remaining and retired
- Contingency used
- Contingency remaining

5.10 Project Progress Monitoring

For the portfolio of implementation projects, progress can be monitored with the help of a one-line progress report per project, indicating the status in respect to the following features. Traffic light symbols or smiley face symbols may be used to give a rapid visual summary of project status.

- physical progress relative to plan,
- financial status relative to budget,
- current problem severity,
- risk severity,
- financial forecast.

Management should then drill down to more detail on under-performing features. As the project proceeds, monitoring should cover the following points.

- Executive summary
- Project background and aims
- Current overall project status
- Status in relation to in-service date
- Schedule progress – any activities delayed and their potential effect
- Budget status planned versus actual, budget projection, contingency used and remaining,
- Projected performance assessment of primary system
- Current and projected status of remaining items of the capability
- Stability of requirements
- Current feedback from stakeholders
- Performance and potential performance of the contractors/suppliers
- Report on resourcing of the development project
- Report on progress with logistic support plan
- Current issues summary
- Risks

5.10.1 Delays and Overruns

Sometimes a project will hit a roadblock, that is, major problem which, unless and until it is resolved, will prevent the project proceeding. For example, in a project

to upgrade a load carrying vehicle it was planned to install a larger engine than that used in the original version. However, tests showed that the new engine overheated when installed in the original layout and that major design revision was required. Unfortunately, the project manager, the stakeholders and senior personnel in the organization continued to focus on schedules and budgets as though the engine overheating issue did not exist, or was about to be quickly resolved. In fact, the redesign problem was very challenging and a two year delay occurred. Money could have been saved by halting many activities while the engine heating problem was resolved.

Performance monitoring and solution risk are important aspects of project management that can easily be sidelined in the wealth of detail and the political commitment to schedules and budgets. Project managers need to have the following questions firmly in mind in regard to technical performance issues:

- Does it work?
- Does is perform to specification?
- If not, can it possibly/probably be fixed – indicate risks
- If so, is there a reasonable plan to probably fix it?
- Is there an acceptable performance level if the fix does not work?
- Is there an acceptable performance level if the item does not meet the original specifications?
- Is there a contingency plan?
- Should we declare a formal delay?
- Should we abandon the project?

Sadly, these questions may be pushed under the carpet, until a multi-billion disaster occurs.

5.10.2 Scope Creep

Ideally the scope of a project should not change once it has started. In reality, the world does not stand still, so that, while we should be generally resistant to changes in project scope, they may sometimes represent the best option for the organization as a whole.

Initial plans for a footbridge over the river in Brisbane were changed midstream to reduce the slope of the approaches and add a lift. This greatly improved the practicality of the bridge for cyclists and wheel chair users. At the time the bridge was described in the media as being late and over-budget, but the final product was successful, very well patronised and was built at reasonable cost in terms of what was actually delivered, though this was about twice the cost of the version that was originally planned. This positive example, however, is not intended to excuse scope creep in general.

5.11 Project Progress Reports

Examples of some graphically focussed project progress reports, based on a plant upgrade project, are shown in Fig. 5.5 to Fig. 5.8.

Factor	Performance to date	Forecast	Comments
Physical capabilities	😐	😐	Satisfactory progress in achieving planned activities to date – mainly civil work.
Cost	☺	😐	Spend to date is less than planned, but is expected to finish on budget.
Schedule	☹	😐	Behind schedule due to shortage of project personnel.
Risk	😐	☹	Risk of transportation problems for SAG Mill.
Requirements volatility	☹	☹	Demand growth indicates need to change the planned capacity to above the original specification
Operational support	☹	☹	Operational groups have not agreed to support the new equipment.
Training	☺	☺	Training program is ahead of schedule
Project resource issues	☹	☹	Shortage of project personnel is delaying tender evaluation for some items.
Suppliers	☺	😐	Suppliers currently engaged are meeting due dates and material needs.
Revenue	😐	☺	Revenue projections remain sound.

Fig. 5.5 Project progress scorecard for a plant upgrade

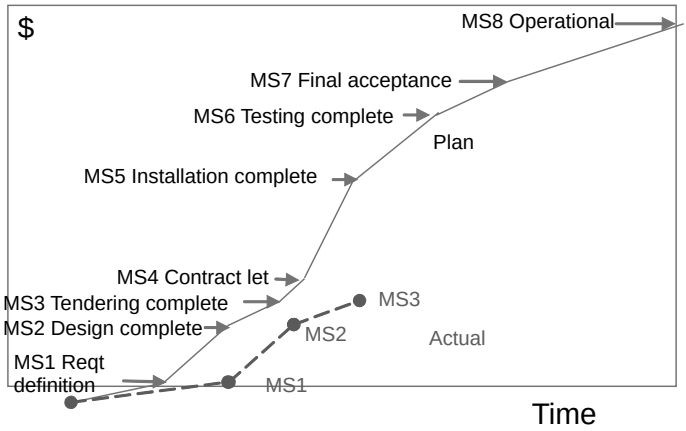

Fig. 5.6 Time and cost milestones – plant upgrade

A. Milestone	B. Cumul Planned Cost $1000s	C. Cumul Planned Time months	D. Cumul Actual Cost	E. Cumul Actual Time	F. % over or under cost (B-D)/B	G. % over or under time (C-E)/C
1= reqt definition	10	2	12	2.5	-20%	-25%
2= design complete	45	3	40	3.5	11%	-17%
3= tendering complete	55	4	45	5	18%	-25%
END	250	6				

Fig. 5.7 Progress data – plant upgrade

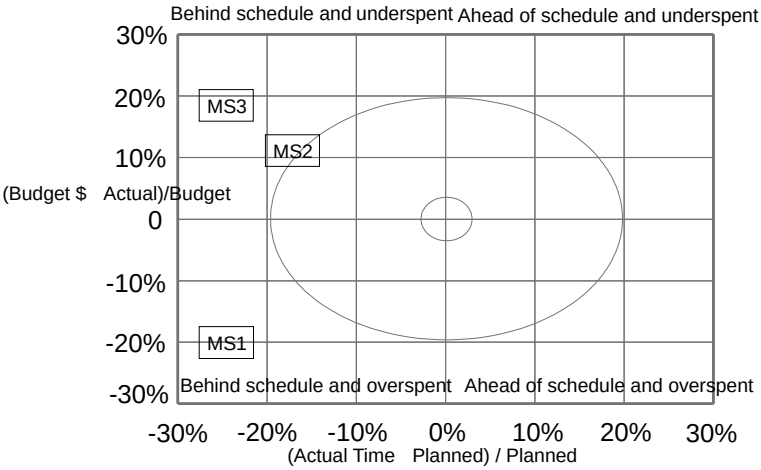

Fig. 5.8 Bulls-eye chart for project progress

5.12 Project Portfolio Management

At any one time a number of projects will be active in the business development plan. These projects comprise the Asset Development Portfolio. Figure 5.9 shows a summary report with one line per project in the portfolio. The status summary columns may be in the form of traffic lights with a red colour indicating projects that are in trouble, green for satisfactory and amber for in-between. For further detail we would refer to reports relating to any particular project of interest.

Changes due to delays from many causes both internal and external, occasional speeding up, cost over-runs and scope changes need to be taken into account in managing the portfolio. Portfolio managers must take action to prioritise and bal-

ance resources, including financial and staffing resources, and keep senior management and project managers well informed of developments and changes.

5.13 Commissioning and Introduction into Service

Commissioning of new plant involves the builder or developer in starting up and operating the plant on a trial basis to check the functionality and satisfactory operation. A commissioning manager should be appointed, with technical support dependent on project size and complexity. The commissioning manager will develop a commissioning plan during the feasibility stage and will manage its implementation. The performance of the plant will be checked and any operating or functional issues will be addressed. This might include such factors as failure to meet performance ratings, leaks, equipment failures or premature wear. Issues of safety in operation and of safe access for operators, maintainers and materials must be addressed. Operations and maintenance should be represented as key stakeholders in the commissioning stage. It is important to have logistic support arrangements in place before introduction into service, otherwise users gallop off with the equipment and there is no support when problems arise.

Row	Project	Team	Budget $M	Prime Contractor	Budget Status	Schedule Status	Solution Status
1	Rail passing loop	Rail	24.5	Railex	Fair	Good	Good
2	Wharf B	Litt	79.4	Asia Cons	Poor	Good	Good
3	Crane 150 tonne	Pur C	2.5	Crane All	Good	Fair	Good
4	Wagons	Rail	10.0	Gowag	Poor	Fair	Fair
5	Control System	Info Tech	5.56	All Soft	Poor	Poor	Poor
6	Dragline Upgrade	Over B	14.7	Huron	Poor	Fair	Fair
7	Road 124	Civil	22.6	Hollander	Good	Good	Good
8	Road 126	Civil	14.2	Hollander	Fair	Fair	Poor
9	Dam C	Civil	23.45	North Bund	Fair	Poor	Fair
10	Ship Loader	Over B	78.63	Huron	Fair	Fair	Good

Fig. 5.9 Summary report for a project portfolio

5.13.1 Operational Readiness

A site operations representative should be nominated, to represent the interests of operations in the installation and commissioning process. Defects identified during reliability testing or during commissioning should be addressed before acceptance of the equipment, and safe operating procedures must be confirmed before handover of the equipment to operations. Plans are to be developed for the transition from the commissioning project to operation at design capacity. The plans developed for all logistic support and information technology issues should come to fruition prior to the equipment entering service.

5.13.2 Training

Training is an important aspect of introduction into service. For both operators and maintainers the following activities should be completed prior to introduction into service:

- Preparation of train-the-trainer material
- Preparation of training material
- Train-the-trainer training
- Training

The operating and maintenance procedures must include the consideration and treatment of hazards, and contingency plans.

5.14 Change Management

Managers should think through the impact of changes on all aspects of work activities during the planning process, although it must be accepted that not every potential impact of a change will be completely anticipated.

In any change, workers will want to protect their jobs and status and that of their immediate colleagues, and change is much simpler if these factors can be respected. Examine the implications of change from a worker/user point of view and consider the redeployment, training or redundancy issues in advance of implementing change. Pilot studies, trial implementations of limited scope and evolutionary changes may help. Ultimately, however, management must be prepared to take responsibility for whatever hard decisions may be required.

Having decided on a change, conversion training from current processes and procedures must be provided. Involve the supervisor and other stakeholders, as local ownership of the solution is essential. Develop an implementation kit containing all the necessary equipment, documentation and training procedures. Provide instructions, procedures, check lists. Ensure sustainability of the solution through

supporting facilities and materials as needed. If the new solution only works when senior management is enforcing it, then it is likely to fail. Ensure that necessary support is on-going. If it really does not work, take a fall back position.

Danger points on implementation of a desirable change occur on the withdrawal of an implementation team and on a break in activity, such as a plant shutdown or a holiday period. Unless the change is well bedded down, operators may revert to the old way of doing things and the benefits are lost.

5.15 Exercise

5.15.1 Pacific Earth Moving Part 3

Pacific Earth Moving has obtained financial support and Board approval to purchase a range of additional earth moving equipment. The plan has been approved in principle, the main equipment to be acquired has been agreed, and an indicative budget has been approved.

The next step is to spell out more detail of the acquisition, including support facilities and services, and to create tender documents. The acquisition process will then proceed. The size and complexity of the acquisitions are greater than those previously undertaken by the company. Your group has been asked to advise on the following points:

a. What organizational structure is needed to effect the acquisition process.
b. What activities will the acquisition management group undertake.
c. What types of management monitoring and reporting will be required.
d. What types of risk may occur in such projects.

5.16 An Acquisition Decision

“We are going to have to get a new car”, said Sheila. “We need a four-seater at least, with somewhere to put a pram and a baby back-pack, besides shopping”.

Their present car was an MG two-seater sports model that dated back to Jock’s bachelor days. Jock said that he would look into the possibilities.

“The Cougar SS seems like a good option”, said Jock later that week. He was looking at a car magazine which gave the vehicle an enthusiastic write-up.

“It’s a sports sedan with a good sized boot and a terrific performance”, he said.

“Let me see”, said Sheila. She turned over a few pages.

“This looks more realistic”, she said, and handed the magazine back to Jock, open at a page which showed a picture of a medium sized Toyota hatchback. Jock groaned inwardly.

“I need to be able to put things in the back, without having to lift them over a sill”, said Sheila. “And anyway, we don’t need fancy performance for doddling around suburbia”.

"We need to get on with buying it", Sheila went on. "We can trade in the MG at the Toyota dealer on Burwood Highway".

Jock saw the last vestiges of his bachelor life fading away. But he couldn't think of a good argument. She had a Functional Specification and an Acquisition Strategy all sewn up.

"Okay", he said.

Jock's domestic scene was looking good, but there was trouble with the project that he was managing. A few days later at work he headed for the water cooler only to find his boss, Sam, already there.

"Project 413 is behind schedule", said Sam, who was not strong on small talk.

"I'm pressuring Dead Sea Systems but these software integration projects are pretty difficult to push along", said Jock. "We've tried some strong arm stuff already. I'll have another go at getting to the bottom of the problem with the project people there".

"Okay, but don't let them pass the blame back to us", said Sam as he left.

Veronica, Jock's favorite work buddy arrived as Sam departed.

"Trouble in't mill?" she said.

"I just can't get any sense out of Dead Sea on this 413 project" said Jock.

"My nephew works for them", said Veronica as Jock was about to start on a tirade of criticism of Dead Sea.

"Hmm", said Jock, "Maybe you could get some inside info"

……

"Anything new from Dead Sea", asked Jock when he met Veronica at the water cooler a week later. Veronica didn't answer directly.

"Software projects are difficult to manage, and it's not always the project people's fault", she said.

"Tell me something", said Jock. "I remember a project that I was on for St Helens Glass. They asked our team leader how long it would take and he said, 'Six months'.

"It was January at the time, and the St Helens guy said, "So you can finish it by July!"

"Yes", said our guy, "If we get the go-ahead today".

"Then nothing happened until another meeting in May, when the St Helens guy asked if the software would be ready by July 'as promised'.

"Does that mean that you are approving the project?" our manager said.

"And they did. It still took six months, but somehow the delay had become our fault".

"There are a lot of witty sayings about software projects and they are all true", said Jock. "Like, projects quickly become 90% complete and then remain that way indefinitely".

"And, you can browbeat a programmer into committing to a deadline, but you can't make him meet it", added Veronica.

"So what is happening at Dead Sea", said Jock trying to get to the point.

"Well everything on Project 413 was given top priority after they got a rocket from us earlier, but some of the work is sub-contracted to Uluru Developments and they haven't delivered."

"Well, sub-contractors are the prime contractors responsibility", said Jock, feeling stern and worried at the same time. "You don't happen to know anyone at Uluru do you?

"No", said Veronica.

Jock wasn't supposed to deal directly with sub-contractors but after a while he couldn't resist. He rang Uluru and asked if anyone knew about Project 413. He got through to Charlie McSporran.

"Your not related to the McSporrans of Dunbar Street are you?" said Jock.

"Aye" said Charlie, "I went to Dunbar Street Primary right enough". It took them half an hour to get on to Project 413.

"What's the hold up?" asked Jock.

"It's you blokes" said Charlie. "We can't get on with our part until your development boys release the operating specs for the radiation sensors". Jock nearly choked.

"Who are you in contact with at our end" he said.

"Stonewall Jackson", said Charlie.

Later Jock wondered if there was any solution to stuff ups like Project 413. The best he could come up with was the two phrases "Date of Decision" and "In Service Date". If every manager had to specify those in every meeting and every report, maybe some sort of awareness would creep in, he thought.

Chapter 6
Management of In-Service Assets

Chapter Aim: The aim of this chapter is to outline the organization and functions involved in providing for the strategic management of in-service assets over their life time.

Chapter Outcomes: After reading this chapter you will be aware of the types of activities needed for strategic management of the deployed assets the organization. This includes the need for having an integrated overview of the deployed assets and of the planning needed to provide support and sustainment of the 'fleet' as a whole on a through life basis.

Chapter Topics:

- Deployed assets
- Asset support
- Organization for in-service support management
- Support activities
- Engineering and technical services
- Configuration management
- Engineering change

6.1 Deployed Assets

Deployed assets are those currently in service with the organization. These assets are sometimes referred to as the "fleet", regardless of the type of asset. There is a need for central knowledge and strategic management of the support, maintenance and logistics of the deployed assets across the organization.

Day to day operation of the assets will be the responsibility of operating divisions and may be geographically dispersed. The extent to which maintenance is

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under the direct control of the asset management function will vary between organizations. First line maintenance will often be devolved to operating divisions.

6.2 In-Service Support Aims

In-service asset support involves ensuring that deployed assets are able to deliver their intended function over their required life. The objectives are to achieve business goals for the deployed assets, by providing productive capacity, availability, quality, safety and other regulator needs. Well directed support policies and matching levels of expenditure, including maintenance, will enable the assets to effectively support business goals and will also save money by avoiding premature replacement and reducing the need for additional equipment.

The management of in-service support for any particular capability is based on the logistic support planning undertaken at the acquisition stage, but involves integrating the activities across the range of deployed assets, and dealing with the current circumstances as they evolve over the life of the assets. Business organizations often isolate OPEX from CAPEX, inhibiting potential trade-offs.

6.3 In-Service Support Activities

The following activities are required to support the deployed assets. This in-service asset management function is a major part of the total asset management role. The extent to which it is a distinct role depends on the size of the organization.

Information and decision support. For any particular range of capability the asset support manager will maintain information on the asset capability required, the current deployment of assets; surplus or shortage in asset inventory levels; equipment condition; configuration and modification status; logistic support status; remaining useful life and requirements and plans for deeper maintenance. This information will be used as a basis for decisions relating to equipment deployment, procurement of spares and replacements and equipment maintenance policy particularly in regard to overhauls or deeper maintenance, and disposals.

Procurement. In the acquisition phase there will normally be an initial buy of equipment, consumables, spares and rotables. Once the equipment is in service the continued acquisition of replacement equipment, consumables, spares and rotables becomes part of the in-service asset management function. This includes monitoring and controlling stock levels, including such issues as reserves and repair pools, setting reorder controls, monitoring procurement contracts and creating new contracts as necessary. It will be necessary to keep up-to-date with technical changes and with changes in supplier and support services.

Facilities and resources. Planning for facilities for maintenance and logistic support across the organization and over the life of the deployed equipment. Main-

tenance staffing plan, maintenance training plan. balancing of workloads of maintenance staff.

Regulatory Issues. Awareness of and response to needs relating to regulatory issues such as safety, health, environment and technical properties of the assets. Statutory requirements for inspections and maintenance activities.

Information Systems. Application development and support

Technical developments. Application of technical developments in maintenance e. g. condition monitoring and pro-active asset care rather than a breakdown approach.

Configuration management. Maintaining records of the configuration status of in-service equipment. Input into modification decisions, planning upgrades including making equipment available, timing of work and facilities and contract management.

Deeper maintenance awareness and planning. Awareness of the status of equipment in regard to deeper maintenance needs. Planning for deeper maintenance, for example planning site shutdowns across the organization so as to minimize impact on business goals and to be consistent with maintenance resource availability. Arranging deeper maintenance contracts.

Outsourcing strategy and contracts for maintenance and related support activities.

Replacement analysis. Reviewing the condition and supportability of equipment, life cycle cost review and management, input to economic life decisions and to repair/replace strategy

Disposal

Budgeting for all of the above.

6.4 Organization for In-Service Support

The structure is shown in Fig. 2.1 and in Fig. 6.1, where we see in-service asset support as part of the activity of each asset management group.

The in-service asset support group will manage at the strategic level, the activities involved in logistic and technical aspects of deployed assets. The detailed activity of maintenance, will be carried out by maintenance departments and workshops which may be part of an operating division or may come directly under the asset management function, or may be outsourced. The management of the outsourcing contract would be an in-service activity, but the detailed work under the contract would be carried out by the contractor. The engineering, finance and legal staff work with the in-service support teams to provide integrated management of the support functions. In a smaller or decentralized organization, in-service asset management may form part of the job of an asset manager.

Staff in the in-service support group will be drawn from experienced maintainers, experienced operations personnel, technical or engineering support personnel, particularly those familiar with the relevant equipment.

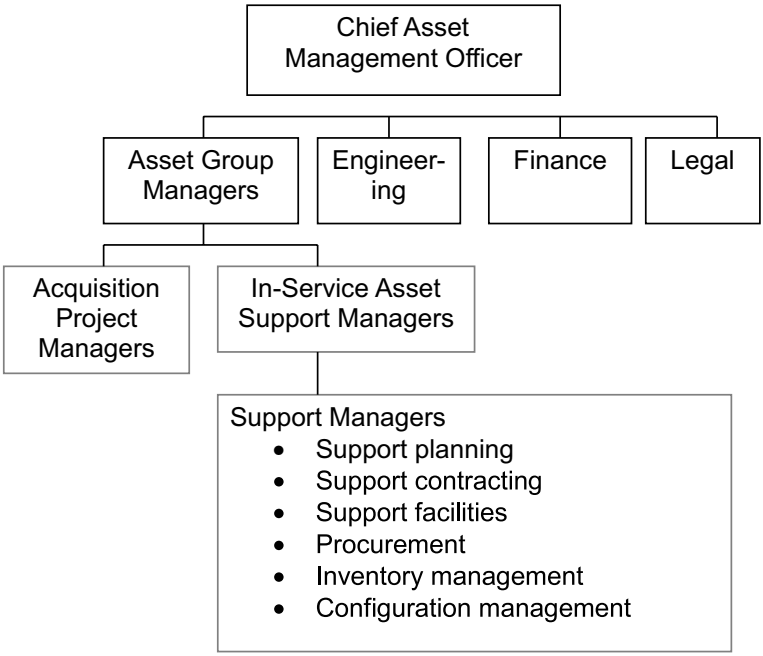


Fig. 6.1 Organization for management of in-service assets

6.5 Engineering and Technical Services

The role of engineering and technical services is to develop and maintain technical knowledge of the main areas of core activity. They deal with the more technical aspects of equipment sustainment and provide a resource which can respond to technical problems which cannot be resolved by line managers and maintainers. They maintain contacts with original equipment manufacturers (OEMs), with local support services and with suppliers. They maintain knowledge of technical developments, including condition monitoring techniques. They carry out studies of technical problems leading to improvements in reliability, maintainability and availability. Depending on organizational size and dispersal they may be centralized to a greater or lesser extent with company asset management.

6.6 Configuration Management

6.6.1 The Need for Configuration Management

A useful reference is ISO10007. Consider an organization which operates a large fleet of buses, perhaps as many as 1000. Buses will have been bought at different

times and will have different specifications. The number of seats, standard of comfort, type of fuel used, audio or video equipment on board, and other features will vary. Older buses may be subject to different regulatory design rules from newer buses. Some buses may have been upgraded, for example by adding seat belts, but this may not apply to all buses which are otherwise similar.

Configuration management involves keeping track of the configuration of buses in the fleet in regard to all the factors which are important for bus operation and maintenance. The same principles apply to all assets in an organization's portfolio. Configuration management extends into controlling and managing changes. Changes need to be evaluated in regard to their functional and logistic implications before being implemented. If configuration management is lacking, an organization can easily find itself with an unknown mixture of equipment configurations, creating problems for operations, maintenance and logistic support. Software and electronic systems installed in or used with assets need to be included in the configuration management record. A configuration management plan should be established as part of the logistic support plan.

6.6.2 Configuration Description

The configuration description of a capability is a description, usually held in a computer data base, of the capability, which details its elements including essential supporting items and details of type including software if relevant. The fields in the configuration description need to be defined as a preliminary to creating the configuration descriptions for the relevant assets.

6.6.3 Configuration Management Process

Configuration management involves creating the configuration description, coordinating, controlling, approving and recording configuration changes and auditing physical configurations to ensure that the necessary capability is deliverable. Without tight configuration management, capability can be lost due the loss of essential components or features, through shifting priorities and lack of awareness of the capability requirements. Configuration management involves keeping track of the current configuration details of our equipment. It may conveniently be linked to the asset register. It should include a record of current condition.

Configuration management is also vital in relation to civil engineering assets and fixed plant, such as:

- Buildings,
- Sites
- Water pipes,
- Drainage,

- Sewerage
- Roads,
- Bridges,
- Embankments
- Piping and instrumentation in chemical, oil and gas plant

6.6.4 Configuration Change Control

Records of actual configurations are made and changes are recorded as they are implemented. Change control involves the analysis of proposed changes, combining technical and business viewpoints, and the application of a formal procedure for the approval of agreed changes. Awareness of and adherence to design and construction standards is an important factor in the approval of configuration changes. The change control process should ensure that related technical information is updated as changes occur. Configuration audits should be carried out to ensure that configuration records are being maintained.

6.7 Change Management

Where changes to in-service assets are required they should be subject to a formal process of evaluation. Factors to be considered include:

- Details of the proposed change
- Reasons for change
- Extent of change e. g. retrofit or not
- Resources required for change
- Operational implications
- Logistic support implications
- Timing
- Cost

If the change is approved, a change management plan will be required involving such factors as:

- Operational plan e. g. downtime required
- Modification procedure
- Modification kits, tools, materials, components
- Disposal considerations
- Documentation changes
- Configuration management.

6.8 Roll Over

Bruce pulled in beside Norm on the beach at Cable Bay. He jumped down and got a Darwin stubbie from the Esky.

"You got a new ute?", he asked.

"No, I cleaned it", said Norm.

"What about the roll-bar, that's new. Who put it on?"

"That little fabrication shop near the old pearl luggers. We all have them now. We've got a contract to do Non-Destructive Testing on the gas pipelines. Our boss rolled his ute on a trip to Uranus Island and was lucky only to break his arm, so now it's become a safety thing. Weren't you supposed to get roll-bars ages ago?"

"Too right. It was after we had a fatal down by the dinosaur footprints. They sent out an engineer, Tom Peirce – I knew him from uni – and he drew up plans for roll-bars. But nothing happened. I saw him again later and he said that the engineering branch had said that they couldn't approve it because there wasn't an official standard to check it against."

"Sounds like a cop-out. They don't want to sign off and then get blamed if it's not perfect."

"Anyway, Tom said the operations people pushed them on it and they decided to do some tests. Apparently his design only covered 90% of situations."

"90% would be better than 0%".

"There was another problem. We bought these utes over a few years and some were imported, some locally assembled from kits and some modified since in various ways. So the configurations are all over the shop, and apart from the original purchase records there is no documentation".

"So they would have to look at every vehicle separately. Not short of money are they?"

"Short of money! Not Canberra. No, there were actually going to do it, but someone pointed out that these utes were past their replacement age anyway so it wasn't worth doing."

"But you're still driving them!"

"Yes, but there is a big fleet replacement project in the works. Could come through any time – but I'm not holding my breath."

"Let's hope that you hold on to your head".

"Hey, look at that chick on the last camel".

"Wow!"

Chapter 7
Asset Continuity Planning

Chapter Aim: The aim of this chapter is to describe how to plan for the provision of assets which are required to meet an on-going need. This is a very common situation, in which demand for a type of asset continues into the future, but older items require replacement and variations occur, due to changes in demand levels and to technical developments.

Chapter Outcome: After reading this chapter you will have learnt how to plan the purchase of items to sustain an on-going capability requirement, by calculating the pre-plan capability gap and then working forwards over the planning horizon calculating the purchase needs year by year and making suitable purchase decisions. You will become familiar with a spreadsheet based method for carrying out the necessary calculations and for graphically illustrating the gap analysis and the acquisition costs.

Chapter Topics:

- Introduction
- Planning example
- Pre-plan gap analysis
- Gap analysis graph
- Planning process
- Planning steps
- Spreadsheet example
- Capital requirements graph
- Planning formulas
- Capability continuity planning

N. A. J. Hastings, *Physical Asset Management*,

7.1 Introduction

Most asset management situations involve planning for the continuity of an existing system of assets, the role of which will continue on into the future. An example is a trucking fleet, where continuity is required in meeting the demands of the business, so that disposal of old trucks at the end of their useful life is matched by acquisition of new trucks, with variations as necessary to reflect business and technical developments. Similar situations apply to assets of many types, ranging from wooden power poles to cargo ships. The term '*fleet*' is often used to describe a set of currently deployed assets; that is, the term is used not only in the commonly accepted sense of vehicle or other transport fleets but also for items of any type.

Issues include the extent to which we stick to preferred suppliers so as to avoid too wide a spread of types for logistic support; the numbers purchased at any one time which may involve considerations of available capital, economies of scale, purchasing policy and keeping the range of equipment types in check. These, however, are relatively fine points and we need to start with a basic planning process.

7.2 Planning Example

An electricity supply company purchases transformers for use in sub-stations. Figure 7.1 shows data relating to a particular size of transformer, for which the unit acquisition cost is $800,000 and the unit disposal cost is $100,000. These unit costs are shown in row 2. The number of units needed in service over the next 6 years is shown as "In Service Need" in row 4. This number includes a provision for local contingency holdings to cover in-service failures or other emergencies. Initially there are 108 transformers in service including local contingency, and 10 transformers in central store, giving a total of 118, shown as the year 1 "Un-augmented qty" at cell B6. Senior management has stated that the central store holding is to be reduced.

The number of disposals of transformers over the planning period has been estimated, allowing for ageing of the existing items and for possible in-service failures or condition deterioration. This is shown in row 5 as "Disposals end of year". The problem is to plan the purchase of new transformers over the planning period and to estimate the financial capital requirements.

	A	B	C	D	E	F	G	H
1	Capacity Planning Example - DATA							
2	Unit Costs $M	Acquisition		0.8	Disposal		0.1	
3	Year	1	2	3	4	5	6	7
4	In-Service Need	108	108	110	112	114	117	120
5	Disposals end of year	2	12	14	10	5	1	1
6	Un-augmented qty	118						

Fig. 7.1 Transformer purchase planning data

7.2.1 Pre-Plan Gap Analysis

The first step is to carry out a pre-plan gap analysis. A pre-plan gap analysis is an analysis of the situation before we plan any acquisitions or other changes. It represents how the situation would unfold if we do nothing. In the example, the gap between the in-service need and the quantity available after disposals is the *pre-plan gap;* this represents the situation before we plan any acquisitions.

We first calculate the un-augmented capacity by subtracting the disposals (row 5) progressively from the initial quantity available (cell B6). Figure 7.2 row 6 shows the result. We then calculate the pre-plan gap by subtracting the un-augmented capacity (row 6) from the need (row 4). Row 7 shows the result.

Figure 7.3 shows the pre-plan gap as a graph, based on the needs (row 4) and the un-augmented qty available (row 6). The space between the two lines is the gap, and can be negative (representing a surplus) or positive (representing a shortage). The pre-plan gap result can assist with acquisition planning. In the example, the minimum total number of transformers required over the planning horizon is 46, given

	A	B	C	D	E	F	G	H
1	Capacity Planning Example - PRE-PLAN GAP ANALYSIS							
2	Unit Costs $M	Acquisition		0.8	Disposal		0.1	
3	Year	1	2	3	4	5	6	7
4	In-Service Need	108	108	110	112	114	117	120
5	Disposals end of year	2	12	14	10	5	1	1
6	Un-augmented qty	118	116	104	90	80	75	74
7	Pre-plan Gap	-10	-8	6	22	34	42	46

Fig. 7.2 Gap analysis calculation

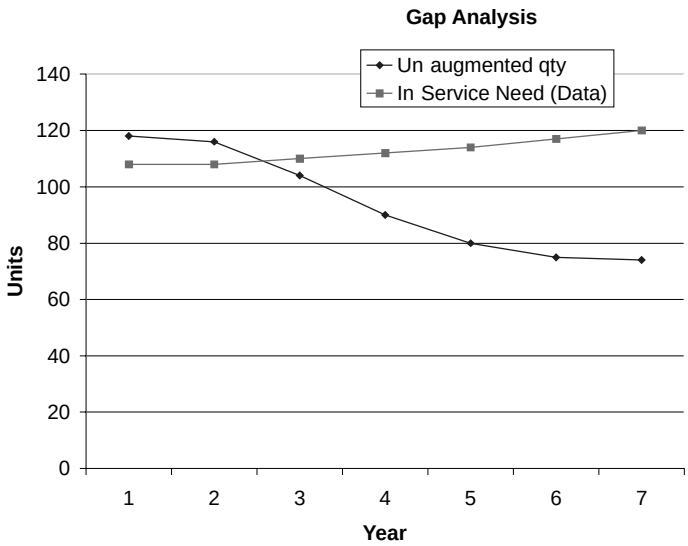


Fig. 7.3 Gap analysis graph

in cell H7. This result can assist us in deciding an acquisition strategy, for example, we may decide to develop a purchase plan covering all 46 transformers from one, or a small number, of potential suppliers, with an agreed take-off rate over the years. We also see that there will be no gap until year 3, and this tells us that we have some lead time in hand.

7.2.2 Planning Process

The planning process is as follows for each year across the horizon. The process is illustrated in **Fig. 7.4** and summarized algebraically in the equations at the end of this section.

a. Calculate the quantity-before-purchase, that is the quantity available in the current year before more items are purchased (Row 9 and Eq. 6.3);
b. Calculate the gap-before-purchase, this gives the minimum number to be purchased to cover the gap, (Row 10 and Eq. 6.4);
c. Create a purchase plan (Row 11, BOY=Beginning of Year) which may vary from the minimum purchases;
d. Calculate the quantity-after-purchase, (Row 12 and Eq. 6.5);
e. Calculate the cost (Row 17).

7.2.2.1 Planning Steps

The steps in the example are as follows. For year 1 we calculate the Quantity-before-purchase and the Gap-before-purchase. In year 1 the Gap-before-purchase is negative so we decide to make no purchases. In year two the gap is also negative

	A	B	C	D	E	F	G	H
1	Capacity Planning Example PLANNING: ROWS 9 to 17							
2	Unit Costs $M	Acquisition		0.8	Disposal		-0.1	
3	Year	1	2	3	4	5	6	7
4	In-Service Need	108	108	110	112	114	117	120
5	Disposals end of year	2	12	14	10	5	1	1
6	Un-augmented qty	118	116	104	90	80	75	74
7	Pre-plan Gap	-10	-8	6	22	34	42	46
8								
9	Qty before purchase	118	116	104	100	102	109	118
10	Gap before purchase	-10	-8	6	12	12	8	2
11	Purchase Plan BOY	0	0	10	12	12	10	10
12	Qty after purchase	118	116	114	112	114	119	128
13								
14	Cumul Purchased	0	0	10	22	34	44	54
15	Planned excess	10	8	4	0	0	2	8
16								
17	Capital Reqt $M		0.2	9.2	11	10.6	8.5	8.1

Fig. 7.4 Transformer purchase planning

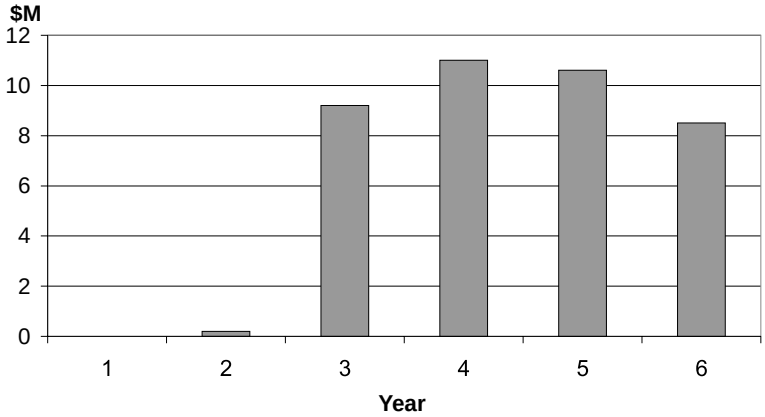


Fig. 7.5 Transformer purchase capital requirements graph

so again we make no purchases. In year three, the Quantity-before purchase, is 104 but the In-Service Need is 110, so we get a Gap-before-purchase of 6. These transformers are normally purchased in multiple quantities of about 10. The reason behind the minimum lot size is that we want to avoid having too fragmented a set of assets and also to achieve economies of scale in purchasing. Since our policy is to purchase in lots of at least 10, we plan to purchase 10. The Quantity-after-purchase then becomes 114, shown at cell D12.

For year 4, the Quantity-before-purchase is found by subtracting the disposals at the end of year 3, and the Gap-before-purchase is calculated. This is 12 as shown at cell E10. We then make a purchase plan decision for year 4, and in the example this is for 12 items. The calculations then continue in the same way, with purchase plan decisions being made for each year. As we proceed, the spreadsheet calculates the capital requirement based on the numbers of purchases and disposals and their costs. A graph of the capital requirements year by year is shown in Fig. 7.5.

The spreadsheet format allows us to easily model a range of data assumptions and plans and to present corresponding tabular and graphical results.

7.2.2.2 Planning Formulas

The planning process is summarized algebraically as follows.
Let

i = year number
N = In-service need (row 4)
D = disposal quantity at end of year (row 5)
U(i) = Un-augmented quantity (row 6)
X(i) = pre-plan gap (row 7)
Q = quantity before purchase (row 9)
G = gap before purchase (row 10)
P = purchase quantity (row 11)
R = quantity after purchase (row 12)

Then for the pre-plan gap analysis:

$$U(i) = U(i–1) – D(i) \tag{7.1}$$

$$X(i) = N(i) – U(i) \tag{7.2}$$

And for the purchase planning stage:

$$Q(i) = Q(i–1) + P(i–1) – D(i–1) \tag{7.3}$$

$$G(i) = N(i) – Q(i) \tag{7.4}$$

$$R(i) = Q(i) + P(i) \tag{7.5}$$

7.3 Capability Continuity Planning

It must be appreciated that the process described in this chapter represents a basic approach to the planning of prime equipment requirements and that in practice a considerable amount of additional work will be required in planning for the continuity of the total capability involved in the sustainment of the assets. Having established the prime asset requirement we continue to plan for the related elements of the capability, and this may cause feedback into the prime equipment plan. In practice a number of interrelated spreadsheets or similar planning systems will be needed.

7.4 Vehicle Fleet Capacity Exercise

A company currently has 10 trucks. Trucks are sold when they reach 7 years old. A forecast of the required number of vehicles to be in-service, and of the projected numbers of disposals year by year, is shown in Fig. 7.6.

New trucks cost $200,000. Old ones are sold for $15,000. The company policy is to own sufficient trucks to cover “base load” requirements. Shortages can be made up by leasing at $50,000 per truck per year. Capital rationing limits purchases to at most 3 trucks in any year.

Determine a suitable purchasing and hiring plan. Estimate the cost year by year and calculate the net present value of costs.

Year	1	2	3	4	5	6
Vehicles Required In-Service	10	12	10	12	12	13
Disposals end of year	1	0	2	1	2	1

Fig. 7.6 Projected vehicle demand and disposals

Chapter 8
Capital Planning and Budget

Chapter Aim: To introduce the concepts of capital and operating budgets. To describe the process for developing a capital budget. To introduce the concept of capital rationing. To consider capital budget prioritization based on returns, risks and criticality of assets.

Chapter Outcomes: After reading this chapter you will know:

- The difference between capital and operating budgets
- The typical structure of capital budgets
- The process for developing capital requirements for particular equipment types and consolidating them across types
- The meaning of capital rationing and how it affects budgets
- Methods of dealing with capital rationing including prioritization based on equipment age and condition, equipment criticality, financial return and risk
- How to summarize the capital budget and to be aware of factors involved in managing the capital project portfolio.

Chapter Topics:

- Capital planning considerations
- What is a budget?
- Types of budget
- Budget structure
- Devolution of authority
- Planning process
- Planning periods
- Source and application of funds
- Capital requirement plans for asset types
- Aggregation across types
- Capital rationing
- Replacement prioritization

N. A. J. Hastings, *Physical Asset Management*,

- Condition/criticality plot
- Financial return and risk ranking
- The capital budget
- Managing the capital project portfolio

8.1 Capital Planning Considerations

The allocation of resources within a company should be directed to those areas which have the best prospects for producing value. Value can take several forms, the most common being a financial return on investment. The return may arise by generating new business, or by increasing production leading to greater sales volume, and in turn to greater sales value. Or the return may arise by reducing costs or alleviating bottlenecks. Other forms of value are more defensive in nature. They include the meeting of legal, environmental, safety or regulatory requirements, the sustainment of existing assets and existing business and the reduction of risk.

8.2 What is a Budget?

A budget is an allocation of financial resources to a specific function or area, and represents a commitment on the part of management to the corresponding activity. Conversely, lack of a budget allocation to an activity is a de facto indication of lack of management commitment to that activity.

Budgets are generally based on reasoned proposals, and they help to promote good planning and a fair allocation of resources. Changes to budgets require senior management approval and require significant justification. Budgets help managers at all levels to plan and control business activity.

8.3 Types of Budget

In asset management there are two types of budget:

a. Capital Budget, known as CAPEX = Capital Expenditure
b. Operating and Maintenance Budget, known as OPEX = Operating Expenditure

The capital budget is used to purchase fixed assets and the operating budget is used to operate the business and to purchase expense items. The difference between the two is dictated partly by taxation systems which allow operating expenditure to be deducted from income in the current year in determining taxable income, whereas, only the depreciation of fixed assets is allowed as a current year tax deduction. Also, the two types of budget require quite different management. The operating

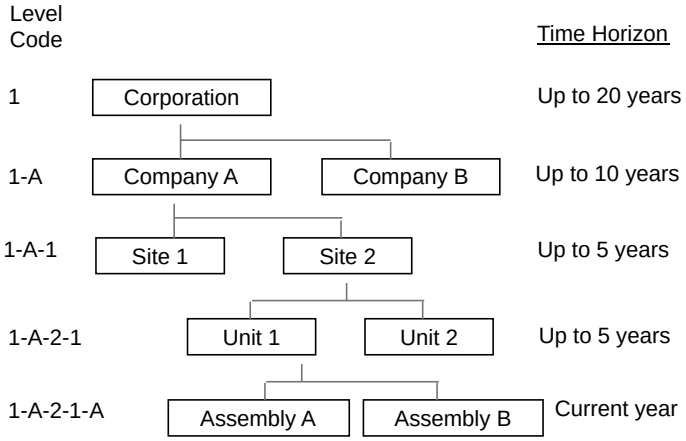


Fig. 8.1 Budget planning levels and time horizons

budget is used by operating departments to cover outlays required to support their immediate activities, such as wages, materials, rents and equipment lease payments. The capital budget is used to acquire major items of plant and equipment, requiring analysis of the business needs and investment options, followed by detailed acquisition planning and implementation.

A common fault is for the CAPEX and OPEX budgets to be too widely separated in terms of management function and responsibility. This can lead, for example, to excessive OPEX expenditure in order to maintain ageing equipment which should have been replaced earlier from the CAPEX budget.

8.4 Budget Structure

Figure 8.1 shows a typical budgetary structure for a large corporation.

8.5 Devolution of Authority

An issue in the organization of a corporation is the extent to which authority should be delegated or devolved down to subsidiary levels. As an example, in a state-wide water supply system, initially there were 10 regions. Each region "owned" its local assets, and managed them – some well, some not so well. Because each region was small their buying power, their access to capital funds and their degree of technical support were limited.

To overcome these problems, ownership and decision making were centralized. This addressed the perceived problems, but had the disadvantage that local manag-

ers felt less interest in and less authority over, the assets in their region. In many cases the assets deteriorated.

"Not my problem", the local managers said, as they disowned the remote centralized bureaucracy.

To strike a balance, the asset ownership was devolved back to four large regions, with positive effects. Technical and financial support functions remained centralized. The benefits and dis-benefits of centralization are debatable, but it is important to keep users involved. The saying is: "big enough to cope, small enough to care".

8.6 Planning Process

Capital asset planning and budgeting involve identifying the most beneficial use of funds, planning and scheduling the resulting funds requirement and arranging for the availability of those funds. Capital planning and budgeting is integral to the business development plan. The plan may involve consolidation, risk reduction or outsourcing and is not necessarily expansionist.

The business development plan leads into a *capital expenditure program.* This will be consolidated across a number of different capability requirement areas. To check the financial viability of the whole program the organization will create analyses showing:

i. Budgeted cash flow
ii. Budgeted balance sheets
iii. Budgeted profit and loss accounts

The detailed development of these analyses will be an accounting or financial planning function rather than an asset management function, so we shall not consider them in detail. However, it is important that the data provided as a basis for these reports is as accurate as possible and this will require asset management input. The results may lead us to question the choice of earlier options, and may require modification for risk.

8.6.1 Planning Periods

The capital expenditure program will consider a range of planning periods, such as one year, three year, five year, ten year and twenty year horizons. The one-year plan is the firm current year commitment.

A rolling review will also apply, as circumstances develop. A balance must be struck between stability and flexibility in regard to changing situations.. An appreciation of the lead times involved in implementing asset acquisition plans is essential, so we will need to firm up on our plans for particular projects for a given period ahead, dependent on the lead times involved.

8.6.2 Source and Application of Funds

It is not unusual for owners or senior management to have favoured areas which do not correspond to those which are most profitable for the business. For example, a railway may get the bulk of its net revenue from freight operations, but may direct the major part of its budget to passenger operations. Significant mismatches in the source and application of funds create a danger for any organization and should be guarded against. However, King Louis XIV is said to have appropriated one third of the revenue of France to his personal use. He got away with it, but eventually his successors did not.

8.7 Capital Requirement Plans for Asset Types

Capital requirement plans for all asset types are developed, usually as part of an annual activity cycle. These are then consolidated into a master development and capital budget plan. The steps are summarized in Fig. 8.2. The consolidation across types is summarized in Fig. 8.3. Asset managers need to be fully aware of, and actively involved in the organization's capital budget planning process. The bringing together of asset knowledge and business and financial knowledge into a sound decision making process is an essential part of the asset management contribution to the wellbeing of the organization.

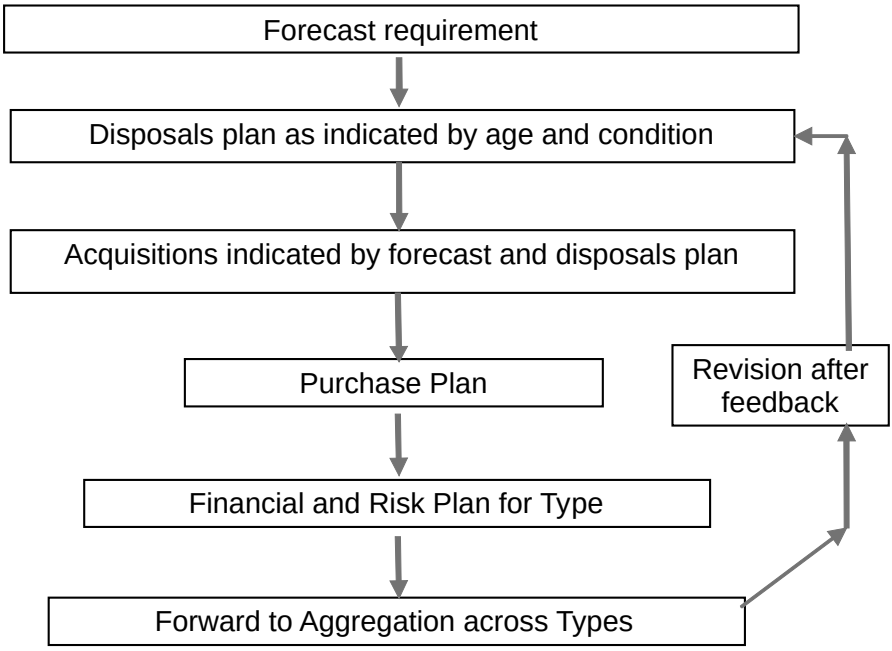


Fig. 8.2 Planning and budgeting outline steps for type

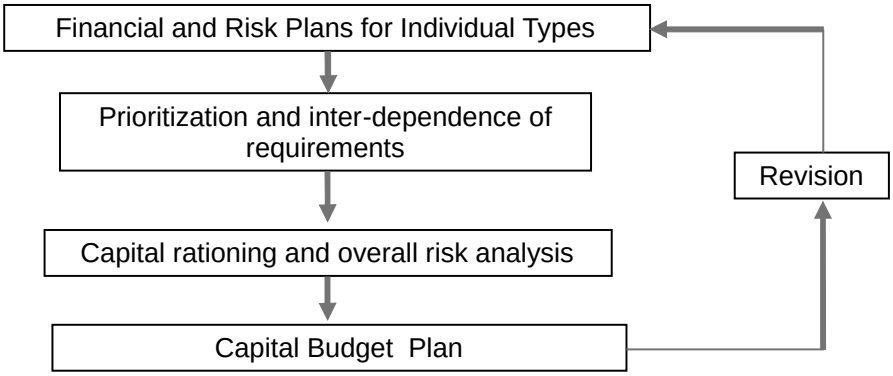


Fig. 8.3 Capital asset budget aggregation across types

8.8 Capital Rationing

The demands on the capital budget often exceed the finance available. The prioritization of projects, and the decisions as to what items can be included in a given capital budget is known as capital rationing.

Some projects may be non-discretionary in a regulatory sense – they have to be done. This typically includes, risk mitigation for health and safety, environmental protection or reliability improvement in critical areas. Others may be essential to the business, such as maintaining the continuity of assets which provide essential services, as well as essential capacity expansions. Other projects may be discretionary, but nevertheless important to the on-going success of the business. A major factor is the financial return on capital invested, and this aspect is considered in detail in later chapters.

The age and technical profile of major capital equipment will be determined by the pattern of installations in the past. We need to ensure that sufficient capital is allocated to meet the requirements for replacement and technical advance. Lumpy replacement patterns give rise to uneven capital requirements. Other things being equal, smoother capital demands through time are easier to manage. However, if major capital expenditure is justified it should be accepted and managed.

8.8.1 Capital Rationing Example – Postal Vans

A simple type of capital rationing decision occurs when a fleet of relatively small items requires on-going renewal.

Example. Newistan Postal Service has a large fleet of vans, but a limited budget for van replacement. The replacement policy is to budget a selected amount each year to replace a number of the oldest and highest mileage vans. Some contingency capital is also set aside for *spend-limit* replacements, that is where an expensive

Registration number	Age (years)	Kilometers	Cumulative cost, $	**Policy**
ABC123	12	146,897	45,000	**Replace**
ABD234	12	142,442	90,000	**Replace**
BWE876	11	159,342	135,000	**Replace**
BES541	11	143,903	180,000	**Replace**
BDF012	11	138,901	225,000	**Keep**
BBX945	11	99890	270,000	**Keep**

Fig. 8.4 Capital rationing – van replacement

repair is required which is not justified in terms of the estimated remaining life of the vehicle, even though that vehicle would not normally be replaced on grounds of age alone.

The vans are identified by registration number. A list of vans is made by age in years and, within years, by kilometres run. Vans are then replaced down the list as far as the capital budget will allow.

Figure 8.4 shows an example in which vans at the oldest ages in the fleet have been listed in descending order by age, and within age groups, in descending order by kilometres run. A budget of $200,000 has been allocated for replacements and the vans cost $45,000 each. The budget allows the vans shown in the shaded area to be replaced. In practice some flexibility in application may allow engineering judgement of van condition to influence the precise outcome.

8.8.2 Replacement Prioritization

In the vehicle fleet example just given, it is easy to rank the vehicles in priority order for replacement, since they are all basically the same. In other cases, we need to create a ranking system, based on factors such as condition and criticality. In

Very High
High
Medium
Low
Very Low
Zero

Fig. 8.5 Classification descriptors for condition and criticality

Rank	Asset	Condition	Criticality	Replacement Cost	Decision
1	Excavator A	Zero	High	$845,000	**Replace**
2	Pump 12	Very Low	High	$290,000	**Replace**
3	Air Motor B	Very Low	Medium	$135,000	**Replace**
4	Pump 56	Low	High	$225,000	**Replace**
5	Conveyor 3	Low	Medium	$380,000	**Keep**
6	Generator 1	Medium	Low	$270,000	**Keep**

Fig. 8.6 Replacement prioritization by condition and criticality

order to establish a consistent terminology we can define descriptors for condition and for criticality as shown in Fig. 8.5.

The budget proposal then shows the condition and criticality of various proposed replacements. Figure 8.6 shows an example, with the replacement decision shown in the right hand column. We see that replacement was approved for items 1 to 4 but not for items 5 and 6.

8.8.3 Condition/Criticality Plot

An example of a type of graphical display which can illustrate the status of many items on one page is shown in Fig. 8.7. This type of plot gives a compact view of the overall status of an organization's assets to senior management.

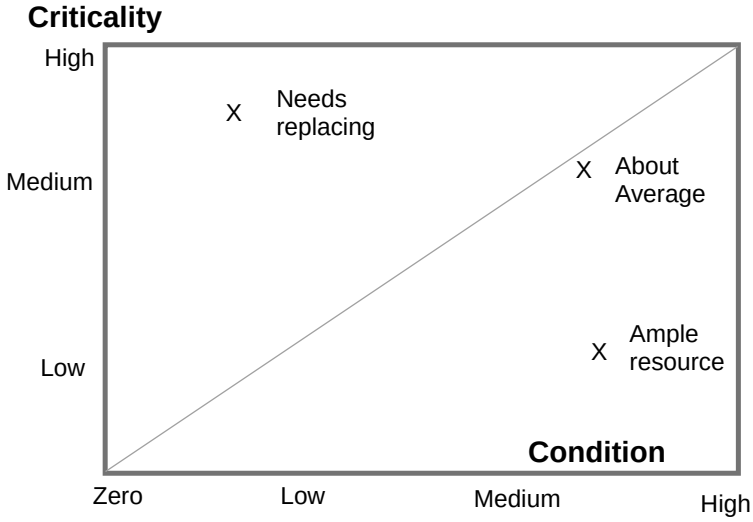


Fig. 8.7 Condition/criticality plot

8.8.4 Financial Return and Risk in Project Ranking

For new projects the financial returns are usually measured by the Internal Rate of Return (IRR). The definition and calculation of this measure are considered in a later chapter. Another factor that needs to be taken into account is the risks involved if a project is or is not undertaken. This may be concerned with safety, regulatory requirements, or a risk of business loss or lost opportunity.

From the point of view of the asset manager it is advisable to make clear to senior management the risks involved both in carrying out a project and also in failing to approve a project. It is then up to senior management to make a final decision. The advantage of the risk based approach is that it can create a situation of positive dialog between asset managers and senior management as the merits and risks of various projects are discussed. A reasonably argued case should be presented for each project, without crying wolf or being smart after the event.

Figure 8.8 shows an example where a number of projects have been presented to a budget committee. The list includes projects which have been included for environmental or safety reasons, and ones which are profit motivated and show their internal rate of return (IRR). The right hand column shows the ranking of the projects by the committee. The rank 1 project is seen as essential from an environmental and regulatory point of view. The rank 2 project has a high internal rate of return and is seen as essential to the on-going needs of the business. The rank 3 project is a safety requirement, and so on.

Project	**Cost $M**	**IRR**	**Risk description**	**Risk rank**	**Project Rank**
Extend tailings dam	1.6	-	Environmental	**1**	**1**
Second unloading station	3.6	36%	Production opportunity cost	**-**	**2**
Replace ventilation compressor No. 3	1.3	-	Safety risk if fails	**2**	**3**
Replace dewatering pumps on level 19	2.8	-	Production loss if failures	**3**	**4**
Acquire 2 loaders	1.55	22%	Production opportunity cost	**-**	**5**

Fig. 8.8 Project rankings with returns and risk

Capital Budget Summary		Years ahead					
Project	**Status**	**1**	**2**	**3**	**4**	**5**	**6**
1. Vehicles type A	In progress	200	150	100	250	250	150
2. Building C development	In progress	250	4000	1500	0	0	0
3. Site X clear and dispose	In progress	500	-3000	0	0	0	0
4. Building B extension	Plan approved	0	1500	1500	0	0	0
5. Pumping system replace	Feasibility stage	0	2000	0	0	0	0
6. Vehicles type B	Feasibility stage	0	0	550	675	300	750
7. Building A refurbishment	Pre-feasibility stage	0	0	0	2000	0	0
8. Production stream A upgrade	Requirements stage	0	0	0	0	3500	0
9. Power transformer replace	Requirements stage	0	0	0	0	5000	0
Total cost $k		950	4650	3650	2925	9050	900

Fig. 8.9 Capital planning budget summary, $k

8.9 The Capital Budget

Ultimately, senior management brings together the various decisions into a consolidated capital budget. An example is shown in Fig. 8.9.

8.10 Managing the Capital Project Portfolio

The direction, monitoring and control of the capital project portfolio is a major commitment of senior management. The summary in Fig. 8.9 shows a portfolio of capital projects which are at various stages of development. The status column shows the stage of progress for each project. For example, project 8, Production Stream A upgrade is currently at the Concept stage. The projects at the top of the list are those that are currently in progress of acquisition or development, projects 1 to 3. Project 4 is approved but not yet started. Projects 5 and 6 are in the feasibility planning stage, project 7 is in the pre-feasibility planning stage and projects 8 and 9 are at the requirements analysis stage. Projects will progress up the list as their status develops towards completion. In practice the number of projects may be much

	A	B	C	D	E	F	G
1	Item	Budget for year	Actual YTD	Planned ROY	Actual+ Planned	Uncommitted	Date
2	Road Section A	$3,692,450	$745,990	$540,221	$1,286,211	$2,406,239	4 Oct
3	Road Section B	$1,458,321	$580,432	$993,450	$1,573,882	($115,561)	
4	Storm Water Area K	$2,576,449	$903,034	$840,453	$1,743,487	$832,962	
5	New Recreation Bldg	$760,652	$188,930	$650,000	$838,930	($78,278)	
6	Parkland Development	$275,500	$98,405	$48,775	$147,180	$128,320	
7	Totals	$8,763,372	$2,516,791	$3,072,899	$5,589,690	$3,173,682	

Fig. 8.10 Current year capital budget

larger and separate tables may be made to focus on projects at particular stages of development or on projects for particular areas of the business.

Each project has a project manager who reports on the project to a senior manager in the area to which the project relates. Senior management will coordinate progress and financial requirements. The availability of finance can depend on many factors and is not necessarily smooth through time. Both the requirements of the projects and the financial situation of the organization can vary dependent upon external and internal factors. It is common to find that projects slip back in time, although this should be avoided wherever possible. Delay factors include changes in scope (naughty), delays in specifying requirements and delays in supply. In organizations with strict annual budgeting systems, delays in one project may work to the advantage of another.

Care must be taken to identify cases where projects are interrelated, since progress in one may then influence the development of another.

8.10.1 Capital Budget for Current Year

In the shorter term, we also need to manage the capital budget for the current year, and for other medium term horizons. Figure 8.10 shows an example of a current year capital budget, showing under a number of item headings, expenditure year to date (YTD) and planned expenditure for the rest of the year (ROY). Uncommitted funds are also shown. The management of the budget will involve working with the managers responsible for the various task items or projects. An understanding of the lead time factors in projects, the need to manage resources within and between projects, and the risks involved, as discussed in other chapters, will assist the budget manager to work towards the best achievable outcome.

8.11 Long River Ferry Company Exercise

The Long River Ferry Company currently operates a fleet of small wooden ferry boats. They are planning to introduce three new, larger boats which are faster and

have air-conditioning. The larger boats will require new pontoons and there is also a requirement that work to protect the riverbank from erosion be undertaken before large boats are introduced. It is believed that the larger boats will increase revenue, but some of the customers for the larger boats will be displaced from the smaller ones. If Long River does not introduce larger boats there is a distinct possibility that a rival company will introduce similar boats and capture the higher priced end of the market.

Long River has three divisional managers who respectively are responsible for:

1. Small boats,
2. Large boat project
3. Shore facilities.

The divisional managers have produced the following budget information.
Shore Facilities.
Pontoons. $2 M required in year prior to commencement of large boat #1, and $1 M in year prior to commencement of large boat#3.
Riverbank. $4 M required in year prior to commencement of large boat#1.
Large boats require a payment of $3 M in the year prior to acquisition and $5 M in the year of acquisition.
Task. Prepare a capital budget for Long River for the four year period. Indicate options which may benefit the business in overall financial and operational terms.

Year	1	2	3	4
Boats req. overhaul @$0.5M per boat	4	4	2	2
Overhaul cost $M	2	2	1	1
Boats req. replace	6	3	0	5
Replacement cost $M @ $2M per boat	12	6	0	10

Fig. 8.11 Small boats cost data

Year	1	2	3	4
Acquisition Boat#1, $M	3	5	0	0
Acquisition Boat#2, $M	0	3	5	0
Acquisition Boat#3, $M	0	0	3	5

Fig. 8.12 Large boat cost data

8.12 Are Your Assets Liabilities?

Shortly after Jock joined the asset management group his boss Dan called him in.

"We are going to do a due diligence on Front-IT", said Dan.

Jock wasn't sure what a due diligence was so he kept quiet. All he knew was that Albany – the large conglomerate where he and Dan worked – were putting together a bid for Front-IT.

"What is the main idea?", asked Jock.

"We need to check out their assets", said Dan. "They have nice offices in a smart location, lots of modern computer gear and the managers all have swishy company cars so it looks pretty good as far as I can see."

Check it out they did. The cars and the computer equipment were all leased. The office building was six months into a three year lease – making it a cost commitment. The only fixed asset on the books was a backroom computer system valued at $5,000,000 – but when they got specialists to look at it, it turned out to be obsolete and to have zero market or practical value.

Dan and Jock made their report. Later at a drinks session to celebrate the acquisition, Sean, a lead guy on the takeover team spoke to Dan and Jock.

"You did a good job on the asset evaluation", he said.

"But they weren't worth anything", said Jock.

"Too right", said Sean, "It brought the price down a treat".

"But why did we go ahead", said Jock, puzzled.

"They had some heavily amortized intangibles we were interested in" said Sean, turning away as though he had said too much.

Jock didn't know what an intangible was, much less a heavily amortized one. Front-IT looked like a dead duck from where he saw it.

At home that night it occurred to Jock that Sheila might know about intangible assets.

"Can I ask you a question?" said Jock.

"Yes", said Sheila, brightly.

"It's not that kind of question", said Jock, "It's about intangible assets and amortization".

"Oh", said Sheila, and she explained that an intangible asset was something like a patent, or intellectual property or goodwill. It had value but was not money and was not a physical thing. The value declined over time, and the decrease was called amortization.

"Its like depreciation", she said.

At work later Jock asked Dan if he knew why Albany had bought Front-IT.

"Apparently Front-IT developed a safety relay for electricity transmission systems years ago", said Dan.

"They still own the patent. It seems that our guys reckon they can develop the idea further and that we can use it on our up-coming projects and also license it out"

"I see", said Jock.

Chapter 9
Discounted Cash Flow and Asset Decisions

The hardest part of financial analysis is not the calculations, but deciding what factors should be taken into account and estimating the costs, revenues and risks.

Chapter Aim: The aim of this chapter is to introduce the concepts of discounted cash flow in the context of asset management decisions. Asset managers need to have a working knowledge of business finance, so they can provide input to business decision processes.

Chapter Outcomes: After reading this chapter you will know about:

- Interest rates and the cost of capital
- Debt and equity capital
- Weighted average cost of capital
- Minimum acceptable rate of return
- Future value, present value and net present value
- The discount factor
- Cash flow diagrams
- The annuity factor and the capital recovery factor
- Equivalent annual cost and equivalent unit cost
- Excel® functions for discounted cash flow calculations
- The application of discounted cash flow to repair or replace decisions
- Inflation and the real rate of interest

Chapter Topics:

- Introduction
- Discounted cash flow
- Interest rate
- Debt capital
- Equity capital

N. A. J. Hastings, *Physical Asset Management*,

- Gearing
- Weighted average cost of capital
- Minimum acceptable rate of return
- Future value
- Present value
- Discount factor
- Net present value
- Cash flow diagram
- Equivalent annual cost
- Annuity factor
- Capital recovery factor
- Equivalent unit cost
- Repair/replace decision – Ore loading vehicles
- Application of Excel functions NPV, PMT, PV
- Inflation
- Adjusting historical costs
- Real rate of interest
- Revision questions
- Exercises

9.1 Introduction

Asset management decisions involve the application of a combination of technical and financial knowledge. Asset managers play a key role in ensuring that the physical facts and the financial and cost data which are used in making asset management decisions are sufficiently correct to enable sound decisions to be made. For this reason they need to be familiar with the language and methods of accounting and financial analysis. They also play an important role in the analysis of risks and of the sensitivity of decisions to risk.

The asset manager is concerned that costs in a project, for example, are known with reasonable accuracy but also, the likely extent to which a figure may vary in practice. This may mean that a cost is $1,000,000 plus or minus 10%. Financial analysts may make related calculations whose results are expressed to the nearest cent. However, the degree of precision provided by the financial calculations does not, in fact, imply any more accuracy than that inherent in the underlying estimates.

Sound decisions depend on understanding and trust between all those involved in a project. To this end, it is important for the asset manager to be familiar with the principles and terminology used in financial and accounting calculations. In this chapter we shall present these principles and shall illustrate them by asset related examples.

9.2 Discounted Cash Flow

Fixed assets such as buildings, infrastructure and plant are items with long lives extending over many years or even decades. Financial analysis related to their acquisition, through life support and disposal needs to take account of the time value of money. In this chapter we introduce the basics of discounted cash flow, including the concepts of interest rate, discount factor, present value, cash flow diagrams and equivalent annual cost. We illustrate these concepts in an asset management context and also use Excel spreadsheet functions to calculate discounted cash flow quantities.

9.2.1 Interest Rate

Imagine that we wish to buy a house and consider two scenarios. The first is that we have the money and can go right ahead. The second is that we need to borrow the money and pay it back over a period of time. In the second case we will have to pay interest on the money that we borrow. Ultimately we will have paid for the house and we will also have paid out interest on the current outstanding loan year by year or month by month. This illustrates the concept of the time value of money, which relates to the fact that having money now is worth more than only having it later. Borrowing money costs money and lending money yields a return.

The interest rate is the cost or return per year of either borrowing or lending money, expressed as either a decimal fraction or a percentage, of the amount borrowed or lent. The interest rate on borrowing is higher than on lending, the difference being the money merchant or bank's margin or source of income.

9.3 Debt and Equity

The capital used by a company generally has one of two types of source: debt capital or equity capital.

Debt capital is money borrowed from a bank or other source and the cost is the loan interest rate. The repayment schedule is a firm commitment and the business is insolvent if it cannot be met.

Equity capital is money provided by investors, either by the purchase of shares or as retained earnings. The cost reflects the expectations of shareholders, who benefit from dividends and also from any increase in the value of the company. Usually the expected return on equity is higher than on debt, but if business is bad, dividends can be reduced or omitted without the company becoming insolvent.

Gearing is the ratio of debt to debt plus equity. Since the interest payments on debt capital must be maintained, a highly geared company is at relatively high risk.

Weighted Average Cost of Capital (WACC) is the cost of capital to the company, taking an average of the proportion of debt and the interest rate on debt with the proportion of equity and the expected return on equity.

Minimum Acceptable Rate of Return (MARR) is the minimum rate of return which a planned investment must reach in order for the company to regard it as worth proceeding with. It must be sufficient to cover the weighted average cost of capital, plus a return to justify the effort of the enterprise, plus an allowance for risk.

9.4 Discounted Cash Flow Terminology

9.4.1 Future Value

The future value of an amount of money, which is available now, is the value that it will become when invested at interest for a number of years. With an interest rate of 10%, say, an investor who invests \$100 for one year will see its value grow to \$110. \$110 is the future value in one year. The future value, V_1 of an amount V_o invested at interest rate r for one year is:

$$V_1 = V_o \times (1 + r) \tag{9.1}$$

If the investment continues for n years the future value will become:

$$V_n = V_o \times (1 + r)^n \tag{9.2}$$

If the interest rate varies through time, taking values r_1, r_2, and so on, the corresponding equation is:

$$V_n = V_o \times (1 + r_1) \times (1 + r_2) \times \ldots (1+r_n) \tag{9.3}$$

9.4.2 Present Value

The present value of an amount of money V_n received in n years time is the amount of money available now which will attain the value V_n if invested at interest over the intervening years. For an interest rate r, the present value, PV, of an amount V_1 received in one year's time is given by the equation:

$$PV = V_1 / (1 + r) \tag{9.4}$$

Thus, with an interest rate of 10%, the present value of \$100 received in one years time is:

$$PV = 100 / (1 + 0.1) = \$90.91 \tag{9.5}$$

For an amount V_n received in n years time, the present value is given by:

$$PV = V_n / (1 + r)^n \tag{9.6}$$

9.4.3 Discount Factor

The multiplier 1/ (1 + r) which occurs in calculating present values, for example in Eqs.9.4 to 9.6, arises frequently in discounted cash flow analysis and is known as the discount factor. The discount factor is the proportion by which an amount is reduced to give its equivalent value one year earlier. We shall denote the discount factor by the symbol p. Then:

$$p = 1/(1 + r) \tag{9.7}$$

Using the discount factor, p, the present value of an amount V_n received in n years time is given by:

$$PV = p^n \times V_n \tag{9.8}$$

Example: Calculate the present value of $100 received in 2 years time, with an interest rate of 10%.

Solution: For an interest rate of 10%,

$$p = 1/(1 + 0.1) = 0.9091 \tag{9.9}$$

$$PV = p^2 \times V_2 = 0.9091^2 \times 100 = \$82.64 \tag{9.10}$$

Table A in the Appendix A gives values of the discount factor for a range of years and interest rates.

9.4.4 Net Present Value

The net present value is the sum of the present values of a series amounts received or expended over a number of years. An example is that of receiving $100 in one year's time and then another $100 in two years time. The first $100 has a present value of $90.91 and the second $100 has a present value of $82.64, giving a total of $173.55. In this case both the amounts are positive, but in a net present value calculation, some of the amounts may be negative.

For a series of amounts $\$V_i$ received in i years time, the Net Present Value, NPV, is the amount of money available now which is equal to the value of the series, allowing for the interest rate.

$$NPV = V_0 + pV_1 + p^2V_2 + \ldots p^nV_n \tag{9.11}$$

An example of a net present value calculation is given in the next section.

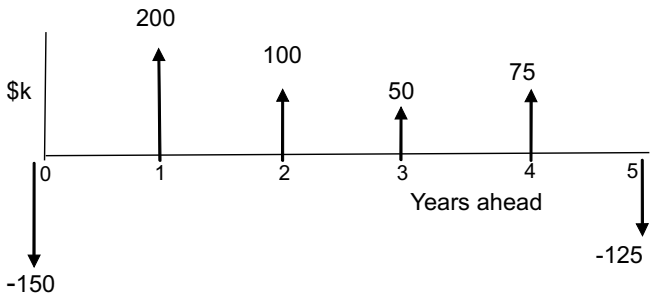


Fig. 9.1 Cash flow diagram

9.4.5 Cash Flow Diagram

A cash flow diagram is a schematic representation of cash received and expended year by year in the course of an activity. A cash flow diagram is a convenient way of visualizing the income and expenditure in a project. As an example, consider a project which involves an initial cost of $150 k and then generates the following returns:

Year 1 $200 k
Year 2 $100 k
Year 3 $ 50 k
Year 4 $ 75 k
Year 5 – $125 k, this being a disposal cost.

The cash flows can be represented as shown in Fig. 9.1. The initial cost of $150 appears in year zero.

The net present value of the cash flows in Fig. 9.1 can be calculated using Eq. 9.11. The relevant interest rate in this case is given as r = 9%. The discount factor is then calculated by Eq. 9.7 as:

$$p = 1/(1 + r) = 1/(1 + 0.09) = 0.9174 \tag{9.12}$$

Applying Eq. 9.11 to calculate the NPV we have:

$$\begin{aligned} NPV = &-150 + 0.9174 \times 200 + 0.9174^2 \times 100 + 0.9174^3 \times 50 + 0.9174^4 \times 75 \\ &- 0.9174^5 \times 125 = \$128.15 \end{aligned} \tag{9.13}$$

9.5 Equivalent Annual Cost

Equivalent Annual Cost (EAC) is the amount of a regular annual cost which, over a given period of years, has the same Net Present Value as any given series of costs. The EAC converts the NPV into an equivalent annual amount. The term Equivalent Annual Value (EAV) is also be used when income as well as cost is considered. An

example of an equivalent annual cost is a mortgage repayment made at a regular amount per year, with the NPV of the payments over the whole period adding up to the cost of the original loan.

Equivalent annual cost is a useful concept in asset management. It helps in the comparison of options, particularly where the options are dissimilar in type or duration. The difference between two options can often be more easily appreciated, particularly in relation to external or risk factors, when converted into an annual cost. Examples are in comparing life cycle costs of different items, or of similar items over different lives, and comparing the discounted value or cost of dissimilar projects.

9.5.1 Annuity Factor

The calculation of the Equivalent Annual Cost is based on the use of the Annuity Factor. The annuity factor is the net present value of an amount of $1 per year, received for n years, with the first dollar being received in one year's time, at a specified interest rate.

The value of the annuity factor is derived as follows. Let:
r denote the interest rate
p denote the discount factor
F denote the annuity factor.

If we receive $1 dollar per year for n years, with the first dollar being received in 1 year's time, the total NPV is the Annuity Factor, F. This is given by:

$$F = p + p^2 + p^3 + \ldots p^n \tag{9.14}$$

Applying the formula for the sum of a geometric progression we have:

$$F = p\,(1 - p^n)/(1 - p) = (1 - p^n)/r \tag{9.15}$$

The relationship between the NPV and the EAV is then:

$$\text{EAV} = \text{NPV}/\text{Annuity Factor} \tag{9.16}$$

The EAV is the annualized value of the return from a project with value NPV.

9.5.2 Capital Recovery Factor

The Capital Recovery Factor (CRF) is the amount we need to receive per year for n years at end of year to have an NPV of $1 at the specified interest rate. The Capital Recovery Factor, C, is the reciprocal of the Annuity Factor.

$$C = 1/F = r/(1 - p^n) \tag{9.17}$$

$$\text{EAV} = \text{NPV} \times \text{Capital Recovery Factor} \tag{9.18}$$

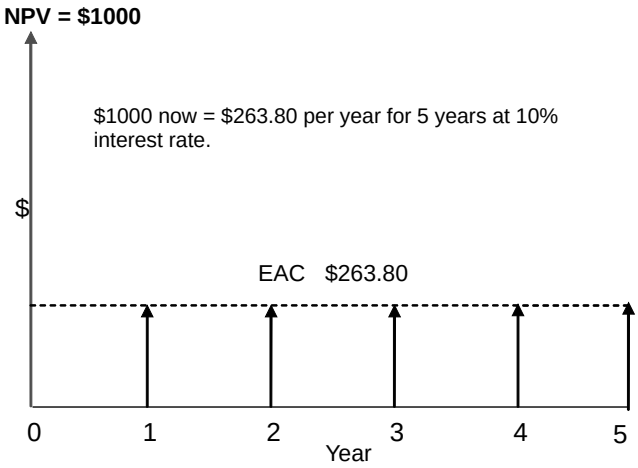


Fig. 9.2 Net present value and equivalent annual cost

9.5.3 EAC Example

A person borrows $1,000 at 10% interest rate and pays off the debt by making five equal annual payments at the ends of years 1 to 5. How much will the annual payments be? Table B in Appendix A gives values of the Annuity Factor for a range of years and interest rates.

Solution: From Table B, for 5 years at 10%, the Annuity Factor is 3.7908.
EAC = 1000 / Annuity Factor
= 1000 / 3.7908 = $263.80 per year

The Net Present Value and Equivalent Annual Cost are illustrated in Fig. 9.2.

9.6 Equivalent Unit Cost (EUC)

Sometimes we need to make comparisons between items which serve similar purposes but have different capacities. For example, we may be deciding whether to purchase haulage trucks of 50 tonne or 200 tonne capacity. The concept of Equivalent Unit Cost is useful here. The equivalent unit cost is the Equivalent Annual Cost (EAC) divided by the number of units of production which the item has capacity to generate, per year. For comparison purposes we need make standardizing assumptions for each of the relevant items, such as how many shifts are worked by each type of equipment. We refer to the productive capacity per year as the Annual Production Capacity (APC). The Equivalent Unit Cost is then given by:

$$\text{Equiv. Unit Cost} = \text{Equiv. Annual Cost} / \text{Annual Production Capacity} \tag{9.19}$$

Consider the case of a 50 tonne haulage truck. Suppose that the Equivalent Annual Cost is $750,000 per year and the capacity for moving material is 2 million tonne-kilometres per year. Using Eq. 9.19. we have,

$$\text{EUC} = 750{,}000/2 = \$375{,}000 \text{ per million tonne – kilometres.} \tag{9.20}$$

For comparison consider a 200 tonne truck with an Equivalent Annual Cost of $1,350,000 and an Annual Production Capacity of 5 million tonne-kilometres. The equivalent unit cost will be:

$$\text{EUC} = 1{,}350{,}000/5 = \$270{,}000 \text{ per million tonne – kilometres.} \tag{9.21}$$

Thus the equivalent unit cost of the 200 truck is lower in this case.

9.7 Repair/Replace Decision for Ore Loading Vehicles

The following example illustrates the use of discounted cash flow in an analysis supporting a decision on whether to repair or replace an ore loading vehicle in an underground mine. As well as illustrating the use of discounted cash flow, the example illustrates the importance of using management judgment in regard to the factors involved in the analysis. In fact, the financial analysis is the simple part for any given set of facts. The hard part is deciding what factors should be taken into account and estimating the costs, revenues and risks involved.

9.7.1 Situation

A mining company owns several vehicles of a type known as Load-Haul-Dump Trucks. The trucks are used underground to move rock containing copper, lead and silver ores, which has been broken up by blasting. The environment is hot, rough and abrasive, and the maintenance costs are high. Figure 9.3 shows one of the trucks at work. Our analysis focuses on a decision relating to a four year old truck which can either be traded in for a new one or undergo extensive repairs/overhaul and continue in use. Specifically, the decision that we shall evaluate is whether to trade in the existing truck or to overhaul it and run it for another four years.

9.7.2 Factors Involved in the Repair/Replace Decision

Initially, we make a list of those factors which are relevant to our decision. Subsequently we shall see how the story unfolds through several stages of analysis. The factors that we come up with are as follows:

Fig. 9.3 Load-haul-dump truck at work

a. Cost of new loader
b. Trade-in value of old loader
c. Repair/overhaul cost of old loader (OEM or local rebuild)
d. Maintenance costs of old and new loader through life
e. How long the old loader will last
f. Reliability/availability of old versus new loader
g. Time taken to repair the old loader
h. Warranty on new loader
i. Possible improvements of new loader versus old
j. Discounted cash flow of costs in each case, taking into account company tax.

9.7.3 New Ore Loader Costs

As a first step in our analysis we calculate the net present value of acquiring a new truck and maintaining it for four years. For this purpose we need data on the costs relating to the acquisition of a new truck. The data shown in Fig. 9.4 have been estimated for the acquisition, maintenance and disposal of a new loader over four years. The existing four year old loader can be traded-in for $150,000.

9.7.4 Cash Flow Diagram

A cash flow diagram for these costs is shown in Fig. 9.5. Note that the maintenance costs are taken as end-of-year costs. This may not be strictly accurate, as maintenance costs will generally occur during the year, but the extra effort of adjusting the discounted cash flow for part year timings is not considered justified.

New vehicle cost = $780,000
Trade-in allowance for existing loader = $150,000
Net acquisition cost = $630,000

Year	Maintenance Costs, $
1	60,000
2	90,000
3	135,000
4	180,000

Resale value at age 4 = $150,000

Fig. 9.4 New ore loader costs

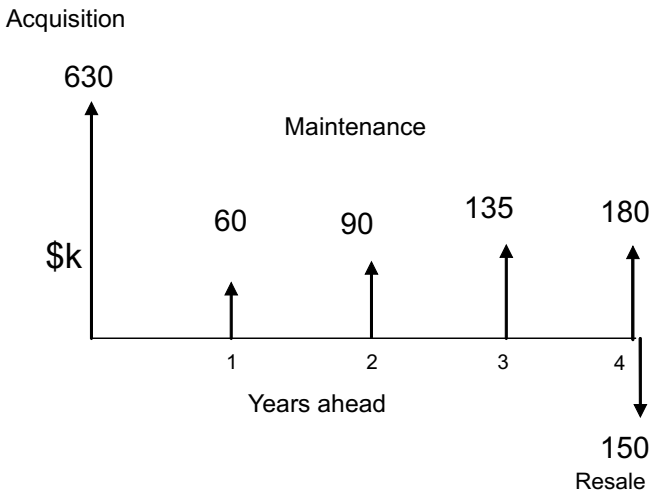


Fig. 9.5 Cash flow diagram for new loader costs

These costs are the life cycle costs for a new loader over a four year life. We can calculate the Net Present Value and the Equivalent Annual Cost of these costs for any given interest rate using the method described in paragraphs 9.4.4, 9.7.5 and 9.5. Using an Excel spreadsheet, the result is shown in Fig. 9.6, and gives an NPV for the life cycle cost of $886,295 with the interest rate specified as 9%. The Equivalent Annual Cost is also calculated in the spreadsheet and is $273,571 per year. It is convenient to label the years starting from zero (Row 2), with the expenditure or income being assigned to the end of each year (Row 3). The start of the project is

the end of year zero, essentially the same as the start of year 1. Note that, although the spreadsheet gives the answer to an impressive degree of precision, the accuracy of the result depends on the accuracy of the various cost estimates, and we should therefore allow for a significant degree of variability in practice.

9.7.5 Excel Function NPV

In Fig. 9.6 the Excel function NPV is used to calculate the net present value of the life cycle costs, and the format of the NPV function is illustrated in the function field. The Excel NPV function calculates the NPV of a series of values at a given interest rate, for annual payments starting in one year's time. An immediate cost, which is undiscounted, in this case the acquisition cost from cell B3, must be shown separately.

9.7.6 Excel Function PMT

In Fig. 9.7 the Excel function PMT is used to calculate the Equivalent Annual Cost of the loader. The function field shows the format of the Excel function PMT. The PMT function value takes the opposite sign to the present value parameter, and the minus sign in front of the function gives the EAV the same sign as the NPV. The PMT function uses the Annuity Factor formula to calculate the equivalent annual cost corresponding to a given net present value. The name PMT derives from the word "payment".

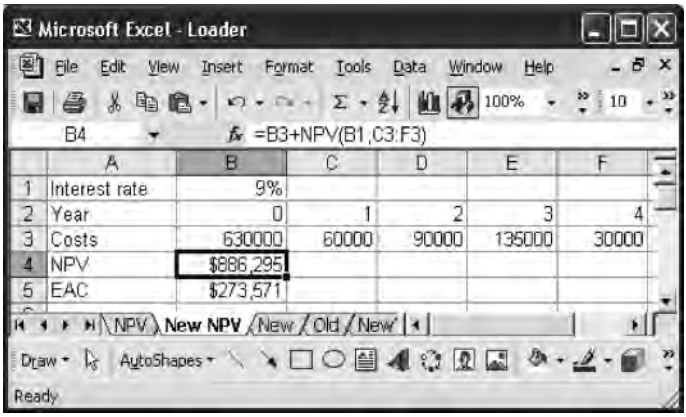


Fig. 9.6 NPV of life cycle cost of new loader

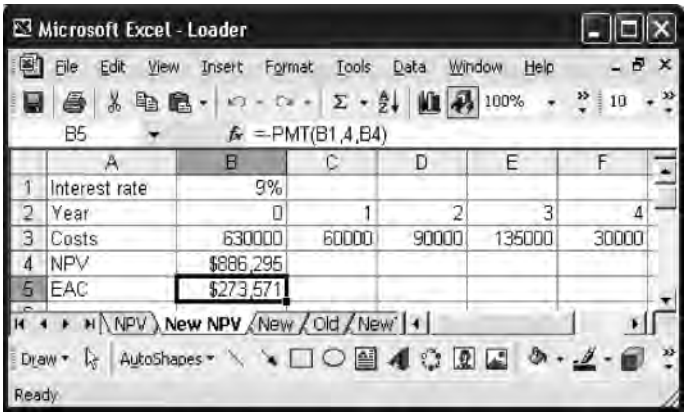


Fig. 9.7 Loader equivalent annual cost using PMT function

9.7.7 Payment or Cost at End

The PMT function has an option for calculating the equivalent annual cost of a payment made at the end of the last period, rather than at the beginning of the first period. This is useful if we require the EAC of a terminal or resale value. An example in which a resale value of $40,000 received in 5 years time is converted to an equivalent annual cost at 9% is shown in Fig. 9.8.

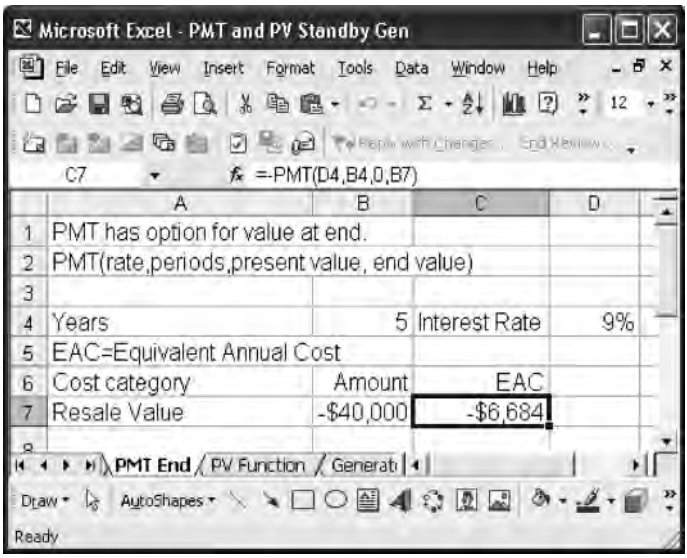


Fig. 9.8 PMT function with payment at end

9.7.8 Life Cycle Cash Flow

The life cycle costs which apply to the new loader are similar in structure for any asset. The general form of these costs is summarized in the cash flow diagram of Fig. 9.9. This uses the following symbols to represent the costs.

A = Acquisition cost
M_i = maintenance cost in year of life i
S_n = Resale value at age n years

Later we shall consider how the cash flow is affected by company tax.

9.7.9 Old Ore Loader Costs

The next step towards our repair/replace decision is to estimate the costs of overhauling and maintaining the old loader over the four year period. These costs are shown in Fig. 9.10, where the costs are taken as occurring at the end of the years shown. The initial overhaul cost is $240,000. The maintenance cost in year 1 is $90,000. In year 2 the maintenance cost is $135,000 and a second overhaul is required at the end of year 2/ beginning of year 3 at a cost of $240,000. The resale value of the loader at the end of year 4 is $0.

The cash flow diagram for the old loader option is shown in Fig. 9.11.

The Excel calculation of the Net Present Value and Equivalent Annual Cost are shown in Fig. 9.12. Use is made of the Excel NPV and PMT functions. We see that

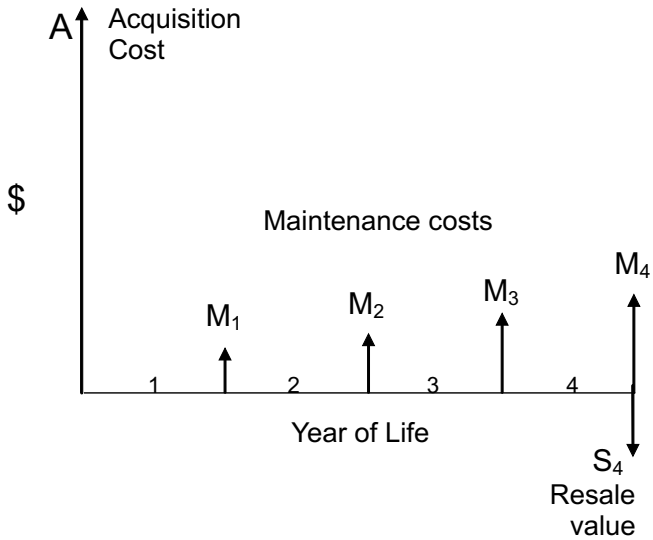


Fig. 9.9 Life cycle cash flow diagram

Year	Overhaul Costs	Maintenance Costs
0	240,000	
1		90,000
2	240,000	135,000
3		105,000
4		150,000

Fig. 9.10 Old loader overhaul and maintenance costs

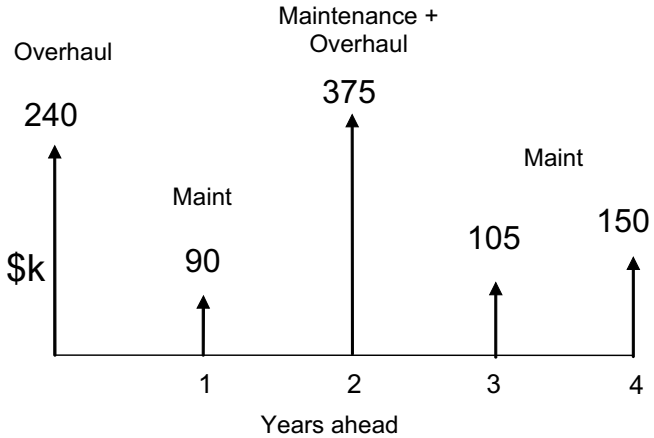


Fig. 9.11 Old loader cash flow

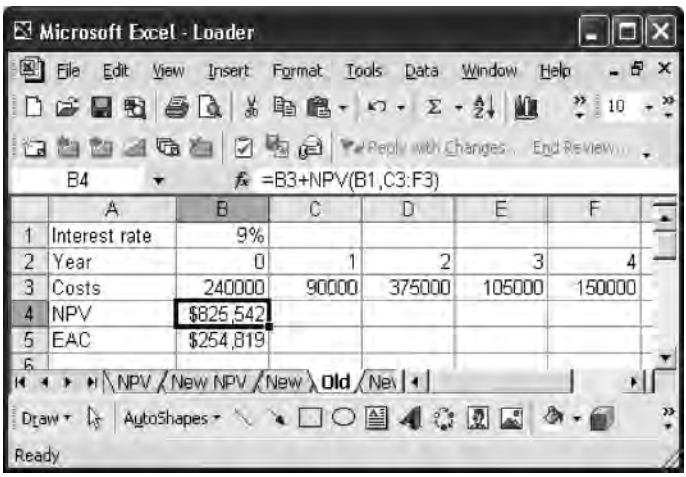


Fig. 9.12 Calculation of NPV and EAC for old loader option

the Net Present Value of costs for the old loader option is $825,542, and the Equivalent Annual Cost is $254,819 per year. At this stage it appears that the overhaul option is cheaper than the replace option. In the application on which this example is based, a decision was made initially to overhaul the old loader, but later, when the full implications of the choice were realized, it became clear that this decision was incorrect. The reasons for this will become apparent as we analyse the problem further.

9.8 The Excel Function PV

The Excel function PV calculates the net present value of a uniform series of annual payments. Figure 9.13 shows an example of the use of the Excel PV function. In a certain application there is an annual scheduled maintenance cost of $2,500 incurred each year for 5 years. We wish to calculate the net present value of this maintenance cost at an interest rte of 9%. The annual cost is at B6, the number of years at B4 and the interest rate at D4. The function PV is used in cell B7 to calculate the net present value of these maintenance costs. The function field shows the use of the Excel function PV. The minus sign in front of the function gives the PV the same sign as the maintenance cost. Exercise 9.11 at the end of this chapter makes use of this feature.

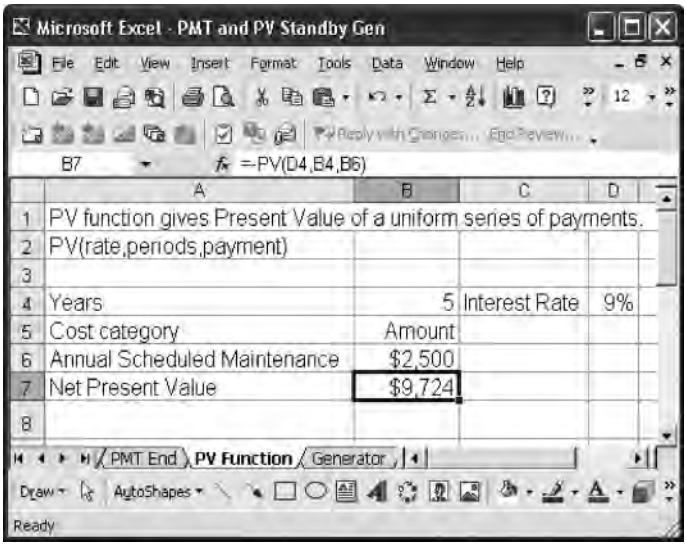


Fig. 9.13 The Excel function PV

9.9 Inflation

Inflation means that identical goods cost more money now than they did a year ago. Equivalently, it means that prices were lower for the same items in the past. Deflation is also possible and corresponds to a decrease in the price of goods with time. The inflation rate is distinct from the interest rate. However, the two are not entirely unrelated, as the interest rate will normally exceed the inflation rate, otherwise there will be no attraction in saving or investing.

Historical average inflation rates are published by statistical authorities, for example, the Consumer Price Index. Where we wish to compare costs which are incurred a few years apart, we can bring them to a common reference date. This is usually the current year, and we then refer to the money unit as "*today's dollars*".

The expression "*real terms*" is used to indicate that a money quantity has been adjusted to allow for inflation. The unadjusted figures we refer to as "*nominal*" dollars. The inflation rate usually varies from year to year.

9.9.1 Adjusting Historical Costs

Consider a maintenance cost of $6,500 incurred two years ago. We may wish to compare that in real terms with the cost of a similar task performed in the current year. If the inflation rate was 7% last year and 9% the year before, we must first inflate the cost by 9% and then inflate the result by a further 7% to put the cost into today's dollars. In this case the result would be:

$$\text{Cost in Today's Dollars} = 6{,}500 \times (1 + 0.09) \times (1 + 0.07) = 7{,}581 \tag{9.22}$$

Try this question.
$20,000,000 was spent last year on maintaining a water supply system,
$20,500,000 is budgeted for this year. Inflation between the years was 4%.
Which of the following is true?

a. Expenditure has increased
b. Expenditure has declined in real terms.
(Answer: Both)

9.9.2 Real Rate of Interest

The "real" rate of interest is the annual increase in the value of invested money in terms of its purchasing power, allowing for inflation. The real rate of interest is approximately equal to the bank interest rate minus the inflation rate. Thus if the bank interest rate is 9% and the inflation rate is 4% then the real rate of interest is approximately 5%. The precise relationship is given in Eq. 9.24. The relationship between the real rate of interest, the bank interest rate and the inflation rate can be illustrated by the Jelly Beans example which follows.

Jelly Beans Example. If I can buy 100 jelly beans for $1 today, then the real rate of interest is the number of extra jelly beans that I can buy in one year's time if I invest the $1 and collect the interest.

Let the inflation rate be 5%. This means that in one year's time, 100 jelly beans will cost $1.05. Suppose that the bank interest rate is 13.4%. Then if I have $1 now and invest it for one year I will have $1.134 in one year's time. Hence, in one year's time I will be able to buy:

$100 \times (1.134/1.05) = 108$ jelly beans

The real rate of interest over the year was 8%, since I can buy 8% more jelly beans at the end than at the beginning.

The general formula for the Real Rate of Interest is as follows. Let
r = bank interest rate as a decimal
f = inflation rate as a decimal
t = real interest rate as a decimal

Then, by following the logic of the jelly bean example we get,

$$1 + t = (1 + r)/(1 + f) \tag{9.23}$$

$$t = (r - f)/(1 + f) \tag{9.24}$$

It is not unusual to use the approximation $t = r - f$, rather than the exact formula.

9.9.3 Adjusting Future Costs

Inflation and interest rates vary widely over time, and are hard to predict. In assessing real costs or values over long periods, great accuracy cannot be expected. Also, some items are not subject to inflation. For example, maintenance costs will inflate, but annual repayments and depreciation based on the original acquisition cost of an item will not inflate. In making financial planning calculations, adjust all inflatable amounts into today's dollars and use the real rate of interest.

9.10 Discounted Cash Flow Revision Question

Explain the following terms:

a. Interest rate
b. Debt capital
c. Equity capital
d. Gearing
e. Weighted Average Cost of Capital
f. Minimum Acceptable rate of Return
g. Future value
h. Present value
i. Discount factor
j. Net Present Value
k. Cash flow diagram
l. Equivalent Annual Cost
m. Annuity factor
n. Capital Recovery Factor
o. Value to Infinity
p. Real rate of Interest

9.11 Standby Generator Exercise

A company is to install a standby generator in a certain location, at which it is required for five years. The initial capital cost is $75,000 and the annual routine maintenance cost is $2,500. The annual unscheduled maintenance cost has been estimated at an average value of $3,500 per year. The value of the generator at the end of five years is estimated at $40,000.

The company wishes to ascertain an equivalent annual cost as a basis for charging out the generator. Running expenses are additional and are not included at this point. The cost of capital advised by the finance department for this application is 9%. At 9%, the five year annuity factor is 3.8897 and the five year discount factor is 0.6499.

Calculate:

a) the equivalent annual cost of providing the generator,
b) the NPV of this cost,
c) If the company rents the generator out at $30,000 per year, how much profit will it make in total?

Answers: (a) $18,598 per year. (b) $72,341. (c) $44,350 (npv)

9.12 Solar or Diesel Power Exercise

Two options are being considered for providing electric power to a remote site. Estimate the life cycle cost of each option. Use discounted cash flow at 7%. Which system would benefit if interest rates rose/fell? Which system is cheapest at zero interest rate? The government wishes to encourage the installation of solar systems. How much up-front subsidy will it need to provide in order to make the solar system cost competitive over a long term future?

Option 1 Solar Power

a) Acquisition and installation cost of all items excluding batteries. $90,000
   Life of Items (a) 15 years
b) Acquisition and installation cost of batteries (deep cycle). $60,000
   Life of Items (b) 7 years
c) Operating and maintenance cost per year for solar power system. $3,000

Option 2 Diesel Power

a) Acquisition and installation cost. $50,000
b) Overhaul cost after 10 years. $20,000
c) Life of diesel system. 20 years.
d) Operating and maintenance cost per year for diesel system. $12,000

The following discounted cash flow factors are given for an interest rate of 7%:

Years	Discount Factor	Annuity Factor
7	0.6227	5.3893
10	0.5083	7.0236
15	0.3878	9.1079
20	0.2765	10.5940

Chapter 10
Profit, Depreciation and Tax

The hand that writes the invoice rules the world

Chapter Aim: The aim of this chapter is to describe how tax and depreciation are taken into account in asset management decisions. Asset managers work with accounting and financial specialists and need familiarity with the terminology and principles involved in dealing with issues of depreciation and taxation.

Chapter Outcomes: After reading this chapter you will understand how after tax profit is calculated, how depreciation is calculated and how the cash flow diagrams used in the analysis of asset management decisions are influenced by tax considerations. The Ore Loader example will be used to illustrate the results. Additional topics considered are the impact of downtime on company revenue, loan repayment calculations, asset valuation methods and an asset value index which provides an overview of the financial status of an organizations assets.

Chapter Topics:

- Introduction
- Profit and company tax
- Capital transactions
- Depreciation
- Acquisition cost
- Book value
- Written down value
- Effective life
- Straight line depreciation
- Declining balance depreciation
- Cash flow after tax
- Tax credits
- Tax on resale

N. A. J. Hastings, *Physical Asset Management*,

- After tax cash flow diagram
- Ore Loader decision analysis with tax
- Revenue impact of downtime
- Loan repayment
- Asset valuation
- Asset value index

10.1 Introduction

In this chapter we consider the effect of taxation, in so far as it influences decisions relating to asset management. In an ideal world, taxes should be structured so that they have a neutral effect on business decisions, but in practice this is rarely the case. Tax is a complex area and it is not intended to address it in detail here. The actual tax situation and the precise rules governing depreciation of a company's assets are the province of the accountant and in practice accountancy input into the related calculations is essential. However, for positive outcomes it is beneficial if asset managers are familiar with the main issues and terminology of company tax. We shall introduce, in a basic context, the main elements of tax and depreciation, and the concept of tax credits as a way of allowing for the effects of taxation.

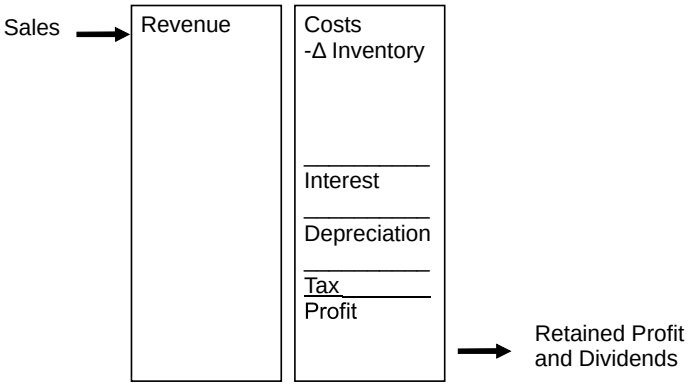
10.2 Profit and Company Tax

Factors in determining the amount of profit made by a company are:

- Revenue
- Operating expenses
- Maintenance expenses
- Interest expenses
- Depreciation
- Tax

The amount of profit is calculated by first calculating the taxable income, given by the sales revenue minus the various expenses and depreciation. Company tax is then calculated as a percentage of the taxable income. Subtracting the company tax from the pre-tax profit gives the after tax profit for the organization. The calculations are normally shown in the Profit and Loss account, illustrated schematically in Fig. 10.1. Company tax is levied on taxable income, typically at a rate of about 30%.

The expenses referred to are typically made up of items, such as wages, fuel, materials, spare parts, leasing charges, rents and interest. Depreciation is the decline in the value of fixed assets in the year, calculated in accordance with accounting rules.



Costs are costs incurred in generating revenue, e.g. labour, materials, overheads. Δ Inventory is the change in the value of inventory held as current assets; this term can be positive or negative.

Fig. 10.1 Profit and loss account

10.3 Capital Transactions

Capital transactions involve the purchase or sale of fixed assets. They also include expenditure on asset creating projects, such as construction of buildings and infrastructure items such as roads or dams. Capital expenditure is not directly tax deductible in the year when the money is spent, as it is assumed that one kind of asset (money) is being exchanged for another kind of asset (machinery, plant, buildings, infrastructure) and that this does not affect the value of the firm. The depreciation of the asset is tax deductible, year by year over its effective life.

10.4 Depreciation

Depreciation is an amount by which the value of a capital item is decreased for accounting purposes, to approximately reflect its decreasing value with age. Depreciation is deductible from income in the current year, in determining taxable income, and hence in determining the tax to be paid.

As an item depreciates, its reduced value is referred to as its "book value" or "written down value". The book value will not necessarily reflect the value of the item in terms of its practical usefulness as an asset at a particular stage of life. It is possible to adjust the book value to reflect market changes.

10.4.1 Acquisition Cost

The acquisition cost of an item is the full purchase price plus any costs of transporting, installing, re-locating or erecting the item.

10.4.2 Book Value (or Written Down Value, WDV)

The book value of an item is its Acquisition Cost minus the Cumulative Depreciation to date.

10.4.3 Effective Life

Effective life is the age to which an item retains value, as specified in tax legislation as a basis for depreciation allowances. Taxpayers may make their own estimate of effective life provided this is supported by reasonable documentary evidence. Some examples of effective lives as published by Australian tax authorities are shown in (Fig. 10.2).

Item	**Effective Life in Years**
Aircraft general use	20
Conveyor belts	6.66
Cars	8
Pumps	20
Mining Compressors	15
Cranes	20
Dragline used in coalmining	20
Electricity industry storage batteries	13.33
Medical cat scanner	6.66
Sewerage treatment plant	20

Fig. 10.2 Examples of effective lives

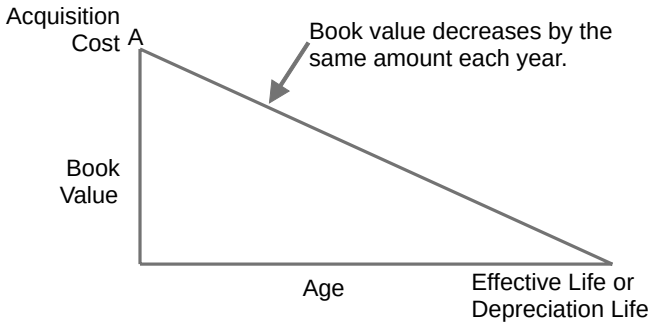


Fig. 10.3 Straight line depreciation

10.4.4 Straight Line Depreciation

There are a variety of ways of calculating depreciation and rules and rates vary from time to time and from jurisdiction to jurisdiction. Here we outline the principles of two common methods. The simplest method of depreciation is straight line depreciation, in which the book value of the item decreases by a constant amount each year over the effective life, starting from the acquisition cost and falling to zero. The annual depreciation is given by the acquisition cost divided by the effective life.

Figure 10.3 illustrates straight line depreciation.

10.4.5 Declining Balance Depreciation

In the declining balance method of depreciation the book value decreases by a constant proportion of its current value each year. For example, at a depreciation rate of 25%, the value will decline by 25% to 75% of the original in the first year and then by 25% of that, to 56.25% of the original in the second year, and so on. Figure 10.4 illustrates depreciation by declining balance.

The formulas involved are as follows. End of year of life i corresponds to age i.

A = Initial Asset Value
d = depreciation allowance rate for tax purposes
W(i) = Written down value at end of year of life i
D(i) = Depreciation in year of life i
W(0) = A = Acquisition cost
W(i) = A × (1–d)^i = W(i–1) × (1–d)
D(i) = W(i–1) – W(i)

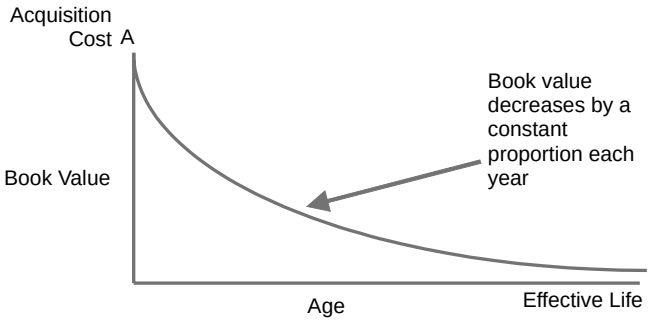


Fig. 10.4 Depreciation by declining balance

Example. An item costs $10,000 and is depreciated by the declining balance method at 25% per year. The book values are as follows.

Age	0	1	2	3
Book Value$	10,000	7,500	5,625	4,219

10.5 Cash Flow after Tax

Let:
R = Revenue
E = Expense
D = Depreciation
c = Company tax rate
T = tax

Cash flow after tax = Revenue – Expense – Tax = R – E –T

Tax = (Revenue – Expense – Depreciation) × Company tax rate = (R – E – D) × c

Cash flow after tax = R – E – (R – E –D) × c = R(1 – c) – E(1–c) + D × c

We see that the effect of company tax on cash flow is equivalent to bringing in the following three adjustments:

a. reducing the revenue, R, by an amount R × c,
b. reducing the expenses by E × c,
c. adding income of amount D × c.

The amounts E × c and D × c are referred to as the operating and depreciation *tax credits* respectively. The term R × c will normally be bigger than the operating plus depreciation tax credits, so although the cost part of the cash flow is reduced, the

revenue part will be reduced even more, with net cost being exactly equivalent to the amount of tax paid.

10.5.1 Tax Credits

A *tax credit* is an adjustment to the pre-tax calculations which has the effect of allowing for tax. Ideally, when assessing project alternatives we should look for the alternative which maximizes profits. However, in many engineering asset applications the revenue and the operating expenses are dependent on business factors which, to a large extent, lie outside the scope of our decision making. It is also difficult to accurately assign profit contributions to particular assets. We may therefore focus on minimizing costs initially, taking account of tax credits. Subsequently we may need to assess the effect of different options on the revenue and operating cost aspects.

In the ore loader overhaul/replace problem the effect of tax differs between the two options, because the effect of depreciation is different in the two cases. We shall return to this application later, but for the moment we look at the use of tax credits in the general case.

To summarize the effect of this analysis on a typical fixed asset, we introduce the following nomenclature:

A = Acquisition cost
i = Year of life
M(i) = maintenance expense in year i,
D(i) = depreciation in year i
S(n) = resale price realized at end of year n
W(n) = book value at end of year n
c = company tax rate.

The tax-credit adjusted maintenance expenditure in year of life i is:

$$M(i) \times (1 - c) \tag{10.1}$$

The depreciation tax credit is

$$D(i) \times c \tag{10.2}$$

The tax credits for year i will be received at the end of year i (at best).

10.5.2 Tax on Resale

On resale at the end of year n, tax is payable on the difference between the resale price realized, S(n), and the written down value, W(n).

$$\text{Tax on resale} = [S(n) - W(n)] \times \text{company tax rate.} \tag{10.3}$$

If W(n) > S(n) this becomes a tax credit, otherwise it means that additional tax is payable.

The effective life of an item can be varied from the tax office standard in some circumstances. One example is when an item which is not fully depreciated becomes unusable due to obsolescence. In this case the item may be written off, essentially the same as selling it for a zero resale value. The written down value is then claimable as a tax credit. Profit will also be reduced, but is best to accept this and to keep the profit and the asset value in line with reality.

The tax office continuously reviews effective lives and variations from the norm should not be considered lightly, but variations are possible where a valid case can be established.

10.6 After Tax Cash Flow Diagram

In making a cost analysis for a fixed asset over its life cycle we allow for the effect of company tax by using tax-credit adjustments to the cash flow, as shown in Fig. 10.5. Maintenance costs give rise to a tax credit in the year they are incurred, as does depreciation. The tax adjustment on resale is also shown in Fig. 10.5.

An impact of company tax on asset decisions arises from the fact that expenses are tax deductible in the current year, whereas capital expenditure is only tax deductible on a deferred basis, in the form of depreciation. This tends to favour repair over replacement and leasing over purchase, but the extent of this depends on the relative underlying costs. Repairs to equipment are tax deductible in the current year, and this may make it worthwhile to postpone a replacement, but we need to be sure that the repairs will deliver adequate reliability and availability over the remaining life of the equipment, so that the savings are not more than offset by losses in performance.

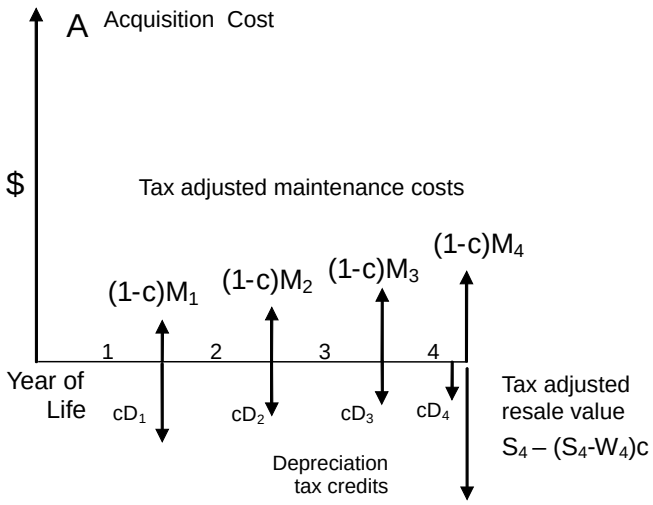


Fig. 10.5 Tax adjusted cash flow diagram

10.7 Ore Loader Decision Analysis with Tax

10.7.1 New Loader Option

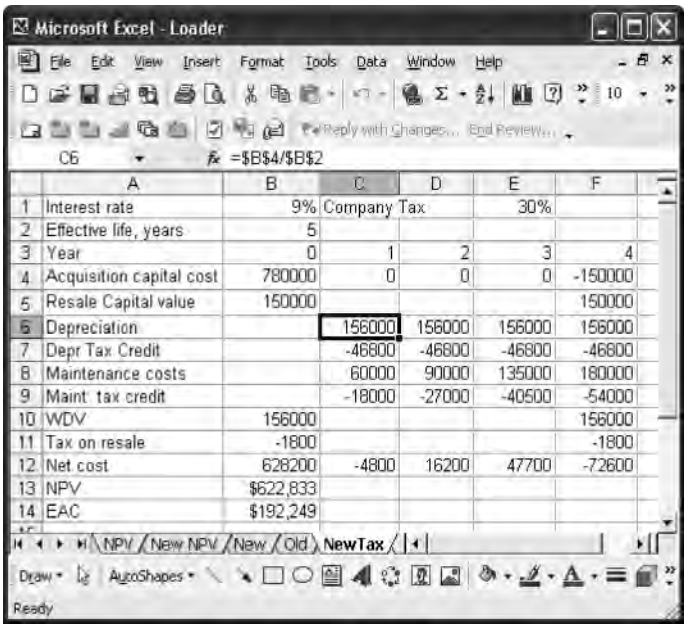
We illustrate the application of tax credits by continuing the repair/replace analysis relating to the ore loader as introduced in paragraph 9.7. The cost analysis for the New Loader option is shown in Fig. 10.6.

The effective life is set at 5 years for depreciation purposes. Straight line depreciation is used. The annual depreciation is shown in row 6 of the spreadsheet. The depreciation tax credits are shown in row 7 and the maintenance tax credits in row 9. To determine the tax on resale, the book value, or Written Down Value (WDV) is calculated and is shown at B10 for the original old vehicle and at F10 for the acquired vehicle. The tax on resale is shown at B11 and F11.

The costs year by year are then calculated as shown in row 12 and the Net Present Value of the costs, and the Equivalent Annual Cost are shown at B13 and B14 respectively. We see that the NPV for the New Loader option allowing for tax credits is $622,833 and the EAC is $192,249 per year.

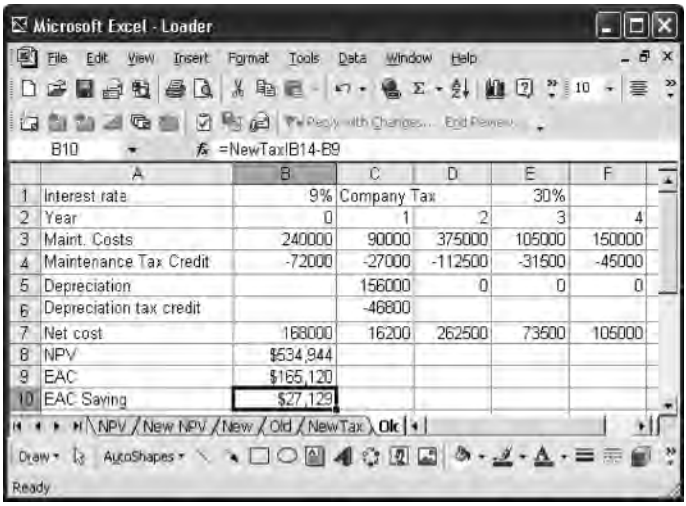
10.7.2 Old Loader Option

For the old loader option the cost analysis is shown in Fig. 10.7. An issue in assessing the tax related position is whether the overhaul cost shown in Fig. 9.10 is an



	A	B	C	D	E	F
1	Interest rate	9%	Company Tax		30%	
2	Effective life, years	5				
3	Year	0	1	2	3	4
4	Acquisition capital cost	780000	0	0	0	-150000
5	Resale Capital value	150000				150000
6	Depreciation		156000	156000	156000	156000
7	Depr Tax Credit		-46800	-46800	-46800	-46800
8	Maintenance costs		60000	90000	135000	180000
9	Maint tax credit		-18000	-27000	-40500	-54000
10	WDV	156000				156000
11	Tax on resale	-1800				-1800
12	Net cost	628200	-4800	16200	47700	-72600
13	NPV	$622,833				
14	EAC	$192,249				

Fig. 10.6 New loader option – cost analysis with tax credits



	A	B	C	D	E	F
1	Interest rate	9%	Company Tax		30%	
2	Year	0	1	2	3	4
3	Maint. Costs	240000	90000	375000	105000	150000
4	Maintenance Tax Credit	-72000	-27000	-112500	-31500	-45000
5	Depreciation		156000	0	0	0
6	Depreciation tax credit		-46800			
7	Net cost	168000	16200	262500	73500	105000
8	NPV	$534,944				
9	EAC	$165,120				
10	EAC Saving	$27,129				

Fig. 10.7 Old loader option – cost analysis with tax credits

operational cost or a capital expenditure. This can be something of a grey area. Repairs or overhauls carried out as part of the normal life cycle of an equipment are generally regarded as operating costs. But a major overhaul aimed at rejuvenating an equipment and hence increasing its capital value beyond that which is normal for an item of the given age is regarded as a capital expense. The book value would be revised upwards and depreciation regime would be adjusted.

However, in the present case the overhaul, which takes place underground at the mine, does not add realizable value to the loader and has therefore been regard merely as a more extensive maintenance cost, which is tax deductible in the current year.

In Fig. 10.7 the maintenance tax credits appear in row 4. There is one year of depreciation remaining as the loader is 4 years old at the start and this is shown in cell C6. The net present value of costs over the four year period is $534,944, cell B8, and the equivalent annual cost is $165,120, cell B9. The value of the saving, as an equivalent annual cost, is given by the difference between the EACs shown in cell B13 of Fig. 10.6 and cell B9 of Fig. 10.7. The saving is shown at cell B10 of Fig. 10.7 and is $27,129 per year.

10.8 Impact of Downtime

The cost of downtime can vary widely depending on circumstances. When a machine breaks down, there is usually a loss of production, as well as repair costs, and little or no saving on other costs of doing business. The following are some types of cost arising from downtime.

Contractual financial loss. Failure to deliver product on time may result in financial loss as part of a contract undertaking. Alternative product may need to be bought in from more expensive sources.

Loss of goodwill. This may result in lost sales in the future and may have negative political impacts.

Loss of production which cannot be made up. In this case, sales of the product are lost and the corresponding revenue is lost. The cost of downtime is the cost of the lost sales minus unused consumables. This applies to every machine for which downtime results in irrecoverable loss of production. Machines which impact fully on lost revenue are referred to as *bottleneck* machines. Asset improvement efforts are often directed at relieving bottlenecks, with the idea of improving throughput and reducing vulnerability of revenue to failures at the bottleneck.

Recoverable production loss. Machine downtime may cause a production loss which can be made up by overtime working, sub-contracting, outside purchasing, etc. When the machine is down, some costs may be saved, eg, power and other consumables. But the cost of idle labour is often not recoverable. In this case the cost of downtime is the extra cost of running the machine in overtime. For sub-contracting it is the cost of the sub-contract minus the saving of unused consumables. For outside purchase it is the outside purchase cost minus unused consumables.

Spare capacity. To reduce the impact of machine downtime we may introduce spare capacity. For example, a mining company operates a fleet of four-wheel drive vehicles to support its operations. In normal operation, 80 vehicles are required to be available. The company has a fleet of 90 vehicles, providing a repair pool to cover breakdowns and routine maintenance. In the case where one of these vehicles is off the road for routine maintenance, the cost of downtime is given by the average cost per hour for providing vehicles of this type. Essentially, the cost is that of providing extra vehicles, and there is no production loss as such. If a breakdown occurs, there may be production loss which is additional to the cost of providing spare capacity.

10.8.1 Physical or Service Losses

It is often easier to identify physical or service losses than it is to put an accurate cost on them. The reduction of losses may well be worthwhile even though we cannot cost them accurately. In making out the business case for an asset or maintenance improvement we should estimate the savings in physical or service terms, even if the precise financial effect is hard to quantify. Financial and operations managers can make their own assessments of the impact of physical savings, and this may vary with the state of the market, levels of stockpiles and so on. For example with the ore loader, a loader moves approximately 5,000 tonnes of ore per week, so this is the physical loss rate from loader downtime. In the ore loader application it turned out that the extra downtime which occurred under the old loader option gave rise to a production loss of several weeks relative to the new loader option. Although the value of this was hard to precisely evaluate, it was clearly greater than

the financial savings for the old loader option, as indicated in the analysis which ignored the downtime factor.

10.8.2 Cost of Failure

Figure 10.8 lists some of the cost factors which can arise when a failure occurs.

10.8.3 Loader Policy Decision

As indicated in paragraph 9.7.9, the initial decision taken by the mining company in the new versus old loader issue was to overhaul the old loader. This was based on the type of cost comparisons indicated in Fig. 10.7. After experiencing one overhaul, however, the decision was changed for future loaders, and the loaders were subsequently replaced at age 4 years. The main reason for the change was the loss of availability whilst the old loaders were being overhauled. Initially it was assumed that the overhaul could be completed during an annual shutdown, but in fact further delays occurred resulting in production losses which could not be made up. Also, the overhauled vehicles had no warranty cover, they were less reliable than new ones, and did not offer various design improvements that the manufacturer had built in to later models. These factors more than offset the savings from overhauling the old vehicles. The saving in Fig. 10.7 of $27,129 per year is less than sales value of the ore moved in one working day by a loader.

Production or Service
- lost sales through downtime, and wind-down and start-up of related areas
- contractual loss
- goodwill loss
- rework

Primary Repair Cost
- labour
- overhead
- spares

Secondary Repair Cost
- labour
- overhead
- spares

Safety/Health
- trauma
- lost time
- workers compensation and insurance

Environment
- clean up
- corrective
- legal

Fig. 10.8 Cost factors of failure

10.9 Loan Repayment

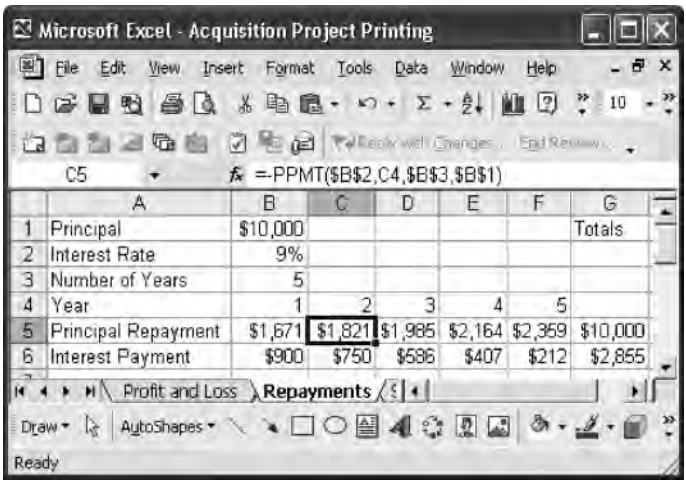
Because interest payments are tax deductible, in some applications we may wish to calculate the amount of interest paid year by year on a loan. Suppose that we borrow an amount, known as the Principal, repayable by equal annual instalments over a number of years, at given interest rate. The Excel® functions PPMT and IPMT give the capital and interest repayments year by year. The functions can also be used for other repayment intervals.

Figure 10.9 shows an example of the use of the Excel functions PPMT and IPMT to calculate loan repayment principal and interest. The loan amount is $10,000 shown in cell B1. The interest rate is 9% shown in cell B2. The repayment period is 5 years shown in cell B3. The repayments of principal are shown in row 5 and of interest in row 6. As an example, the PPMT function for cell C5 appears in the function field. PPMT and IPMT reverse the sign from that of the Principal, so a minus sign has been used in the function field to give positive answers.

10.10 Asset Valuation

Asset valuation methods are subject to accounting rules and the relevant rule should be identified and applied. The best cure for a bad rule is to rigorously apply it. A summary of asset valuation methods is given in Fig. 10.10.

The first and most straightforward method is the acquisition cost depreciated, shown in row 1 of Fig. 10.10. This is the conventional book value. The advantage of this method is that it is objective, that is anyone applying the same rules will get



	A	B	C	D	E	F	G
1	Principal	$10,000					Totals
2	Interest Rate	9%					
3	Number of Years	5					
4	Year	1	2	3	4	5	
5	Principal Repayment	$1,671	$1,821	$1,985	$2,164	$2,359	$10,000
6	Interest Payment	$900	$750	$586	$407	$212	$2,855

Fig. 10.9 Loan repayment calculations

the same result. Disadvantages, particularly for long life assets, are that it takes no account of inflation or of market or technical changes. It may therefore be far from the market value of the item, or from the value of the item to the firm.

A second method is based on increasing the book value to allow for inflation. This does not reflect changes other than inflation which may have occurred since the item was acquired.

A third method is to assess the net realizable value of an item. This means that the value is based on the current market value of the item. This can be highly volatile, as market sentiment can vary with all kinds of events. The terms mark-to-market and fair value are also used. This method is suited to items that are traded, such as financial securities. A simple case is shares that are worth their current market value.

A fourth method is to assess the replacement cost of the item and then depreciate that to allow for the age of the current item. For example, consider an item with an effective life of 40 years which is currently 20 years old. Its replacement cost is assessed at $50,000. Assuming straight line depreciation the assessed value by this method is $50,000 × 20/40 = $25,000.

The fifth method is the optimized replacement cost. In this method we consider not just the replacement cost, but also whether we want to replace the existing item. Changes in business or technology may mean that some action other than a like with like replacement is preferred. This introduces more subjective assessments into the picture. This method features in some regulatory regimes.

The sixth method is deprival value. The deprival value is how much worse off the owner would be if they did not have the asset, but wanted to continue on with

Method	**Features**
1. Acquisition cost, depreciated	Objective. May not be close to real current value.
2. Inflation-adjusted acquisition cost, depreciated	Inflation index may not reflect change in value of item
3. Net realizable value, mark-to-market, fair value.	Based on the current market value of item. Can be highly volatile. Suited to traded financial instruments such as shares.
4. Replacement cost depreciated	Need to assess the replacement cost.
5. Optimized replacement cost, depreciated	Optimization considers whether an equivalent item is available or is needed. Favored by regulators.
6. Deprival value	What the owner would lose if they did not have the asset. The same as the “savings” in the equipment replacement analysis chapter. Logically sound.

Fig. 10.10 Summary of asset valuation methods

business, taking all current and future considerations into account. For example, an old person owns an old car with zero book value and zero resale value. However, the car serves the purposes of the owner, who would be faced with buying another if they were deprived of the old one. The deprival value can be highly volatile as circumstances change. This method appears in some regulatory schemes. It is logically sound. It can give a negative value, for example if an owner has a large loan secured by a property that has lost value.

10.11 Asset Value Index

A top level assessment of the state of assets in financial terms can be obtained by comparing the current value of the assets with the value of similar assets when new. The valuations can be based on any of the valuation methods described in the previous section. Here we shall assume that the option 4, Replacement Cost Depreciated, is used. We define an asset value index for an item as the ratio of the Replacement Cost Depreciated to the Replacement Cost:

$$\text{Asset Value Index} = \text{Replacement Cost Depreciated} / \text{Replacement Cost} \quad (10.4)$$

Consider an asset with an effective life of 10 years, with straight line depreciation; when it is five years old its Asset Value Index, in percentage terms, will be 50%.

The index can be applied to a group of assets by totalling the Replacement Cost Depreciated of the group, totalling the Replacement Cost of the group.

For the group we then calculate the Asset Value Index as shown in Fig. 10.11 Asset value index.

The index can similarly be applied to the whole asset portfolio of an organization, so that a plant with all new assets would have an Asset Value Index of 100%, while a plant with all very old assets which had been fully depreciated would have an Asset Value Index of 0%. Thus we see that the index gives an indication of the overall status of any chosen set of assets.

Taking it across the range of a company's assets, it indicates how the assets stack up in terms of their age relative to their effective lives. If the index is well below 50% then major capital expenditure is likely to be needed in the near future.

The Asset Value Index also serves as a pointer to the actions of management in relation to fixed assets. If the index is falling, we should expect evidence that the management is initiating plans for renewal at the appropriate times, and for the financing of the new items. The Asset Value Index should be reported in the annual accounts, giving a direct insight into the asset health of the company.

$$\text{Asset Value Index} = \frac{\text{Group Total Replacement Cost Depreciated}}{\text{Group Total Replacement Cost}}$$

Fig. 10.11 Asset value index

Chapter 11
Asset Investment Criteria

"If you can look into the seeds of time
And say which grain will grow and which will not,
Speak then to me."
Shakespeare, Macbeth

Chapter Aim: The aim of this chapter is to describe the methods used in evaluating the financial merits of investments and to illustrate these by examples from the asset management area. These investments may be of a wide range of types, including asset acquisitions, modifications, upgrades, overhauls or other improvements to existing plant or facilities. This chapter is concerned with situations where we can quantify direct financial benefits associated with an investment. Situations involving non-financial and cost-benefit analysis are considered in a later chapter.

Chapter Outcomes: After reading this chapter you will know about the methods used to assess financial returns on investments, including the net present value, the payback period, the internal rate of return, the minimum acceptable rate of return and the profitability index. You will also learn about comparing and selecting projects and issues involved in leasing. The chapter concludes with a consideration of the concepts of fixed and variable costs and breakeven analysis.

Chapter Topics:

- Net present value
- Payback period
- Internal rate of return
- Excel® function IRR
- Minimum acceptable rate of return
- Profitability index
- Project financial measures
- Comparison and selection of projects

N. A. J. Hastings, *Physical Asset Management*,

- Planning horizon
- Leasing
- Fixed and variable costs
- Breakeven analysis

11.1 Net Present Value

The first consideration regarding an asset investment is – what is its net present value? Specifically, if we are to invest in an acquisition or development, what financial returns can we expect, when can we expect to get them, and what will be the resulting net present value at a suitable interest rate. For the investment to be worthwhile, the net present value must be positive, otherwise we should not invest. Also, the larger the net present value, the more the investment is worth in absolute terms.

Suppose we initially invest an amount V_0 and this generates returns V_1, V_2, V_3, V_4 in years 1, 2, 3 and 4. With interest rate r and corresponding discount factor p, the net present value of the investment is given by.

$$NPV = -V_0 + pV_1 + p^2V_2 + p^3V_3 + p^4V_4 \tag{11.1}$$

For example, consider an investment in a new material handling system where the data in Fig. 11.1 are given. Using Eq. 11.1 and an interest rate of 5% the net present value is calculated as $527,944. This return will be assessed in deciding if the investment is worthwhile. Factors that go into the decision will include whether there is an even better use for the funds and also the risks associated with the cost and return estimates.

11.2 Payback Period

The payback period is the time required to recoup an investment. Suppose that we initially invest an amount V_0 in a given capability and that it generates returns V_1, V_2, V_3, … in years 1, 2, 3, … The payback period is when the net present value of the sum of V_1, V_2, V_3, … first exceeds V_0. This is illustrated in Fig. 11.2, which shows the *cumulative* discounted cash flow for the investment and its subsequent returns.

V_0 = 1,000,000
V_1 = -200,000
V_2 = 500,000
V_3 = 750,000
V_4 = 750,000

Fig. 11.1 Investment data

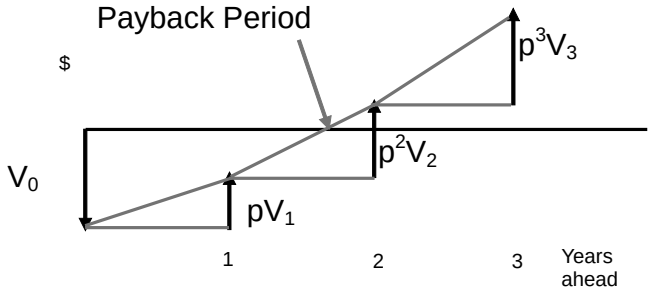


Fig. 11.2 Payback period cumulative plot

The payback period avoids the difficulty of evaluating a long series of returns, since all we focus on is how quickly the series becomes positive.

To determine the payback period we calculate the cumulative net present value of the investment plus its related returns, working forward year by year until a positive value is obtained. The investment terms are negative and the returns generated by the investment are usually positive, although some negative values may occur if the investment takes some time to establish. The equation is

$$NPV = -V_0 + pV_1 + p^2V_2 + \ldots \tag{11.2}$$

The payback period is the number of years that we must work forward until the NPV is positive.

11.2.1 Payback Period Example – Materials Handling System

A new materials handling system in a chemical plant has costs and returns which have been estimated as follows:

a. System purchase and installation at beginning of year 1 costs $1,000,000.
b. Additional costs associated with workflow changes and training in year 1, less benefits in year 1, amount to a net cost of $200,000, considered effective at end of year (EOY).
c. Net benefits in year 2 are $500,000 (EOY) and thereafter $750,000 pa (EOY).

The cash flow diagram is shown in Fig. 11.3.

Figure 11.4 shows the calculation of the net present value of the investment plus returns working forward year by year. The financial data are in row 3, and year 4 shows the NPV of the cumulative returns up to years 1, 2, 3, 4.

As an example of the calculation, the formula field shows the formula used to calculate the returns up to end of year 3. This is given by the initial investment, from cell B3, plus the NPV of the returns from end of year 1 to end of year 3, from cells C3:E3. The result for year 3 is –$89,083, showing that we have not fully recouped the investment by the end of year 3. However, for year 4 we get a positive

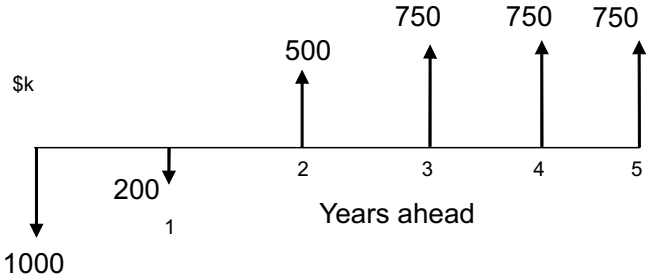


Fig. 11.3 Materials handling system cash flow

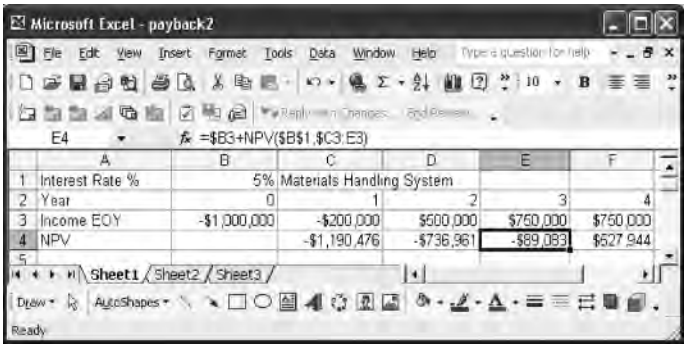


Fig. 11.4 Materials handling payback period calculation

value of $527,944, shown in cell F4. Hence we see that the payback period for this investment is a little over 3 years.

11.3 Internal Rate of Return (IRR)

Suppose that we invest an amount V_0 in a given capability and that it generates returns V_1, V_2, V_3, … V_n in years 1, 2, 3, … n. The internal rate of return is the value of the interest rate which makes the present value of the sum of the returns exactly equal to the value of the investment. This is illustrated in Fig. 11.5, which shows the *cumulative* discounted cash flow for the investment and its subsequent returns. If p is the discount factor corresponding to the internal rate of return, r, then:

$$V_0 = pV_1 + p^2V_2 + \ldots p^nV_n \tag{11.3}$$

The internal rate of return is the rate at which our project is generating returns from the money invested in it. The internal rate of return is the return generated on the money *remaining in* the project, with returns dropping out of consideration as they are generated. The IRR is *not* the return on the whole original investment V_0 over the whole n years.

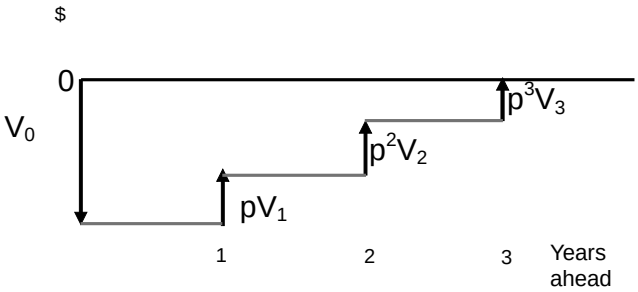


Fig. 11.5 Cumulative NPV at the internal rate of return

11.3.1 Excel Function IRR

Calculation of the IRR is complex, as it involves solving Eq. 11.2 for the discount factor, p, and hence getting the value of the internal rate of return, r. Excel includes an IRR function which will carry out the necessary calculations.

11.3.2 IRR Example – Communications System

Purchase of a new communications system by a maintenance organization has been estimated to save money in travel time and staffing. The cost of the new system is $2,500,000. The system will be used over a five year period in which the expected savings year by year are as shown in Fig. 11.6. Estimate the IRR.

Figure 11.7 shows the solution using Excel. The investment amount of $2,500,00 is in cell B3 and the expected savings are in cells C3 to G3. Cell B4 shows the IRR which is 15.85%. The IRR function is shown in the function field.

Year	1	2	3	4	5
Saving (End Of Year)	$500,000	$750,000	$900,000	$900,000	$900,000

Fig. 11.6 Communication system savings

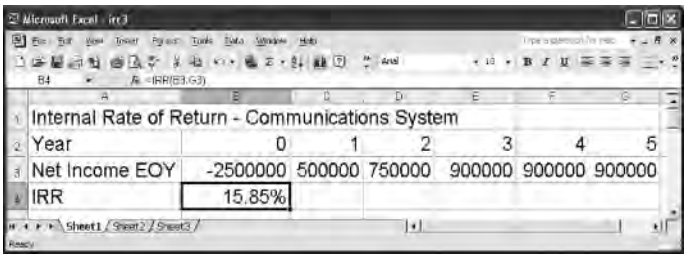


Fig. 11.7 Communication system IRR using Excel function

11.3.3 Minimum Acceptable Rate of Return (MARR)

It is common business practice to expect an investment to achieve at least a certain rate of return, if it is going to receive financial approval. This return is known as the Minimum Acceptable Rate of Return (MARR), or as the Hurdle Rate.

The minimum acceptable rate of return is a return which will cover the cost of capital, including both the interest charged and the repayment of the capital over the period of the investment, plus an element of profit on the project, plus an allowance for risk. Typically this leads to a MARR of not less than 15%.

In the communications example the IRR was 15.85%, so that, at an MARR of 15%, the project is just acceptable.

11.4 Profitability Index

Another investment measure is the Profitability Index. This is defined as:

Profitability Index = Earnings Net Investment / Investment

The calculations are based on discounting at the MARR. For a project to be acceptable, its Profitability Index must be greater than 1. Competing projects can be ranked by their profitability index.

Figure 11.8 shows the calculation of the Profitability Index for the Communications System Example. The investment of $2,500,000 is at C4, the returns are at D5 to H5. The NPV of the returns is calculated at B6 using the NPV function and the MARR interest rate. Profitability Index is calculated at B7. The Profitability Index is slightly greater than 1, which we expect as the IRR is slightly greater than the MARR.

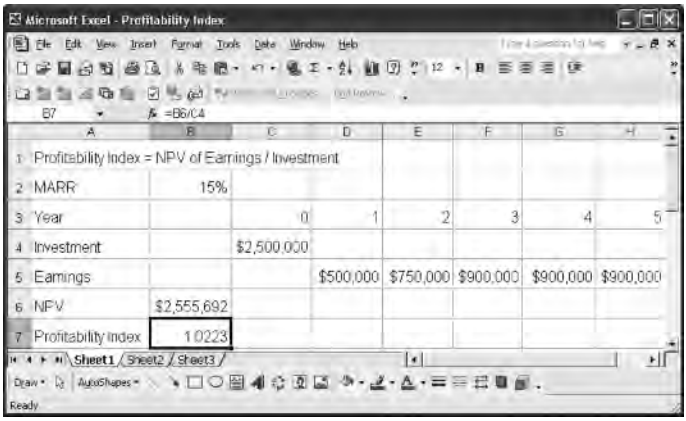


Fig. 11.8 Profitability index

11.5 Project Financial Measures

The following project financial measures have been outlined. Here we summarize some of their features. In practice we may evaluate several of the measures to help us in our investment decisions.

a. Net Present Value NPV: This is the only measure that indicates the size of a project.
b. Payback Period: Gives an indication of how soon we expect a project to be "in the black". It is not sensitive to revenue or costs estimates far out into the future.
c. Internal Rate of Return IRR: Probably the most important measure from a business viewpoint. When compared with the Minimum Acceptable Rate of Return (MARR), it indicates whether a project is a financially worthwhile investment.
d. Profitability Index: Simpler in concept than the IRR, but plays the same role in estimating the financial viability of a project.
e. Value to Infinity: Appeals to the long term thinker.

11.6 Comparison and Selection of Projects

In making project comparisons it is important to ensure that the options are treated comparably in relation to:

- Starting conditions;
- Ending conditions;
- Project duration and duration of service;
- Performance and output achievable.

The suggested basic method is to rank projects by their Profitability Index at the Minimum Acceptable Rate of Return. Where different production capacities are involved we need to consider cost per unit of production.

Projects may not be mutually exclusive, so that the choice of one project may mean that one of the others is not needed, or has to be modified. In which case a more complex multiple evaluation is required. A useful approach, particularly in complex cases is "With and Without" analysis. This considers the future scenarios with the project and without the project.

11.6.1 Planning Horizon

In analysing an investment project we need to choose a planning horizon or planning cycle. Care must be exercised to ensure that the choice of horizon does not

bias the result. Calculating an NPV for a finite horizon is the easiest method to comprehend. Be careful to set reasonable terminal values, such as written down values or resale values, depending on the age of items at the horizon. Discounting makes terminal values less critical in long projects. Annualized costs are useful as a basis for comparing costs incurred with differing life cycle durations.

11.7 Leasing

Lease costs can be expected to be higher than costs of ownership because the lessor needs to make a profit. Compare the lease cost rate with the EAC of ownership, or compare the total leasing cost with the NPV of ownership over the corresponding period. In a long lease, the lease cost will normally rise with inflation, whereas the capital cost of acquisition, and any interest charges or repayments, remain linked to the original purchase price. The simplest example of this is in a renting versus buying a house. Over a long period rents will rise but the mortgage repayments remain the same. However, several advantages of leasing can offset the higher cost. Leasing:

a. Avoids a capital requirement. This is an advantage if there is a restriction on available capital.
b. Avoids long term commitment, providing flexibility
c. Reduces fixed costs. The fixed costs associated with the equipment become the responsibility of the lessee;
d. May be the cheapest way to meet a short term requirement;
e. The whole cost is tax deductible in current year.
f. Risk in equipment reliability and performance is transferred to lessor.

A leveraged lease is a partial lease/purchase, where the lessor borrows part of the purchase price of the asset. This allows the lessor to obtain tax deductions associated with buying and owning the asset, such as depreciation and interest charges, whilst still enjoying the features of leasing.

11.8 Fixed Costs, Variable Costs and Breakeven Analysis

Fixed costs are costs which do not vary with the volume of business. Variable costs do vary with the volume of business. Examples of fixed costs are:

- The interest on loans for the purchase of plant or buildings;
- The cost of inspection of a boiler which is required to be carried out annually, regardless of the extent of utilization of the boiler.

Examples of variable costs are:

- Costs of materials used in manufacturing;
- Fuel costs which depend on volume of production.

The profit made by a company in a given year is based on the sales revenue minus the sum of variable and fixed costs. Products have an operating profit margin, given by their selling price minus the variable cost of production. As a year proceeds and sales are made, the cumulative operating profit increases, initially to cover the fixed costs and then to yield an overall profit. At a given operating margin, a business is more assured of avoiding a loss making situation if its fixed costs are low. This also applies even if the reduction in fixed costs causes a moderate loss in operating margin. Figure 11.9 illustrates the situation.

For this reason, there is always a desire to reduce fixed costs. This can lead to pressure to reduce maintenance costs, which often include a large element of fixed costs. But there is then the danger that if the maintenance budget is too low, greater losses will occur, due to lack of machine availability, and that catastrophic failures may occur. Awareness of the fixed cost issue helps managers to assess the role of fixed and variable costs in budget setting.

Leasing, renting and outsourcing are activities that convert fixed costs to variable costs. They give a business greater flexibility in the event of a downturn in sales. However, if business is good, they tend to reduce profits by being more expensive than direct ownership.

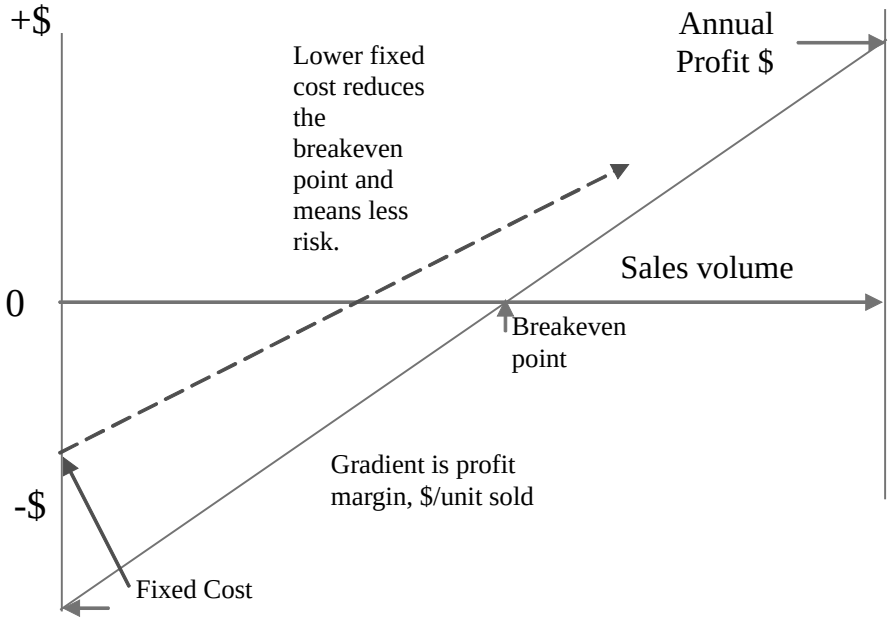


Fig. 11.9 Fixed and variable costs

11.9 Financial Analysis of a Turbo-Generator Project – Exercise

An electric power generation company can install a small gas turbine powered generator at an initial cost of $15 million, to provide peak load power. The revenue from the sale of electricity from this plant, and the corresponding expenses have been estimated, on an End of Year basis, as shown in the following data table.

Year	Revenue ($M)	Expense($M)
1	12	5
2	12	5
3	13	6
4	13	7
5	14	8

The Minimum Acceptable Rate of Return used by the company is 15%. Calculate the following.

a. The net present value of the project over 5 years at a cost of capital of 8% ($11.53 million).
b. The payback period (3 years).
c. Show that the internal rate of return over five years is approximately 35%.
d. What is the value of the project to the company, over and above the minimum acceptable return ($7.40 million).

Chapter 12
Cost-Benefit Analysis

"A cynic is a person who knows the price of everything and the value of nothing"
Oscar Wilde

Chapter Aim: The aim of this chapter is to discuss situations where the benefits of activities are not measurable in terms of direct financial returns. We then indicate how asset management decisions may be approached in these cases.

Chapter Outcomes: After reading this chapter you will be aware of those areas where benefits are wholly or partly of a nature which not readily quantifiable in financial terms. You will learn about how to approach problems of this type and how to carry out cost-benefit analysis using a planning balance sheet.

Chapter Topics:

- Introduction and reference
- Non-financial benefits
- Cost-benefit analysis
- Needs and wants
- User pays principle
- Measures of benefit
- Cost benefit analysis steps
- Planning balance sheet
- Cost benefit spider diagram
- Regional health clinics exercise

N. A. J. Hastings, *Physical Asset Management*,

12.1 Introduction and Reference

Cost-benefit analysis is a major factor in asset developments which have environmental or social impacts. A detailed treatment of these issues is given, for example, by A.S. Goodman and M. Hastak in "Infrastructure Planning Handbook", particularly chapters 11 to 13. The aim here is to present a basic outline of the concepts used in approaching cost-benefit analysis.

12.2 Non-Financial Benefits

Not every worthwhile project has purely financial drivers. The following are example of types of project where there are non-financial benefits, or benefits which are hard to quantify in financial terms.

- Provision for community needs, such as health, educational, recreational or sporting facilities and general-user infrastructure. This is a major area where cost-benefit analysis is an issue.
- Meeting regulatory requirements. This is usually in relation to technical, health, safety or environmental considerations and may include the identification of, and compliance with, technical regulations or standards.
- Value preserving or protecting activities, in that they reduce the probability of or effects of deterioration, failure, accidents, faults, fatigue or delays. Paragraph 10.8 which discuss the revenue impact of downtime may assist in evaluating the benefits of these activities.
- Improvements in layout, storage, materials handling, access, communication, good housekeeping or simplifying operations.
- Exploratory or pre-feasibility studies which may or may not lead on to business generating projects, examples; geological evaluation of a prospective mineral area; evaluation of a condition monitoring technique in a particular application.
- Research with the aim of furthering knowledge, but without a specific, predefined financial motivation.

12.3 Cost Benefit Analysis

Cost Benefit Analysis is the evaluation of alternative scenarios where the outcomes involve both financial and non-financial benefits and dis-benefits. The aim is to strike a balance between the financially quantifiable and the more subjective aspects of an issue.

Examples occur particularly in areas involving the environment and in public works. An example is the Brisbane – Gold Coast freeway, the route of which was changed to protect the habitat of koala bears, though this was only done after the

State government had been voted out by the pro-koala lobby. Another case is the Mullum Mullum tunnel in Melbourne which was created to avoid disturbing a flora and fauna sensitive area. The cost of these route choices was significantly higher than the minimum cost alternative, but was considered acceptable by the general community. With electricity transmission lines there is often public resistance to the creation of new routes, and it is easier to upgrade an existing route than to create a new one. However, almost every project of any size gives rise to protests, and there is a general awareness that costs and consequences of loss of service are factors that cannot be simply ignored.

12.3.1 A Basic Example

The problem addressed by cost-benefit analysis can be characterized by the following scenario based on options for a road building project. The cost-benefit analysis here is looked at from a general community perspective. The financial analysis of the project as an investment for a toll road would focus financially on construction cost versus toll income, but may include a contribution from government in recognition of amenity value. The following options, costs benefits and dis-benefits exist for the project.

1. Do not build the road. This is the base case against which the other options are compared.
Cost. Zero
Benefit. Zero
Dis-benefits: Traffic congestion and environmental impact on existing roads.

2. Build a tunnel.
Cost. $2,000,000,000, Toll of $5 per vehicle.
Benefits: Reduced traffic congestion and environmental impact on existing roads. Reduced travel times for vehicles, leading to greater general efficiency of movement and trade.
Dis-benefits. Nil.

3. Build road through parkland.
Cost. $1,000,000,000. Toll of $2.50 per vehicle
Benefits. Reduced traffic congestion and environmental impact on existing roads. Reduced travel times for vehicles, leading to greater general efficiency of movement and trade.
Dis-benefits. Reduced area of parkland for community. Impact on wildlife habitat.

4. Route the road through an existing developed area by compulsory purchase of land and properties.
Costs. Road building $500,000,000, Compensation to existing property owners $200,000,000. Toll of $1.90 per vehicle

Benefits. Reduced traffic congestion and environmental impact on existing roads. Reduced travel times for vehicles, leading to greater general efficiency of movement and trade. Property owners who are compensated can redeploy their part of the cost and this is therefore a financial transfer rather than a sunk cost.
Dis-benefits: Impact on habited areas close to route.

The point of cost-benefit analysis is that there is no simple financial solution, and that a judgment must be made between options that involve some well defined costs, some less well defined financial costs, revenues or transfers, and some subjective benefits and dis-benefits.

12.4 Needs and Wants

In cost benefit analysis it is desirable to recognize the difference between needs and wants. Thus, a community *needs* an adequate and healthy water supply, but may also *want* to preserve swamp land for frogs. Of course, this is also an issue of priorities, with an assumption in the frog case that the humans are more important than the frogs. Ideally, a balance of expectations must be struck.

We should aim to increase combined economic and social benefits to the community as a whole. It helps if we enable members of the community to participate in selection and prioritisation of projects, but it is likely that some people will oppose any given outcome. In a democratic system, if the legal rules are followed, the decisions of the elected government can reasonably override the objections of a few protesters. Public education regarding the various options will help to achieve a solution which reflects the balance of community priorities.

A Value Engineering style of analysis can be useful in refining options in relation to cost-benefit based public sector developments and a possible questionnaire is shown in Fig. 12.1.

12.5 User Pays Principle

Cost benefit analysis is, by definition, applied to areas where not all the issues are financially tractable. Nevertheless, it should be recognised that money represents a broadly based measure of "good" and a financial approach should not be abandoned too lightly. Any thing that can reasonably be costed should be costed. The User Pays principle should be maintained, that is, those who benefit from an asset or service should expect to pay for it, though in a cost-benefit situation this will often mean that the user does not pay the full price. The amount paid by the user acts as a regulator of demand, and also guards against frivolous use or misuse. Payment rules should avoid crating situations where an organization has an open-ended commitment to provide a service at below cost. Cross-subsidization, that is assets or services being provided for one group but being paid for by another, should be kept to minimal levels. Unfortunately, those least entitled to a subsidy are often the most

vocal or politically astute in claiming it. Some acceptance of cross subsidy is, however, likely to involved in many cost benefit cases. The term postage stamp pricing applies to cases where all users pay the same price for a service, even though the cost of delivery varies.

Some people are likely to have genuine loss of amenity and in this case compensation will be a reasonable issue. It will be necessary to evaluate the claims of vocal as against non-vocal groups and to deal with the NIMBY or Not In My Back Yard effect.

12.6 Measures of Benefit

Quality adjusted life-years is a concept used in evaluating the benefit of medical treatments to patients. Other measures correspond to the types of key performance indicators discussed in the chapter with that title.

12.7 Cost Benefit Analysis Steps

Cost benefit analysis proceeds through the following steps:

a. State the objectives.
b. Obtain of basic information.
c. Identify measures to be used in evaluating scenarios.
d. Selection of scenarios.
e. Financial cost and benefits statement for costable elements.
f. Benefit and dis-benefit statements for non-costable elements.
g. Rank options.
h. Present result as a Planning Balance Sheet.

12.7.1 Planning Balance Sheet

A planning balance sheet is a statement which summarizes the results of cost benefit analysis. It typically covers the following points.

a. Identify the services which the project will provide.
b. Identify services which will be lost as a result of the project.
c. Identify the parties who will pay for services and the cost, e. g. ratepayers, taxpayers, users, non-users.
d. Identify parties who will be disadvantaged by loss of amenity,
e. Identify parties which will benefit.
f. For each service and party, specify the benefit (in money, physical or intangible terms).
g. Present the results in the form of a list of gains and losses.

Question	Comment
Is expenditure from the public purse justified for the function	
Can all or some of the function be User Pays	
Can the function be provided within an existing overhead	
Can the function replace or reduce an existing one	
Does the proposal provide an opportunity to rationalize related activities	
Are all the features requested really required	
Are the requested capacity and availability fully justified	
Can the function be outsourced	
Can economies be made in regard to development effort, materials, finishes, energy consumption, maintenance.	

Fig. 12.1 Value analysis questionnaire for cost-benefit project

12.8 Regional Health Clinics Exercise

A regional health organization is facing increased demands for services. At present, there are four small clinics in separate locations. Users are asking for reduced waiting times and for a greater range of services. There is local concern that government may close some clinics in order to save money.

In fact, government is willing to spend more money but requires a cost-benefit analysis as an input to planning. Give an outline cost-benefit analysis in dot-point form. Factors include the following:

- Large clinics can have more facilities.
- Attendees at clinics include significant numbers of parents with young children.

Options are:

1. Retain the four small clinics, and make modest improvements each clinic at its existing location
2. Create a large central facility and close the other clinics
3. Create an intermediate sized central facility and retain 3 existing clinics.

A solution in dot point form is in the exercise solutions section.

12.9 Cost Benefit Spider Diagram

The factors in a cost-benefit analysis may be represented in a spider diagram. Figure 12.2 shows a diagram for the Regional Health Clinics Example. Four factors are illustrated. The upward line represents cost, with lower cost being further from the centre. The cheapest option is Option 2 which is to have one large clinic, and the most expensive is to retain all the clinics with improvements at each location. The various other criteria are shown in the diagram. Option 3 gives intermediate results on every criterion but was ultimately chosen as the best option. Option 3 has the benefit of an improved service range at the main location without major impact on user travel.

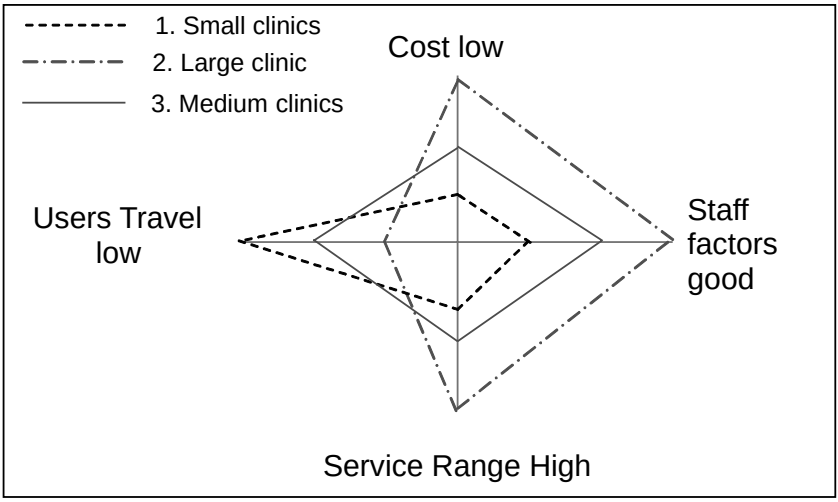
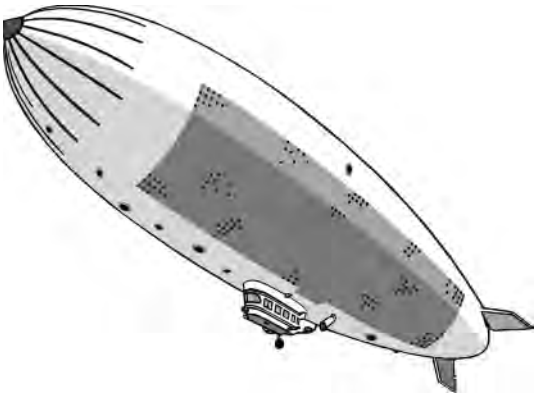


Fig. 12.2 Cost benefit spider diagram for health clinics

Chapter 13
Risk Analysis and Risk Management

The risk in a project is proportional to the square of the hype associated with it.



Chapter Aim: This chapter introduces the concept of risk, gives references to standards and major documents which deal with risk, and defines terms relating to risk. The procedures in the management of risk are then outlined and the legislative approach to risk is discussed and illustrated by an example. Various types of risk are described, and hazard analysis and the assessment of consequences are discussed. Factors in mitigating risk and contingency planning are presented and an example of the use of layer of protection analysis is given. The chapter concludes with an example of risk analysis and management in a water supply system.

Chapter Outcomes: After reading this chapter you will know how to analyse and treat risk. This will include an awareness of the legal approach based on meeting duty-of-care and regulatory obligations, and the analysis and assessment of risk in relation to projects and to plant and machinery. You will be aware of techniques of hazard analysis, the assessment of consequences, the use of contingency allowances

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and of methods of mitigating risk. You will have seen how risk analysis was used in a water supply system application.

Chapter Topics:

- Introduction
- Definitions
- Management of risk
- Legislative approach
- Types of risk
- Hazard analysis
- Consequences
- Risk matrix
- Contingency allowance
- Mitigating risk
- Contingency planning
- Quantitative risk analysis
- Layer of protection analysis
- Safety integrity level
- Event trees
- Project risk examples
- Water supply system example

13.1 Introduction

Risk is concerned with situations where an adverse event may occur. Risk is a very broadly based concept, and one whose range has expanded in recent times to cover everything except a racing certainty. Zealous commitment to a project and the wide engagement of senior personnel and a range of high level stakeholders make it harder to admit and avoid risk. Had the voyage of the Titanic not been such a high profile event it is most probable that the ship's captain would have slowed down and not hit an iceberg at fatal speed.

The following documents deal in detail with the issue of risk in a variety of contexts.

- AS4360. Australian Standard for general risk analysis and risk management
- AS3931 or IEC60300-3-9. Risk analysis of technological systems.
- IEC61882:2002. Risk analysis in chemical plants and other high risk environments: HAZOP – Hazard and Operability Studies. Standard: Hazard and Operability Studies Application Guide.
- API 580 and API 581 Risk Based Inspection. Oil and gas industries. Many publications and training programs from the American Petroleum Institute.
- Lees' "Loss Prevention in the Process Industries" published by Elsevier, (3 volumes) provides a comprehensive cover of risk.

In risk analysis we are concerned with identifying plausible risks and in reducing their potential effect through mitigation policies. Events can have favourable as well as unfavourable consequences, for example, a construction project may encounter good or bad weather. Risk analysis should assist us to avoid adverse effects, and to be prepared to deal with them when they occur. Risk assessment involves a willingness to consider possibilities which we would rather not consider.

13.2 Definitions

AS4560 Risk Analysis defines a range of terms relating to risk, including the following.

Risk: the chance of something happening that will have an impact on objectives.
Hazard: a source of potential harm.
Consequence: the outcome of an event in the form of loss, gain, disadvantage, advantage or injury.
Likelihood: a qualitative description of probability or frequency.

13.3 Management of Risk

Risk management involves the recognition of risk as an issue and the creation of roles and responsibilities in relation to risk. A hazard analysis is undertaken in which we make a list of the risks, known as a risk register. We then analyse the

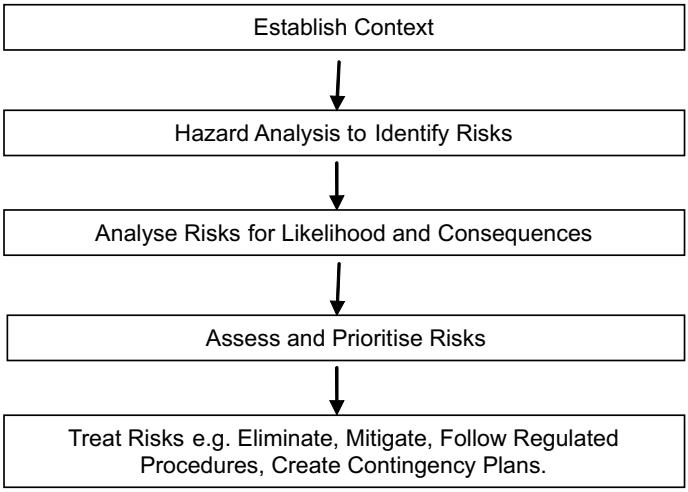


Fig. 13.1 Risk management outline

risks, considering their significance and how they may be overcome or mitigated. We then create the necessary controls, procedures and contingency plans. A general outline of the procedure is shown in **Fig. 13.1**.

In setting roles and responsibilities the general principle is that managers with budgetary authority over an area have responsibilities for risk in that area. This is because budgetary authority is required in order to take the steps necessary to address any risk issue.

Specialist advice is also likely to be required in relation to technical functions and specific hazards. For this purpose we may create a company-wide risk assessment role which specialises in understanding the types of risk that occur in the business. This can be a task of the asset management group, or the relevant asset manager, but it is also important to engage local operations personnel. Specific equipment specialists, legal liability specialists and health, safety and environmental specialists may be engaged as necessary. The risk assessment team advises on the analysis of risk, risk mitigation activity, and contingency plans and recommends funding support to the regular budgetary authority, such as a plant manager.

13.4 Legislative Approach

The legal approach to risk centres on meeting prescribed requirements of legislation, standards or good practice. It is important to be aware of legislation and related standards which apply to our activities, and to comply with these. The documents listed in the Introduction section of this chapter form a useful starting point, and some other relevant standards are listed in the Standards section at the end of this book.

A *duty of care* exists (under Common Law) where there is a foreseeable and predictable cause and a hazardous effect and where it is practicable to remove the cause or control the effect. If a zoo keeps a tiger, it is up to the zoo to ensure that the tiger does not get out and kill someone. Conforming to an appropriate regulation can provide a legal defence in a prosecution for breach of an obligation. Where there is no defined regulation, you must be able to show that you took reasonable precautions and exercised due diligence in managing exposure to risk. If the procedures associated with the precautions are not documented then they do not exist!

Thus maintenance specified by a manufacturer must be carried out unless a convincing reason otherwise can be presented. The maintenance that is carried out must be recorded. Regulations applying to the design or operation of equipment must be complied with, and good practice must be followed in regard to issues such as operation and supervision by competent persons, extending if appropriate to assessment of equipment condition by technically qualified staff.

Figure 13.2 illustrates the issue of satisfying a duty of care in an application involving an electricity cable. A contractor digs up and severs the cable causing damage and disruption to businesses. The contractor argues that the electricity company which owns the cable has failed in its duty of care. The duty of care of the elec-

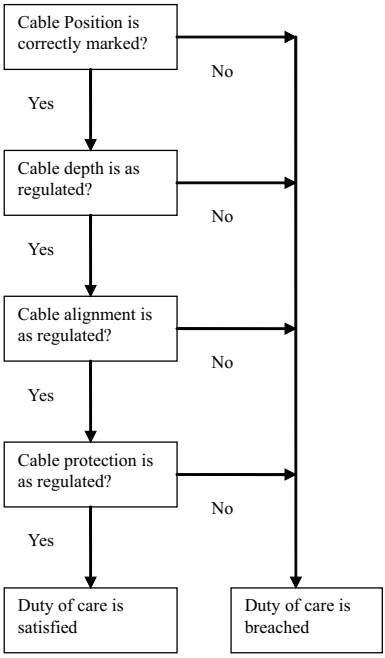


Fig. 13.2 Satisfying a duty of care

tricity company covers four regulated features; marking the position of the cable; placing it at the correct depth; aligning it correctly in relation to nearby buildings and providing protection in physical and electrical terms (e.g. circuit breakers). If the electricity company has carried out these duties correctly it will have a presentable defence against the contractor's arguments. Probabilistic risk analysis is not highly regarded from a legal viewpoint.

13.5 Types of Risk

13.5.1 Sovereign Risk

Sovereign risk is risk associated with high level events outside your organizational control, particularly those involving government actions.

- Government changes the law, the regulatory rules or the level of subsidies after you have invested;
- Political change of sentiment;
- War and peace.

13.5.2 Solution Risk

Solution risk is where the expected solution to a problem or the technology underlying a project turns out not to work. Solution risk is easy to overlook or underestimate. Many major losses have occurred because the wrong solution was selected for a development. Project managers should be aware of this issue and avoid excessive commitment to a solution which is in fact unproven.

13.5.3 Technical Development Risk

Development work is notoriously risky. Assumed technical progress is often not realized. Projects involving software, combining software and hardware, or integrating of two or more systems are particularly difficult. It is advisable to regard development strictly as development, and not to jump into a production phase before a concept is proven.

13.5.4 Performance Risk

The performance resulting from development may prove to be unsatisfactory. Production or support aspects of a development may prove unsatisfactory, or new developments may overtake the original concept.

13.5.5 Commercial or Financial Risk

Sales may not be realized – fewer buyers or users may appear than forecast. The profit margin will then be eroded by lack of sales. Competition is another factor that can depress sales. Costs may be higher than forecast, leading to an eroded profit margin. Anticipated capital funds may not become available.

13.5.6 Administrative Risk

Risks can arise from events inside your organization but outside your project. Other departments do not commit; there are delays in or lack of approvals, and delays in or non-delivery of related activities needed for your project. A rendezvous is a weakness in a plan.

13.5.7 Safety and Environmental

Safety and environmental impact are often risk factors. Extensive legislation and procedures relating safety and environmental protection are normally specified for any hazardous industry or occupation and the relevant rules must be identified and followed.

13.5.8 Supplier Risk

A supplier may fail to deliver, or may delay delivery. There may be changes to pricing or level of support.

13.5.9 Resources

Physical facilities or human resources in design, development, acquisition, production, operations, or sales may fail to eventuate.

13.6 Hazard Analysis

Hazard analysis means considering all the things that might go wrong and making a list of them. This is a basic step in addressing risk. Hazard analysis should be carried out by persons with a thorough knowledge of plant or service characteristics and methods of operation – steady state and transient. Formal processes have been developed and extensively documented to assist with hazard analysis, including the following.

- Hazard and Operability Analysis (HAZOP)
- Failure Mode and Effects Analysis (FMEA),
- Reliability Centered Maintenance (RCM)
- Risk Based Inspection (RBI)

13.7 Consequences

A *consequence* is the result of an adverse event occurring. Consequences associated with risk include the following:

- loss of business, at minor or major level;
- legal liability and costs;

Fig. 13.3 An adverse consequence of risk

- loss of reputation;
- lost production;
- project failure;
- project delays or additional costs;
- emergency service costs;
- repair costs;
- secondary damage;
- adverse environmental impact;
- injury
- loss of life.

Figure 13.3 illustrates an adverse consequence of risk.

13.8 Risk Matrix

Judgment may be assisted by an agreed scaling, such as that shown in the risk matrix, Fig. 13.4.

Likelihood	**Consequence**				
	Insignificant	**Minor**	**Significant**	**Major**	**Severe**
Almost Certain	Medium	Medium	High	High	Extreme
Likely	Medium	Medium	Medium	High	Extreme
Moderate	Low	Medium	Medium	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium

Fig. 13.4 Risk level matrix (AS4360)

The various levels of risk call for action to be taken as follows:

- Extreme: Immediate executive action is required
- High: Executive action is required
- Medium: Management assignment of action and responsibilities is required
- Low: Manage using routine processes.

13.9 Contingency Allowance

Contingency allowances are the most common way of allowing for risk in projects. Typically, 10% to 20% contingency funds will be allowed in project budgets. The level depends on an assessment of the risks.

13.9.1 Retirement of Risk

When a risk is no longer relevant, the corresponding contingency allowance should be retired. Contingency allowances are best held on a central basis, as this allows for flexibility. However, the existence of contingency allowances should not be taken as a substitute for good management. An issue that arises is whether, as contingency funds are retired, they should be applied to increasing capability within the same project or should be returned to higher levels for re-allocation. In principle, return to higher level is the norm, but project managers often put forward strong and successful cases for using retired contingency to enhance their particular project.

13.10 Mitigating Risk

The primary reason for considering risk is in order to avoid undesirable consequences. This means that we need to take steps to eliminate, mitigate, or reduce, risk. At the general business level, some techniques which we may use to reduce risk are as follows:

- Contract terms to limit risk.
- Delphi technique. A group of experts is used to assess risk. An example is assessing the potential market for new products, e. g. new versions of mobile phones.
- Use skills of experienced estimators and managers in creating and managing projects.
- Record and apply corporate knowledge of previous risks.

In the remainder of this section we provide a brief resume of more technical techniques in the risk mitigation area, but note that it is important in practice to be aware of and follow the detailed techniques relevant to the actual situation of any particular industry or service.

13.10.1 Design for Safe Operation

The following are some examples for techniques which can be applied in design for safe operation.

- Procedures and action to be taken in response to specific readings of instruments or signals, e. g. pressure, temperature
- Setting control trips
- Selection of automatic control and operation overrides
- Establishment of safety limits on plant characteristics, e. g. thinning of pipes
- Inspection practices and follow up action
- Maintenance tasks and intervals
- Design of operation interlocks
- Design and operation of protection systems
- Automatic shutdown
- Restriction of plant operation
- Formulation of recovery methods
- Root cause analysis of trips and faults.

13.10.2 Facility Siting and Layout

Ref: OSHA (USA) CFR 1919.119. API RP-752. Consider process hazards, including fire, explosion and toxicity, in relation to:

- Site workers;
- Occupants of buildings;
- Nearby residents;
- Location of control room;
- Access to emergency facilities.

13.10.3 Fitness for Service Assessment

Fitness for service criteria are to be established and applied to assets. These will specify inspection and performance standards relating to such issues as the following. Reference should be made to industry standards where appropriate. For example, for the oil and gas industry, see API 579.

- Thickness of pipes and pressure vessels;
- Cracks, e. g. in structures, cranes;
- Misalignment;
- Vibration;
- Levels of corrosion or wear;
- Insulation resistance in transformers and other electrical equipment.

13.10.4 Safety Practices

Identify, publicize and enforce good safety practices in relation to the following:

- Standard operating conditions
- Actions when deviations occur
- Incident reporting procedures
- Accident reporting procedures
- Isolation procedures
- Emergency procedures
- Electrical safety
- Radio use
- Fire protection
- Driving rules
- Manual handling rules
- Use of protective clothing: Helmets, Footwear, Goggles, Gloves, Ear Muffs and Respirators.
- No smoking areas.
- Behaviour : no horseplay, alcohol, drugs, walk don't run, hold the hand rail.
- Good housekeeping
- Colour coding of pipes and valves
- Paint the name of the fluid inside on the pipe or valve
- Label equipment which is supplied from a switch or valve
- Identify water quality as potable or otherwise
- Remove hazardous material
- Check that concentrations of toxic substances are low enough for safety
- Remove items that may collect foreign objects, toxic material or corrosion e. g. dead ends of old pipes
- Keep unnecessary people away
- Have a works modification approval procedure and form
- Use portable gas detector alarms
- Avoid having welding or grinding sparks in potentially dangerous places

13.10.5 Tags

Tags are used to as a sign that equipment is out of service or under repair. Tags indicate that equipment is not to be switched on except by, or on the authority of, the person who placed the tag.

- *Out of service tag*. Placed on a switch indicating plant must not be switched on because needs repair. This is to prevent damage to plant.
- *Personal danger tag*. Placed on a switch indicating that a (named) person is working on the machine. This is to prevent personal injury.

13.10.6 Permits

A system of permits is required covering work in hazardous circumstances, such as:

- Confined space
- High level
- Ground opening
- Hot work
- Permit to work (from operations)

The person who signs the permit should always check first to assess the potential hazards involved and the current conditions. For confined spaces there should be a standby person. Possible sources of danger include low level of oxygen; toxic gas; flammable gas.

13.10.7 Danger Signs

Operators and maintainers should have a general awareness of danger signs such as:

- Leaks
- Alarms
- Gauges indicating out of specification
- Flames
- Hot spots
- Ice where no ice should be
- Vapour

and must be aware of what action to take in response.

13.11 Contingency Planning

Contingency planning is making plans to be brought into effect if adverse conditions eventuate. An example from a contingency plan is shown in Fig. 13.5, which shows the locations to be adopted by crew members of a passenger ferry in the event of various types of emergency. Further detailed procedures for different circumstances would form part of the contingency plan.

Person	Fire	Collision	Mechanical Failure
Captain	Bridge	Bridge	Bridge
1st Officer	Direct fire fighting priorities	Assess and report damage status	Assess and report navigational status
2nd Officer	Report fire status	Monitor external danger	Monitor external danger
Engineer	Engine room	Damage site, direct action	Failure site, direct repairs
Assistant Engineer	Manage fire fighting	Engine room	Engine room
Crew	Fight fire	Repair activities	Repair activities
Radio Op.	Send alarm	Send alarm	Notify status
Chief Steward	Control passengers	Control passengers	Communicate with passengers
Stewards	Lifeboat stations	Lifeboat stations	Assist passengers

Fig. 13.5 Contingency plan for passenger ferry

13.12 Quantitative Risk Analysis

Quantitative risk analysis works in terms of a definition of risk as a probability. Concepts in a quantitative approach are,

- *Probability of occurrence:* The probability that an event occurs in some defined period or situation of risk.
- *Occurrence Rate:* The average number of times an event occurs per year, or other time interval.
- *Risk-cost:* the probability that an adverse event occurs multiplied by the cost if it does.
- *Risk-cost per year:* The occurrence rate of events per year × $ cost per event.

Techniques for estimating risk-cost include the following:

- statistical analysis of failure and successful performance data
- “gut feel” based on experience and judgment
- use of event trees, or simulation.

Although risk-cost can be a guide to our thinking, the product of a very low occurrence rate multiplied by a very high cost does not always result in a meaningful number when related to conventional financial analysis.

The risk-cost of business liabilities can be difficult to assess. It is desirable to get senior management to make an assessment of potential risks and costs, as middle management can waste time and resources on excessively detailed studies, when a decision, say to replace or retain a certain group of old equipment, may be quickly made by a senior manager with a more overall view of the situation.

13.13 Other Methods

Other methods of risk analysis involve a more analytical or detailed level of approach. These include:

a. Use scaling system for factors such as event probability and severity, as in Failure Mode and Effects Analysis (FMEA)
b. Application of hazard indices, see for example, Lees' op cit, Volume 1, Chapter 8.
c. Quantitative analysis of wear rates based on materials and operational temperatures and pressures, as applied in Risk Based Inspection
d. Fault trees analysis, described, for example, by J.P. Bentley, "Quality and Reliability Engineering, Longman.
e. Sensitivity analysis for various scenarios: Optimistic, Best Estimate, Pessimistic
f. Risk adjusted discount factor. The discount factor is increased to penalize risky investments;
g. Simulation modelling including reliability block diagrams

13.14 Layer of Protection Analysis

A layer of protection is something that reduces risk by a factor of 10. Safety is improved by adding Layers of Protection. An example is a pressure vessel which could explode causing damage. To protect against this we have layers of protection as shown in Fig. 13.6.

Figure 13.6 represents a situation where an overpressure occurs in a vessel in a chemical plant. The initial layer of protection is provided by a gauge and a warning light on a control panel. An operator should respond to this warning by taking action to make the situation safe. If the operator does not act an audible warning signal sounds to attract the attention of the operator. This is the second layer of protection. If the operator still does not act, a safety valve opens, and if this does not work or does not reduce the pressure sufficiently, an automatic local or general shutdown occurs.

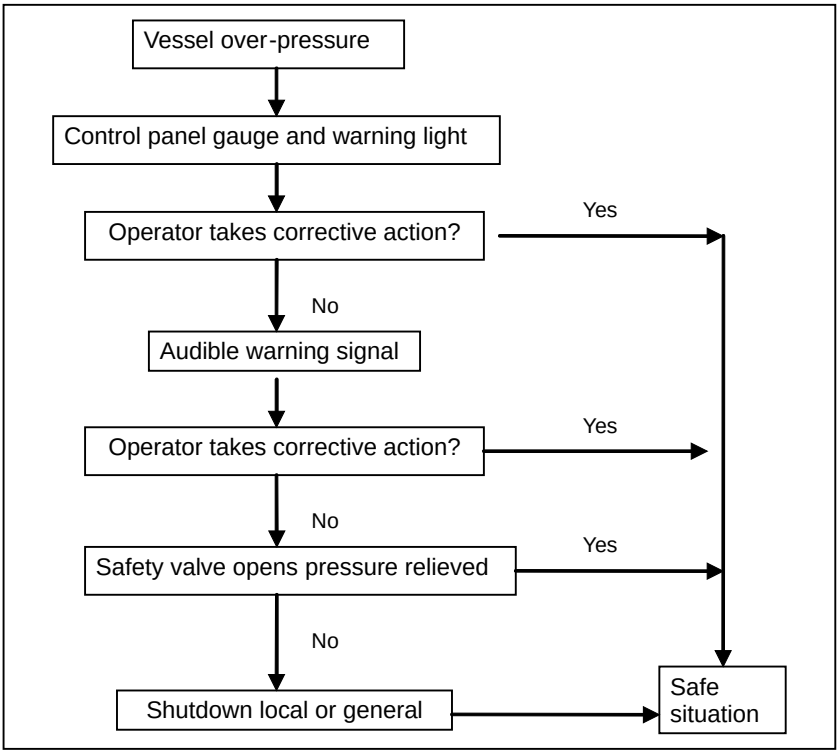


Fig. 13.6 Layer of protection analysis

13.15 Safety Integrity Level

The Safety Integrity Level of a system is a measure of its relative safety as achieved by the application of Layers of Protection;
Steps include:

- Identify safety critical equipment, including both primary equipment and safety devices such as pressure relief valves or fire pumps;
- Carry out fault tree analysis to establish risks;
- If necessary, modify the design to add layers of protection until the required safety integrity level is reached;
- Create and apply checks, tests and maintenance tasks so that the safety integrity level is maintained.

13.16 Event Trees

An event tree is a systematic approach to assessing the probability of rare events. It helps us to assess risk and risk-cost. It also provides a basis for discussing and agreeing on risk assessments, or for evaluating alternative risk scenarios and judgments.

Event tree analysis helps us to decide:

- whether a risk is at an acceptable level
- whether a risk-cost is at an acceptable level
- what improvements can be made to reduce risk or risk-cost.

The steps involved in event tree analysis are:

- defining potential events and their relationship in a "tree" structure
- assigning conditional probabilities to events
- calculating total probabilities of events
- Assessing costs of events and then using the tree to calculate risk-costs.

13.17 Project Risk Examples

In an acquisition project, machinery is being purchased from an overseas supplier whose technical documentation, operating procedures and training manuals are in another language. A local contractor has been engaged to provide translation of the documentation, and adaptation to local technical and environmental standards. The possibility that the local contractor has bitten off more than he can chew constitutes a risk in the overall acquisition and deployment.

A number of complex machines are being made to order. Demand on the manufacturer for products generally is rising, and there is a risk that our production will be delayed. Although this will give rise to cost penalties, the negative impact on our company may be significant.

Equipment may fail acceptance requirements. This is always a possibility, but the position will become clearer from early results and supplier responses to problems.

13.18 Water Supply System Example

The following example, relates to the assessment of risk in a water supply system. The system involves pumping water from a river to supply an irrigation system and a town. A flow chart of the system is shown in Fig. 13.7. The heavy arrows indicate water flows.

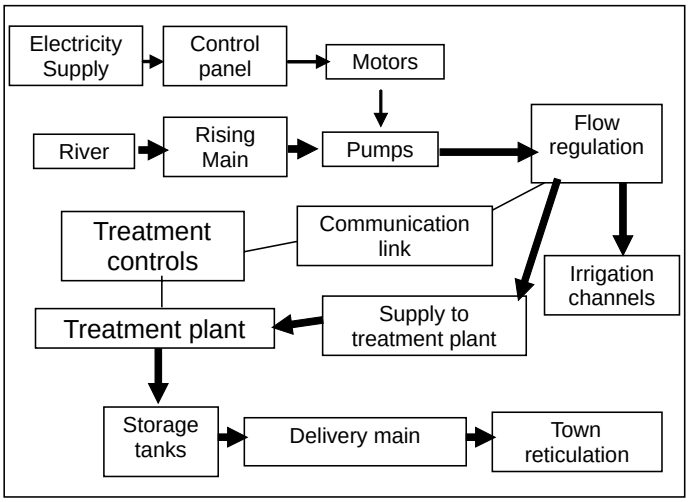


Fig. 13.7 Flow chart for water supply system

The hazards were identified using the system flow chart and fault trees. The flow chart identified each component of the system e. g. pumps, rising main, pipes, valves, channels, power supply, switchboard, control system, communication system.

Fault trees were then used to identify possible faults in each component. For each possible fault, risk assessments were then made. The results were recorded on forms using the concepts suggested in AS4360, although the actual form layouts were different. Examples of completed forms are shown in Fig. 13.9.

13.18.1 Hazard Analysis

In this application the fault or hazard rate assessments were based qualitatively on the scale shown in Fig. 13.8. The scale was refined by allowing non-integer in the range 0 to 1 to reflect varying degrees of likelihood of rare events.

The nature of the risks was assessed under the headings:

- Safety,
- Cost,
- Function,
- Environment

The consequences were assessed on the same 1 to 5 scale as Fig. 13.8, giving a risk rating under each heading.

1=Very Low,
2=Low,
3=Medium,
4=High,
5=Very High

Fig. 13.8 Risk ranking scale

A risk rating was then calculated for each potential fault using the formula:

Risk Rating = Hazard Rate × (Safety + Cost + Function + Environment.)

For example in Row Reference 3 of the Risk Register in Fig. 13.9 the following hazard analysis is shown:

a. Hazard is "Unable to Supply Water Due to Pump Failure"
b. Hazard Rate: 3 = Medium
c. Consequences:
d. Safety: 1 = very Low
e. Cost: 4 = High
f. Function: 5 = Very High
g. Environment: 1 = Low

Risk Rating = Hazard Rate × (Safety + Cost + Function + Environment)
= 3 × (1 + 4 + 5 + 1) = 33

The highest score (worst case) is a rating of 100.

Mitigation for this hazard was to have a trailer-mounted standby pump available to cover a number of locations and applications.

13.18.2 Risk Treatment

Examples of a risk treatment analysis and risk treatment plan are shown in the second and third parts of Fig. 13.9. The example focuses on the risks associated with failure of the control switchboard of the water supply system. This is the hazard listed at Ref. 7 in the risk register on the first page of Fig. 13.9 Water supply risk documents (3 pages). In this study the risk of loss of the switchboard, due to a fire, for example, was considered significant, and a risk treatment analysis was developed.

Risk treatment analysis considers the options for treating the various risks. An action plan documents the management controls to be adopted and lists the following information:

- Who has responsibility for implementation of the plan.
- What resources are to be utilised.
- Budget allocation.
- Timetable for implementation.
- Details of the mechanism and frequency of review of compliance with the treatment plan.
- Urgent repair or replacement
- Non-urgent repair or replacement
- Plant redundancy
- Insurance spares
- Contingency plans
- Condition assessment and monitoring

13.18.3 Monitoring and Audit

Monitoring and audit records should document:

- Details of the mechanism and frequency of review of risks and the risk management process as a whole.
- The outcomes of audits and other monitoring procedures.
- Details of how review recommendations are followed up and implemented.

Risk tends to increase as items enter the wear-out phase. This is due to the long term degradation of materials such as decay of plastics and other insulating materials, rust, wear, vibration, fatigue, creep, physical impact.

Risk Register		Compiled by	NAJH			Date		
Title	Irrigation System	Revised by				Date		
Ref.	Hazard	Current Controls	Rate	Safety	Cost	Func-tion	Enviro-nment	Risk Rating = R*(S+C+F+E)
1	Unable to supply water due to leak in rising main resulting from erosion of embankment	None	2	1	5	5	1	24
2	Unable to supply water due to pipework seal failure	nspect annually	2	2	3	3	2	20
3	Unable to supply water due to pump failure	Routine maintenance	3	1	4	5	1	33
4	Flooding of property	Operating procedures	1	3	2	2	2	9
5	Unable to supply treated water to town due to control failure	Communication link	1	3	3	3	5	14
6	Unable to supply water due to switchboard minor failure	None	1	1	2	5	1	9
7	Unable to supply water due to switchboard major failure	None	1	2	5	5	1	13

Fig. 13.9 Water supply risk documents (3 pages)

Risk Treatment Schedule and Plan	**Compiled by NAJH**	**Date**	23-Dec-00		
Title: Irrigation System	**Revised by**	**Date**			
Ref. Hazard	**Current Controls**				
7. Unab e to supp y water due to sw tchboard major fa ure.	None				
Treatment Options	**Cost Benefit Summary**				
A. Upgraded f re detect on and a arm system and regu ar thermograph c mon tor ng.	A. Cost est mate $20,000 p us $3000 per year. May not ent re y prevent fa ure.				
B. As opt on A but w th add tona cont ngency p an w th jury r g sw tchboard wh ch can be act vated n 6 hours.	B. Cost est mate $30,000 p us $5000 per year. Loss of supp y for 6 hours may occur.				
C. Keep standby sw tchboard.	C. In t a cost $100,000. A so s gn f cant costs n ma nta n ng dup cate board as system deve ops.				
		Initial		**Revised**	
Implementation Recommendation:	Opt on B.	Rate	0.2	Rate	0.02
Person responsible:	Northern Eng neer ng Manager.	Safety	2	Safety	2
Action Plan Reference:	AP 4/2000	Cost	5	Cost	5
Timing:	To be n p ace by 1 Ju y 2001	Funct on	5	Funct on	5
		Environment	1	Env ro	1
		Risk Rating	2.6	Risk Rating	0.26

Fig. 13.9 (*continued*) Water supply risk documents (3 pages)

Risk Action Plan		Compiled by:		Date:
Title:	Irr gat on System	**Reviewed by:**		**Date:**
Hazard:	7. Unab e to supp y water due to sw tchboard major fa ure.	**Ref.**		
Summary	A. Upgraded f re detect on and a arm system and regu ar thermograph c mon tor ng.add tona cont ngency p an w th jury r g sw tchboard wh ch can be act vated n 6 hours.			
Ref. No.	**Proposed Action**	**Responsibility**	**Timing**	**Resource Reqts.**
7.1	Insta upgraded smoke a arm and f re detect on system	Northern Eng neer ng Manager	by 1/3/2001	
7.2	Insta carbon d ox de spray system.	Northern Eng neer ng Manager	by 1/3/2001	
7.3	Estab sh contract for thermograph c mon tor ng.	Operat ons manager	ASAP	
7.4	Comm ss on des gn and manufacture of m ted funct on standby board.	E ectr ca eng neer	by 1/2/2001	
7.5	Insta m ted funct on standby board.	E ectr ca contractor	by 1/7/2001	
	Reporting and Monitoring Required	**Responsibility**	**Timing**	**Resource Reqts.**
7.1.M	Annua funct ona check of smoke a arm and f re detect on system.	Operat ons manager		
7.2.M	Annua check of carbon d ox de spray system.	Operat ons manager		
7.3.M	Three month y thermograph c cond t on mon tor ng.	Operat ons manager		
7.4.M	Report to Northern Eng neer ng Manager when m ted funct on standby board ready for nsta at on.	E ectr ca eng neer		
7.5.M	Conf rm nsta at on of board to Operat ons manager.	E ectr ca contractor		

Fig. 13.9 (*continued*) Water supply risk documents (3 pages)

Chapter 14
Logistic Support

Chapter Aim: The aim of this chapter is to describe the factors involved in supporting physical assets from the point of introduction into service, over their life time through to disposal. These factors also influence the initial choice of equipment.

Chapter Outcomes: In the chapter you will learn that many problems in physical asset management can be reduced by considering the supportability of equipment at the acquisition stage. You will learn about the many factors that need to be taken into account in planning equipment support, and will be provided with check lists to assist this type of planning.

Chapter Topics:

- Introduction
- Value engineering
- Reliability centered procurement
- Equipment commonality
- Asset appraisal and acceptance
- Test and evaluation
- Preferred suppliers
- Logistic support analysis
- Level of repair analysis
- Integrated logistic support
- Through life support
- Supplier viewpoint

N. A. J. Hastings, *Physical Asset Management*,

14.1 Introduction

Physical assets require the support of people, services and resources of many types, including operators, maintainers, repair facilities, consumables, spare parts, documentation and training. To ensure that these supports are provided and budgeted for, several types of analysis are needed. The following techniques are applicable:

- Value Engineering – involves a critical review of features of the proposed capability to eliminate unnecessary elements and simplify things where possible;
- Equipment Commonality – aims to ensure that unnecessary equipment diversity and support systems complexity are avoided;
- Logistic Support Analysis – the detailed analysis of support requirements;
- Level of Repair Analysis – is concerned with deciding where particular types of repair will be carried out, for example, what will be done by local technicians, what by central workshops and so on.
- Integrated Logistic Support – is a system for ensuring that, once we have decided on our logistic support concept, all aspects necessary to implement it are identified and implemented.
- Through Life Support – is a concept which emphasizes the need for logistic support to extend over the whole life of the equipment. This consideration is important where contracts for support are to be let.
- Supplier Viewpoint – Under this heading we consider the issue of logistic support from the point of view of a manufacturer or supplier, for whom both commitments and business opportunities exist.

The aims of these techniques are to:

- Form a basis for planning and budgeting of equipment acquisition, operation, through-life-support and disposal;
- Optimize costs over the life cycle of equipment, and not just focus on minimizing acquisition cost;
- Get value for money;
- Avoid nasty surprises down the track.

In the case of common user equipment, purchased and used in an urban or industrial environment with many surrounding support services, the techniques outlined in this chapter are relatively easy to apply. This does not mean that the principles involved can be ignored or that it is impossible to go wrong. However, the available support of equipment distributors, manufacturers and specialized maintenance organizations can greatly reduce the extent to which asset owners need to deal with the details of logistic support. By contrast, if we are to operate away from a supportive environment, great care must be taken to ensure that the essential logistic support elements are in place.

Figure 14.1, the Iceberg Diagram, based on original by Ben Blanchard, illustrates graphically the dangers of failure to recognize the activities and costs involved in logistic and through life support of physical assets.

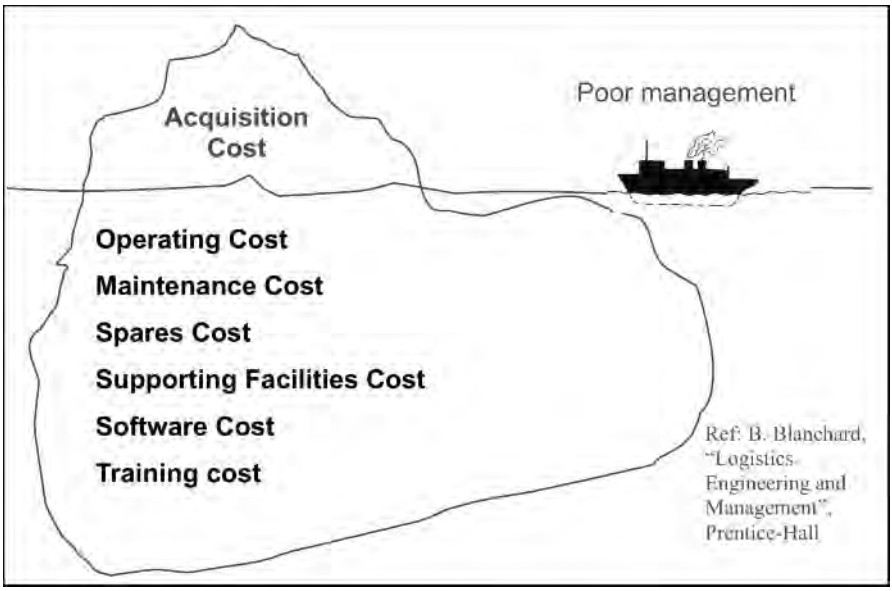


Fig. 14.1 Iceberg diagram

14.2 Value Engineering

Value engineering is a systematic process of reviewing the capability defined in the Capability Plan to see how it might be achieved in a cost effective manner. It involves asking a series of questions which in practice often lead to cost reductions, logistic support savings or design improvements. At the same time we must avoid a "penny wise, pound foolish" approach, which may make short term savings but cause longer term expense, and compromise the aims of the development. Figure 14.2 provides a check list of questions typical of value engineering.

14.3 Reliability Centered Procurement

Reliability Centered Procurement is the concept of considering the long term reliability and sustainability of equipment at the procurement stage. It involves making decisions which make it easy to subsequently maintain and sustain the equipment, and to ensure that it is reliable both initially and through life. It involves giving weight to the selection of equipment which is known to be reliable and maintainable and for which logistic support is most readily delivered. In practice this often means selecting equipment which is readily available *off-the-shelf* and which is in common use already. It involves checking for reliability and satisfactory installation at the time of acquisition. Key factors are equipment commonality, reliability and maintainability appraisal, and acceptance testing.

Questions	Comments
Can the function or equipment be eliminated	
Can the function be achieved in another way	
Is there a cheaper alternative	
Are all the features of the equipment required	
Is the capacity greater than necessary	
Can cheaper materials be used	
Can parts be standardized	
Are the finishes specified essential	
Can installation time be reduced by design changes	
Can energy consumption be reduced	
Can maintenance costs be reduced	

Fig. 14.2 Value engineering check list

14.3.1 Equipment Commonality

Commonality of equipment and systems helps to ensure a minimum of problems in operation and support. Commonality facilitates the achievement of high standards of productivity, reliability and availability, by avoiding unnecessary operational and logistic problems. It involves applying the following principles:

a. Keep to common equipment and to common systems across all sections of the organisation. This minimises diversity in operation, training and maintenance, reduces total spares requirement by type and quantity; minimises demands for tools, test equipment, range of know-how, and facilitates cannibalisation.
b. There can be negative aspects in reducing the diversity of systems to an absolute minimum. If a significant fault occurs it will affect all items, although there is then a counter argument that this will mean a rapid focus on solving the problem. It can also mean that the user is committed to just one supplier who may exploit this as a commercial advantage. A compromise is to use two suppliers, striking a balance between the benefits of diversity reduction and supplier competition.
c. Purchase items which are of a type widely used in the community – operational and maintenance skills and spares will be available and relatively cheap.
d. Purchase items locally manufactured, assembled or widely supported – operational and maintenance skills and spares will be available and relatively cheap.

14.3.2 Asset Appraisal and Acceptance

a. Set performance standards for operations, reliability and maintainability.
b. Carry out a formal appraisal of operations, reliability and maintainability. This will involve setting up a trial in order to check that equipment performance is up to expectations in terms of operating, reliability and maintainability criteria. For

equipment with design features special to your application, a Reliability Centered Maintenance approach should be adopted, reviewing equipment functions, potential failure modes, potential effects of failure including safety and environmental effects, and related maintenance or inspection tasks.

c. In assessing a new type of equipment, consider (and cost) the training and logistic support required
d. Stick to generally accepted technical standards.
e. Ensure that products are in good condition and meet necessary specifications before acceptance.
f. Pay attention to installation and set up.
g. Resist political or prestige purchases where possible.

14.3.3 Test and Evaluation

Test and evaluation criteria are required in order to ensure that equipment perform to a sufficient standard to deliver the required capability. At the pre-acquisition stage, relevant standards and tests should be specified. Ideally, testing of items should take place early in the requirements phase, so that a realistic appreciation of expectations of equipment can be formed, and test criteria specified in the contract phase. Equipment is usually specified to prescribed standards such as ISO, BS, DIN or EN. At the acquisition stage the relevant standards should be identified and specified. The standards form the basis for acceptance verification and testing. In relation to the specific application, consideration should be given to such factors as:

a. Operability
b. Functional performance
c. Reliability
d. Maintainability
e. Logistic supportability
f. Health, safety and environmental factors
g. Compatibility with, and integration with, related systems

Formal tests should be organized as part of the acquisition process, both in deciding on the acquisition and in verifying the equipment selected. At the pre-acquisition phase, a test and evaluation management plan should be created. The results obtained in the application of the test and evaluation plan should form key milestones in the subsequent acquisition process.

14.3.4 Preferred Suppliers

The principles just outlined, particularly regarding commonality, may conflict with the requirements of open tendering. A compromise position can involve the use of

preferred (or accredited) suppliers, whose technical and logistic support credentials have been established in advance.

Suppliers are invited to pre-qualify as accredited suppliers. A panel is established which determines the range and quality of equipment which a given supplier can provide, the extent and location of logistic support, and the ability to work with users to meet needs over a period of time. It is important to allow for new entrants and business transparency. The market generally should be kept informed of needs and be allowed to respond to developments and requirements as technologies evolve.

Where several manufacturers produce to an established international standard, it can be difficult to distinguish between suppliers. Life cycle costing provides a basis for taking into account factors beyond the initial acquisition cost. However, the operating expenses in the life cycle cost are often a less firm Figure than the initial capital costs. Ultimately a tender selection problem remains to be resolved by a combination of performance, cost, logistic support analysis and judgment.

14.4 Logistic Support Analysis (LSA)

Logistic support analysis is the determination of the equipment, people and facilities required to support a given capability throughout its life. Logistic support analysis is designed to determine the "what, how and where" of the provision of support resources and services for physical equipment. It is carried out in the decision making phase in which we decide the broad parameters of the provision of logistic support for our equipment. A key aim of logistic support analysis is to ensure that our assets can be logistically supported in a practical and cost-effective way. The analysis may influence the choice of the equipment itself, and can influence the nature and structure of our supporting services. LSA is concerned with:

- assessing the net maintenance and logistics load created by the asset,
- setting the maintenance and repair policies at a strategic level,
- establishing the extent and location of maintenance, repair and overhaul facilities. This may involve decisions to outsource some or all of these tasks.

Logistic support analysis starts by identifying the type and quantity of assets involved, and the utilization rate. For example, with a vehicle fleet this will mean identifying the vehicle types, quantities and average kilometres run per year. At this stage we will also identify any special environmental or operational factors that affect our analysis. This can include climatic factors such as heat, cold, dust or corrosive environments and operational factors such as equipment loading and planned equipment availability. In addition, we consider the extent to which the new equipment will replace existing equipment, and the impact that this will have on the net requirement for logistic support.

14.4.1 Logistic Support Basic Data

In order to carry out Logistic Support Analysis, basic data regarding the equipment to be supported must be established. This includes:

- Asset type
- Asset quantity
- Utilization rate or "rate of effort"
- Planned equipment availability
- Period of support or overall operation duration
- Specific environmental or operational factors
- Nature and quantity of equipment to be retired and the effect of this on support requirements

14.4.2 Logistic Support Detailed Factors

LSA continues with an analysis of the logistics of operational support, including the provision, transport and storage of consumables. This can be summarized as follows:

- Consumables by type
- Consumption rate
- Transportation
- Access
- Storage
- Shelf life of consumables

We then turn to a consideration of operation, maintenance, repair and overhaul. Factors include the life of the prime equipment, the major assemblies or subsidiary items involved, the provision of maintenance facilities and of spare parts. Key points are summarized as follows:

- Planned life of main equipment
- LSA mission duration (e. g., provisioning of spares for first three years)
- Equipment criticality, reliability, availability targets
- Test and evaluation criteria and standards
- Extent of in-house or outsourced support
- Major assemblies types and life
- Repair / Replace policy
- Spares and Rotables requirements
- Level of repair policy
- Maintenance facilities
- Maintenance labour requirements
- Support and test equipment
- Maintainer training and training facilities
- Operator training and training facilities

14.4.3 Level of Repair Analysis

Level of Repair Analysis is concerned with determining where various maintenance activities are to be carried out, so that appropriate staff and facilities can be provided. The analysis starts by considering the volume of work which is estimated to be required at each level of repair. For example, for a vehicle fleet, the type and quantity of vehicles and the planned utilization will form a basis for estimating the amount of routine servicing. From this data we can decide whether a dedicated vehicle servicing facility is required, whether to provide and staff this in-house at a specific location, or whether to let an outsourcing contract. Similar considerations apply to the other levels of repair.

To evaluate an entire system from scratch, including costing all options is a considerable task. In practice, for any particular acquisition we can usually draw on experience from similar or existing equipment, although this does not mean that we should not fully consider the options and how developments of equipment and technology impact on the evolvement of logistic support. The following structure usually applies, and is illustrated in Fig. 14.3.

14.4.3.1 Operator Maintenance

Operators should have some responsibility for and ownership in, the equipment which they operate.

14.4.3.2 Servicing

Estimate the routine servicing load and provide resources.

14.4.3.3 First Line Maintenance

Plan the range of repairs to be carried out at first line, that is at the user area, including immediate technical support, diagnosis and troubleshooting. Estimate the numbers and type of tradespersons to be located with users, and the spares, tooling, documentation and training required.

14.4.3.4 Second Line Maintenance

This provides workshop facilities in a general location to support major plant, or as a support facility for plant scattered over a geographical area. Consider any particular repairs or system changeovers that will be carried out at this level and determine the corresponding requirement for facilities such as heavy lifting equipment, major welding, machining or chemical treatment, specialized technical skills, repair, test-

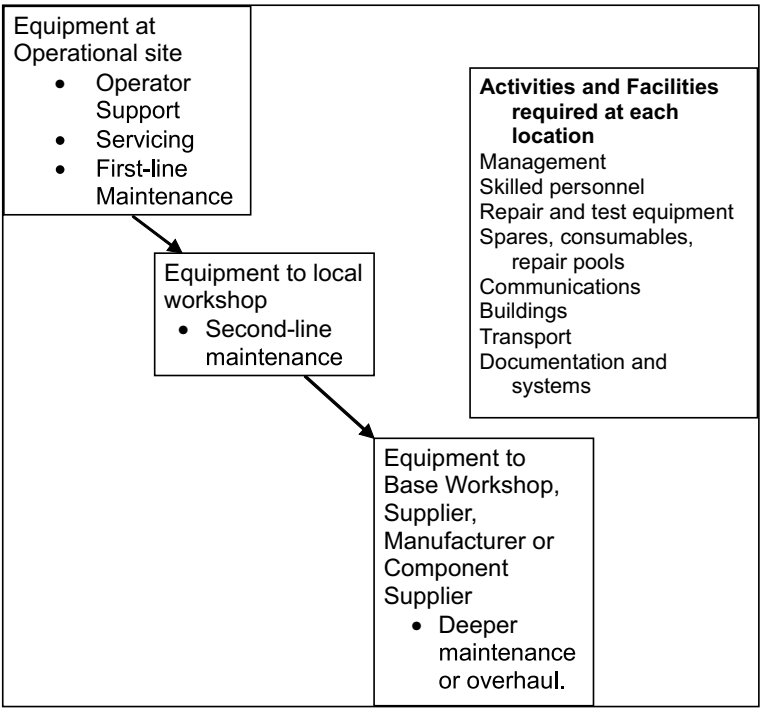


Fig. 14.3 Logistic support and level of repair elements

ing, monitoring. Also normally acts as a base for recovery teams, emergency teams and field repair teams and for more specialized trades such as instrument, electronic or communications specialists.

14.4.3.5 Third Line or Base Maintenance

This provides in depth facilities e. g., overhauls, and may be provided by a equipment manufacturer, a supplier or a contractor.

14.4.3.6 Repair / Replace Policy

Policy decisions on whether to carry out certain types of repairs or to replace equipment should be made as part of the logistic support analysis. The results will influence the logistic support needs, particularly in regard to second and third line maintenance.

For example, an electricity transmission company was planning the acquisition of a new radio communication system for use by field repair teams. A decision was made that only first line repairs would be carried out by the company, mainly con-

sisting of performance checks, setting adjustments and complete unit or sub-unit replacements. No second or third line work was to be carried out by the company. A support contract was made with the supplier to accept any items requiring deeper maintenance and to provide refurbished or new replacement items within an agreed turnaround timeframe.

Equipment outline description, sketch/Flow chart/Outline drawing.
Equipment acquisition timings and allocation to sites
Installation plan
Configuration List.
Supplier and Contractor Details.
Transport Plan
Site Preparation Plan
Disposal Plan
Operations
Operator Staffing Requirements and Plan
Operating Manual
Operator Training Plan
Operator Training Materials
Consumables Specification and Pricing
Consumables Provisioning Plan
Consumables Storage Plan
Consumables Disposal Plan
Engineering
Technical Documentation and Drawings
Technical Data
Safety Plan
Engineering Support Plan
Engineering Training

Maintenance Support Plan
Maintenance Policies for each Level of Repair:
- Operational
- Intermediate
- Depot

Maintenance Procedures and Workshop Manuals
Repair Plan for Repairables (Rotables, Repair Pool)
Repair / Replace Policy
Maintenance Staffing Plan
Maintenance Training Plan
Support and Test Equipment
- List
- Provisioning and Installation
- Test Specifications

Bill of Materials
Spare Parts Catalogue and Pricing
Spare Parts Provisioning Plan

Fig. 14.4 Integrated logistic support factors

14.5 Integrated Logistic Support (ILS)

Integrated Logistic Support is a system for ensuring that, once we have decided on our logistic support concept, all aspects necessary to implement it are identified and arranged for. Integrated Logistic Support takes over from where Logistic Support Analysis (paragraph 14.4) left off. ILS uses formal check lists as an aid to identifying the items to be supplied and checked as satisfactory before the equipment is formally accepted by the user. Ref: MIL-STD-1388-2B.

Integrated Logistic Support starts from the list of assets forming the capability, noting the amount of equipment involved, and the utilization rate. For example, with a vehicle fleet this will mean identifying the vehicle types, quantities and average kilometres run per year. Figure 14.4 indicates the scope of factors covered by Integrated Logistic Support.

14.6 Configuration Management Plan

The configuration of an equipment means the detail of its specification and its key assemblies. In managing deployed assets it will be necessary to keep track of the configuration of the items, as modifications occur, variant models are introduced, or, in the case of fixed plant, new facilities are added and old ones become disused. A viable plan for configuration management should be formed at the logistic support planning stage. More detail of configuration management itself is given in section 6.6.

14.7 Logistic Support Plan

The end result of the logistic support analysis is a logistic support plan which states how the logistic support elements required by the acquisition are to be provided. The plan defines responsibilities for:

a. testing and evaluation criteria for acceptance;
b. packaging, handling, storage and transportation;
c. transport vehicles, four wheel drives, vans, trucks
d. engineering support;
e. consumables provision and transportation;
f. repair, maintenance and overhaul support;
g. spare parts provision, storage, information system;
h. recovery vehicles and crews;
i. provision and training of operators and maintainers;
j. workforce accommodation, recreational facilities;
k. technical data provision and management;

l. configuration management;
m. workshops, site offices, compound, plant yard, covered storage;
n. cranes, fork lifts, handling equipment;
o. electrical power provisions;
p. water supply and treatment if necessary;
q. support facilities and test equipment;
r. occupational, health and safety issues;
s. environmental issues;
t. waste disposal facilities;
u. disposal of equipment which is replaced.

14.8 Through Life Support

The through life support of assets is provided by support systems which cover a range of activities including:

- Operations
- Supply
- Maintenance
- Engineering
- Training

An indication of the range of support activities required is given in Fig. 14.5.

Operations	**Supply**	**Maintenance**	**Engineering**	**Training**
Operators	Supply Personnel	Maintenance Personnel	Engineering Personnel	Training Personnel
Operating Facilities	Supply Facilities	Maintenance Facilities	Engineering Facilities	Training Facilities
Operating Support Equipment	Transport, Storage and Handling Equipment	Maintenance Equipment	Engineering Support and Test Equipment	Training Equipment
Operating Documentation	Supply Commodities and Spares	Maintenance Manuals	Engineering Drawings and Data	Training Materials
Operations Management	Supply Management	Maintenance Management	Engineering Management	Training Management
Operating Management Information Systems	Supply Management Information Systems	Maintenance Management Information Systems	Engineering Information Systems	Training Information Systems

Fig. 14.5 Through life support systems required

14.9 Through Life Support Contract

Factors to be considered in letting a through life support contract include:

- Maintenance support
- Supply support
- Engineering support
- Labour augmentation for periods of high demand or specific needs
- Cataloguing

Performance indicators relating to such a contract include:

- Prime equipment availability
- Rotables availability
- Reliability following repair

14.10 Logistic Support Example

A logistic support example is shown in Fig. 14.6.

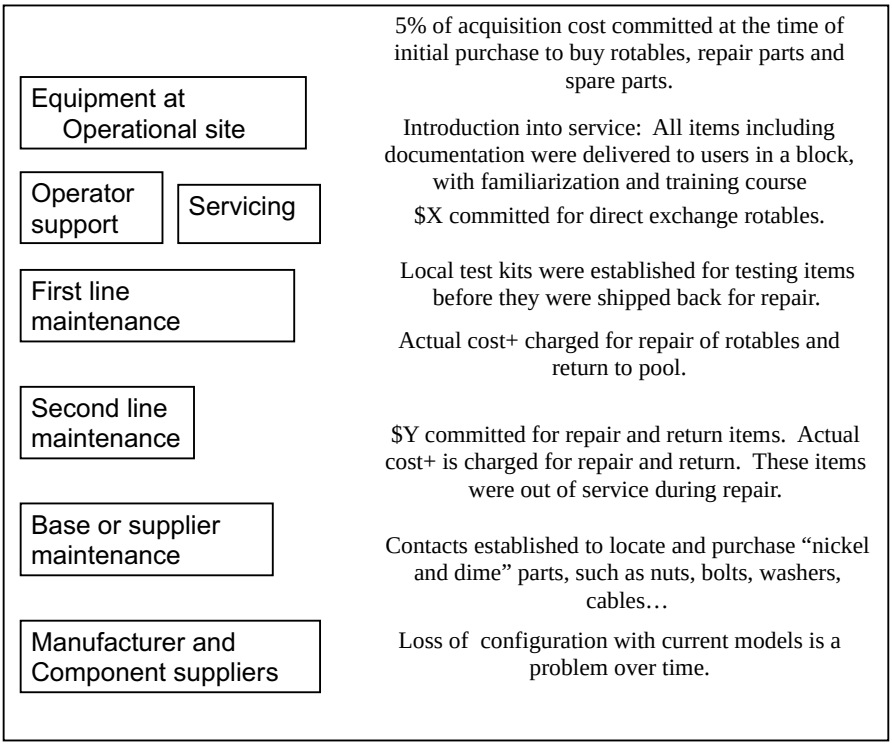


Fig. 14.6 Logistic support example

14.11 Supplier Viewpoint

Suppliers will be involved in original equipment provision and in subsequent logistic support. There will be a requirement for the supplier to provide user documentation and information relating to equipment operation, including safety issues, and this is often augmented by a performance warranty. Maintenance recommendations, workshop manuals and spare parts catalogues are also developed and provided by the supplier.

From the supplier's viewpoint, the provision of logistic support beyond the basic minimum is an additional business opportunity, although care must be taken to ensure that costs are covered and an adequate profit is generated. The provision of logistic support by a supplier can also be a plus in securing the original sale. However, users must be aware that suppliers can only provide support to the extent that it is good business to do so. It is common for users to underestimate the cost of providing support, and thus to have unrealistic expectations of support provisions. If on-going support is to be provided by a manufacturer, they need to consider the cost of maintaining production processes for original equipment and components to which they are committing, and to identify the people and facilities needed to maintain support, in terms of skill sets, numbers, training requirements and training facilities.

Services that may be provided on a contract basis include:

a. consumables provision, transportation and storage;
b. spare parts provision and stock holding;
c. support for introduction into service;
d. repair, maintenance and overhaul support;
e. training of operators and maintainers;
f. training of operator and maintainer trainers;
g. technical data management;
h. configuration management;
i. support facilities and test equipment
j. disposal.

As a supplier, it is important to adequately cost the provision of such services and to assess the physical and cost requirements over the life cycle of the equipment which is supported. Activity based costing can be important in this application. Do not try to subsidize the logistic support contract from the initial sale contract. Consideration will need to be given to the provision of the skills required for the tasks to be undertaken, and to being able to retain these skills out into the future. A common approach is to establish separate distributor and support businesses which need to be viable in their own right.

Key elements of logistic support provision are the same in principle as for the user, but the support may extend across a range of users, so the types and numbers of items must be assessed accordingly. Thus we need to consider the following aspects across the range of items supported.

- The types of item for which maintenance is to be supplied;
- The numbers of items of each type;
- The level of utilization;
- Operating environment and any special factors arising from this.

Identify the maintenance level to be covered such as

- workshop inspection and repairs,
- deeper maintenance,
- overhauls,
- rotables and related repair pools,
- repair/replace policy and related equipment replacement pools.

Plan numbers of trainees for operations, maintenance and trainers; prepare training facilities; provide an on-line spares catalogue and cost the service provision.

Consider the cost and practicality of maintaining the resources and skill sets necessary to provide the intended support services over the contract period. The equipment supported and the range of technical facilities required in your business will change over time and personnel will retire or move on. Do not under estimate the cost of support provision for aging assets. Consider disposal of consumables, used and unused spares and equipment. Consider the cost of contract preparation, negotiation and on-going management.

14.12 Cunning at the Castle

Scene: An Ante-Chamber in the Palace
Enter Roderick, an asset manager and Cuthbert, a political strategist.

R: Look here Cuthbert, this plan of King Henry's is crazy. He wants to take the army to France and conquer it!

C: What's wrong with that?

R: The French will knock the stuffing out of our lot, that's what.

C: Surely not – what about Agincourt and the gallant English archers?

R: Don't forget the Welsh – but either way the archers are no more. They were disbanded after Formigny.

C: Formy – what?

R: Never mind – it's French. It won't feature in English history because we lost. The point is that the French have cannons that out-range our archers by a mile and can crumble a castle like chips. We've got no chance against them until our boys down at the Arsenal develop some new skills.

C: So we need a strategy.

R: It's more serious than that, Cuthbert, we need to do something. Get thinking.

C: *thinks* … Maybe we could make the French expedition more of a fashion show. The French are cool dudes and if we work it so that Henry goes "all-clinking

in gold like a heathen god", to coin a phrase – but just wants to gallop around flashing the Spurs – then they might buy it.

R: Good one Cuthbert. The French first team is off in Italy as it happens; its game on at Milan. So we'll go for your plan. Vive le spin.

A week later

C: The French trip is under control, but it's the Scots that I'm worried about. They're getting up a mighty head of steam with King Jimmy and the Bishop telling them they can beat hell out of us and grab England now Henry is on his way. Get your thinking cap on to that one.

R: Nothing that some creative asset management can't handle; we'll send Henry's troops only the old gear, bows and arrows, swords and heavy armour, and keep the newer stuff here.

C: Good, but who's going to run the show against the Scots?

R: Easy – Queen Katherine. She may not be good at producing sons but she sure can run a war.

C: She can't lead the army though – and don't tell me about Joan of Arc.

R: No, but she's smart enough to put Tommy in charge, and we'll draft requisitions for the supporting logistics, and bring in plenty of those soccer hooligans from up North.

some months later in a back room of the Palace

R: Nice one Cuthbert!

C: Nice one Roderick!

They drink

R: Henry flashed his Hampton in Flanders and good old Norfolk gave Scotland a flogging at Flodden.

C: Just shows what you can do when political strategy and asset management work together.

R: But methinks we should retire post-haste. Henry is at the gate.

14.13 Exercises

14.13.1 Logistic Support Analysis – Tooth Brush

The Antarctic Corporation (AC) is sending a party of 100 persons to a remote antarctic site for one year.

Carry out a Logistic Support Analysis for three toothbrush options:

- Manual
- Electric battery discardable
- Electric battery rechargeable

14.13.2 Racing Cycle Team

You are the logistic support manager for a cycle racing team. Outline in dot point form the logistic support requirements and plan for the team.

14.13.3 Level of Repair Analysis

A maintenance organization is acquiring a new radio communication system. The organization needs to decide its "Level of Repair Analysis" policy.
Analysis shows the following failure modes:

- Battery fails to charge
- Broken knobs, leads and connectors
- Extensive physical damage
- Electronic fault requiring complex diagnosis and repair facilities.

What Level of Repair policy do you recommend?

14.14 Revision Questions

a. What is value engineering?
b. What is Logistic Support Analysis?
c. What are the aims of Logistic Support Analysis?
d. When is Logistic Support Analysis carried out?
e. What data are required for Logistic Support Analysis?
f. What is Reliability Centered Maintenance?
g. What is Level of Repair Analysis?
h. What is Integrated Logistic Support?
i. What is Configuration Management?
j. What would a supplier need to consider in offering a logistic support contract?

Chapter 15
Life Cycle Costing

Chapter Aim: The aim of this chapter is describe the technique of life cycle costing and to illustrate it with an example. We also consider the concept of economic life which provides a theoretical basis for deciding how long a life cycle should be considered.

Chapter Outcomes: After reading this chapter you will understand the reason for life cycle costing and have seen a check list of factors that go into a life cycle costing analysis. You will have seen an example of a life cycle cost analysis. You will have been introduced to the concept of economic life and will have seen an example of an economic life calculation.

Chapter Topics:

- Aim of life cycle costing
- Life cycle asset management plan
- Input to project budget
- Life cycle costing elements
- Life cycle costing example
- Economic life concept
- Economic life example

15.1 Aim of Life Cycle Costing

Australian Standard AS4536 Life Cycle Costing is a useful reference on this topic. Life Cycle Costing (LCC) is the analysis of the cost of acquiring, introducing, operating, maintaining and disposing of equipment. It is "cradle to grave" cost analysis. The aim of life cycle costing is to avoid doing something stupid, such as neglecting or badly estimating a major cost area. Because it relates to a wide range of items

N. A. J. Hastings, *Physical Asset Management*,

and activities over a long period of time, life cycle costing is not generally as accurate as formal acquisition costing. There is a tendency for the focus in acquisitions to be on acquisition cost, with less attention paid to such issues as operating costs, consumables, life of the item, spares costs, life of key components, diversity of spares and tools and issues related to training.

Figure 15.1 illustrates the stages in the life cycle of an equipment, showing schematically the cumulative cost and the opportunity to influence costs. The opportunity to influence costs is concentrated at the planning and acquisition stages. It is important in selecting equipment that we take due account of logistic support considerations, otherwise equipment support costs, performance and availability may produce poor results that negate perceived advantages in initial cost.

An illustration of the application of life cycle costing relates to a company which builds prisons. In some cases it will be competing for a contract to design and build a prison and then hand it over to another organization to run it. In other cases the contract will be to design, build and operate the prison. In the first case, the company will create a design which is inexpensive to build, but pays little attention to the operational aspect. If it did otherwise it would almost certainly not win the contract because its tender price would be too high. In the second case the design would take account of the fact that the company would itself be operating the prison, and they would therefore aim to minimize costs over the whole life cycle of the contract.

Life cycle costing is applied initially at a broad brush level to assist with capability development analysis, and later at a more refined level in the course of making a firm acquisition decision. It is intended to ensure that all relevant costs are identified, and that through life costs are considered at the planning, acquisition and budgeting stages.

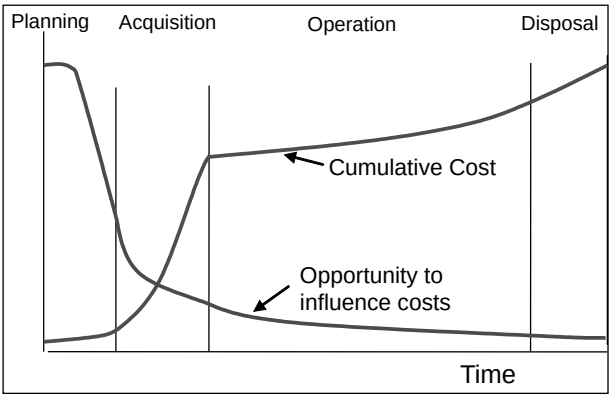


Fig. 15.1 Life cycle stages

15.2 Life Cycle Asset Management Plan

Life cycle costing is dependent on the determination of the life cycle asset management plan. This involves identifying the main elements of the operating, maintenance, repair and overhaul strategy, and then estimating the associated costs. The costs and resources will depend on the quantity of equipment, the rate of utilization and the maintenance requirements. Maintenance requirements will include routine maintenance and an estimate of non-routine maintenance requirements. Logistic support analysis, carried out as part of the feasibility phases of the development will provide a basic input into the Life Cycle Asset Management Plan. The details must reflect current decisions regarding equipment type and operating rates. If operating rates, for example, are significantly changed, the life cycle asset management plan and costs must be reviewed.

15.3 Input to Project Budget

When developing a business case for an acquisition project the results of through life support analysis and Life Cycle Costing feed into the proposal which is taken forward for final approval.

15.4 Life Cycle Costing Elements

The topics listed in this section form a check list of items to be considered in Life Cycle Costing. The main areas considered are:

- Acquisition
- Installation
- Transportation
- Operations
- Computer systems
- Engineering
- Maintenance
- Support services
- Supply
- Spares/Cataloguing
- Training
- Disposal

Acquisition

- Pre-acquisition and acquisition project costs
- Prime equipment cost

- Support equipment cost
- Supporting utilities
- Test and evaluation
- Operational facilities
- Supporting computer and information systems
- Technical data and related systems
- Storage, handling and transportation
- Initial training development
- Initial training
- Commissioning / introduction into service

Operations

- Net personnel requirements for operations
- Materials and consumables;
- Energy (eg, power, fuel);
- Personnel recruitment
- Personnel training
- Personnel transport and accommodation if required
- Operational documentation
- Information technology systems and training;
- Equipment and facilities
- Net operating cost

Maintenance

- routine maintenance including lubricants, consumables.
- breakdown maintenance, downtime
- planned upgrades.
- major overhauls.
- maintenance labour
- maintenance training;
- maintenance facilities;
- maintenance documentation
- contractor services, selection, management
- maintenance IT support.
- engineering support
- engineering modifications
- configuration management
- repair parts (rotables)
- spare parts
- life of major assemblies where different from the complete equipment

Support Services

- office facilities
- corporate management;

- administrative overheads;
- Information technology
- insurance.
- human resource management;
- consumables, spare parts and materials in support areas;
- warehousing facilities;
- packaging, shipping and transportation.

Disposal

- System shutdown.
- Disassembly and removal.
- Recycling or safe disposal.
- Product residual value.

In the case of buildings, the industry is well served by architects and quantity surveyors. We briefly summarize some main headings:

Buildings – Design and Construction

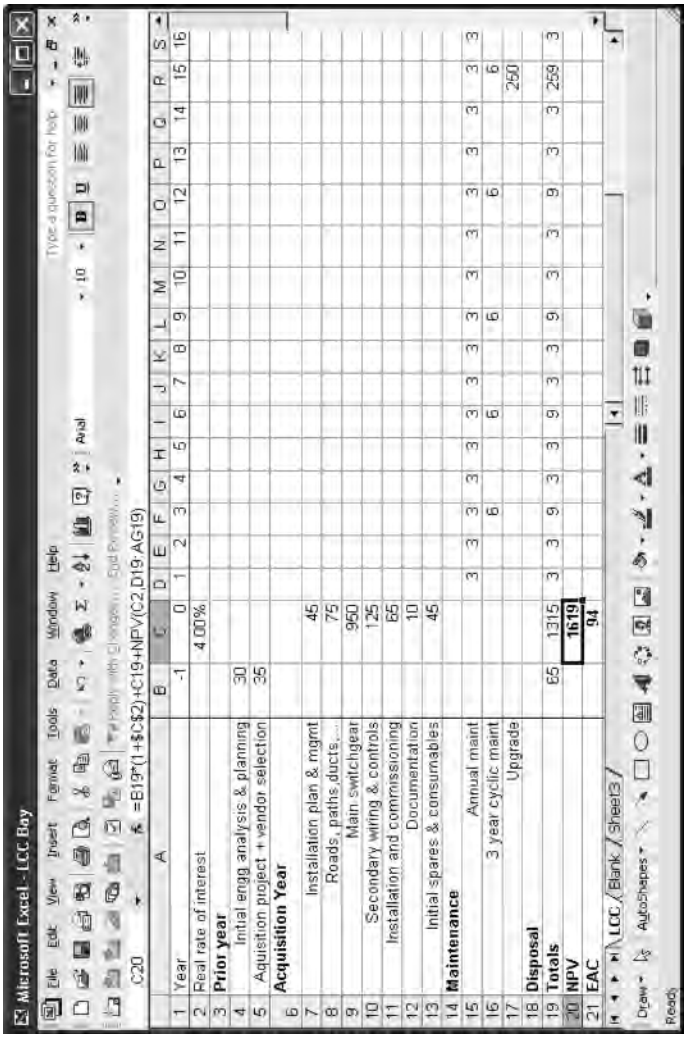
- Market research.
- Development of concept and detailing of needs.
- Preparation of requirement specification of the building.
- Site acquisition.
- Design and design documentation.
- Construction tendering and selection.
- Construction planning
- Construction management
- Construction
- Mid-life refurbishment, décor, lifts, escalators, gates

Buildings – Operation, Maintenance, Disposal

- Owners operational outgoings e. g. cleaning, power, gardening
- Owners maintenance outgoings e. g. maintenance of heating, ventilating and air conditioning, lifts, escalators, painting, water, drains
- Supplies
- Support services
- Disposal value

15.5 Life Cycle Costing Example

In Life Cycle Costing the costs associated with acquisition, operation and through life support are brought together in a spreadsheet or in a similar purpose built system, and the total costs across the life cycle are calculated in the form of the Net



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Year	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	Real rate of interest		4.00%																
3	**Prior year**																		
4	Intial engg analysis & planning	30																	
5	Aquisition project + vendor selection	35																	
6	**Acquisition Year**																		
7	Installation plan & mgmt		45																
8	Roads, paths ducts...		75																
9	Main switchgear		960																
10	Secondary wiring & controls		125																
11	Installation and commissioning		65																
12	Documentation		10																
13	Initial spares & consumables		45																
14	**Maintenance**																		
15	Annual maint			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
16	3 year cyclic maint					6			6			6			6				6
17	Upgrade																		250
18	**Disposal**																		
19	**Totals**	65	1315	3	3	9	3	3	9	3	3	9	3	3	9	3	3	259	3
20	**NPV**		1619																
21	**EAC**		94																

Fig. 15.2 Life cycle cost for circuit breaker bay

Present Value and the Equivalent Annual Cost. Figure 15.2 shows an example of the life cost analysis for a Circuit Breaker Bay. The details are simplified to show the principles involved, and no operating costs are shown as they are not a significant issue in this case. The Bay has a 30 year life, with the first 16 years being shown in Fig. 15.2.

The year labelled –1 is the year prior to acquisition, when initial engineering analysis, acquisition project work and vendor selection are carried out. Year zero is the year of acquisition. Life cycle cost elements include the planning and management of the installation; the building of roads, paths and ducts; the acquisition of

the main switchgear and of the other items shown under the "year zero" heading in column A.

Maintenance costs, shown in rows 15 and 16, extend across the spreadsheet, with an annual maintenance cost of $3,000 and a 3 year cyclic maintenance cost of $6,000. There is also provision for a mid-life upgrade costing $250,000, shown at R17. A disposal cost of $48,000 is incurred in year 30, which is not shown in the figure, as this only shows years up to 16.

Inflation is allowed for by expressing costs in year-zero values and using the real rate of interest, which is estimated at 4% and shown at C2. The Net Present Value of costs is $1,619,000, shown at C20 and the Equivalent Annual Cost is $94,000 shown at C21.

15.6 Economic Life Concept

In life cycle costing, the length of life of the item may be based on technical judgment, or on more formal cost analysis. The length of life chosen will significantly influence the result. In principle, the life chosen should be the economic life, that is the life duration which minimizes its cost per unit time, or, allowing for discounted cash flow, its equivalent annual cost.

From a practical point of view, "economic life" is a somewhat idealized concept, as many factors can influence the decision to replace an item. These are considered in detail in a later chapter.

The basic concept of economic life is illustrated in Fig. 15.3 and Fig. 15.4. In Fig. 15.3, A is the acquisition cost and the curved line represents the cumulative maintenance cost over the time. Typically, this curve becomes steeper over time, as the item ages. The radius vector or straight line from the origin to the curve has a gradient which is the average cost per unit time. This is a minimum when the radius vector is a tangent to the curve, as shown, and this determines the economic life.

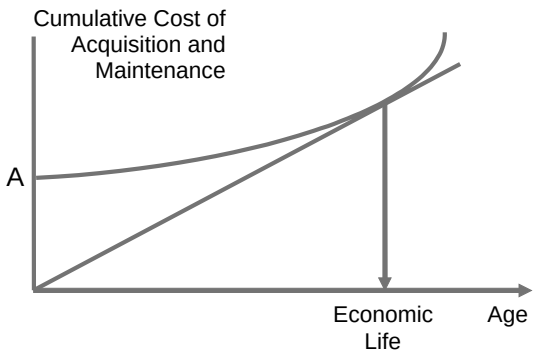


Fig. 15.3 Economic life – cumulative cost plot

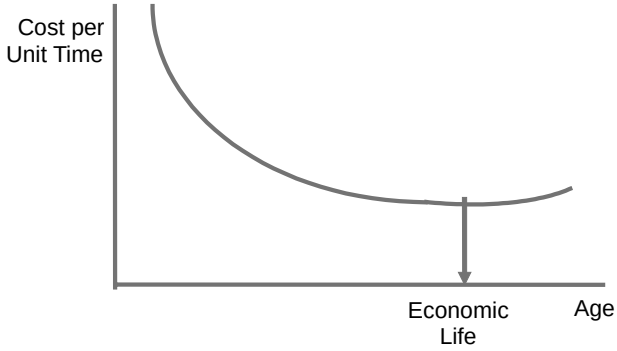


Fig. 15.4 Economic life – cost per unit time plot

The economic life occurs when the marginal cost rate for maintenance equals the average cost rate for the life cycle.

Figure 15.4 shows the same data presented in terms of cost per unit time. This is given by the cumulative cost to date divided by the age. The cost per unit time falls initially as the acquisition cost becomes spread over time, and then starts to rise when the economic life is reached. The economic life will be at the same point in either presentation of the same data.

The economic life graphs shown in Fig. 15.3 and Fig. 15.4 relate to a cost minimization analysis. In some cases it may be more appropriate to consider profit maximization, for example when revenue is dependent on asset age or condition, or when profit margins are regulated by book value. A further practical consideration is risk, particularly when there is a risk of catastrophic failure which increases with age. This aspect is considered further in the equipment replacement chapter.

15.7 Economic Life Example

The following example is simplified, so that we can concentrate on the cost structure. A certain type of vehicle is purchased for an acquisition cost of $300,000. The operating and maintenance (O&M) costs and trade in values in years 1, 2, 3, 4 of the life of the vehicle, are as shown in Fig. 15.5. Calculate the economic life.

Year	1	2	3	4
O & M Cost, $	30,000	45,000	65,000	117,500
Trade-in Value $	235,000	190,000	160,000	127,500

Fig. 15.5 Vehicle life cycle cost data

15.7.1 Undiscounted Case

Consider the case where discounted cash flow and taxation are disregarded. We calculate the cost per year for each of the options of 1, 2, 3 or 4 year life cycles. For replacement at age Y the total cost, C, is given by:

C = Acquisition cost + Cumulative O & M cost – Resale value

And the cost per year is C/Y.

For example, if the policy is to replace the vehicle at age two years. The total cost over the life of the vehicle, C_2, is given by:
C_2 = Acquisition Cost + O & M Costs Year 1 + O & M Costs Year 2 – Resale Value at end of Year 2 = 300,000 + 30,000 + 45,000 – 190,000 = 185,000

The $185,000 is the cost incurred over a two year period and to get the average cost per year we must divide by 2. Thus the cost per year is 185,000/2 = 92,500.

For replacement at age 3 we have:
$/yr = (300,000 + 30,000 + 45,000 + 65,000 – 160,000)/3 = 93,333

and for replacement at age 4 we have:
$/yr = (300,000 + 30,000 + 45,000 + 65,000 + 117,500 – 127,500)/4 = 107,500

Figure 15.6 Economic life analysis without discounting shows these calculations. Row 7, columns C to F, show the costs per year for the 1, 2, 3 and 4 year cycles respectively. By inspection we see that the minimum cost per year occurs with the 2 year cycle and is $92,500 per year.

15.7.2 Discounted Case

When costs are discounted and we have life cycles of different lengths we base our comparisons on equivalent annual cost, EAC. We therefore need to calculate the EAC for each possible cycle length, 1 year, 2 year, 3 year or 4 year.

Figure 15.7 Cash flow for 3 and 4 year lives, shows the cash flow diagrams as they apply for a three year and a for a four year life cycle. Let replacement occur at age n. Let r be the interest rate and p the discount factor. Then the net present value of the cost of the vehicle over n years is:

$$NPV = A + \sum_{i=1}^{n} p^i M_i - p^n S_n$$

and the equivalent annual cost is:

$$EAC = r \times NPV/(1 - p^n)$$

	A	B	C	D	E	F
1	Year, Y	0	1	2	3	4
2	Acquisition cost, A	300000				
3	O&M Cost EOY, M		30000	45000	65000	117500
4	Resale value EOY, R		235000	190000	160000	127500
5	O&M Cumulative, T		30000	75000	140000	257500
6	Total Cost C = A+T-R		95000	185000	280000	430000
7	Cost per Year C / Y		95000	92500	93333	107500
8	O&M = Operating and Maint Cost in Yr.			EOY = End Of Year.		

Fig. 15.6 Economic life analysis without discounting

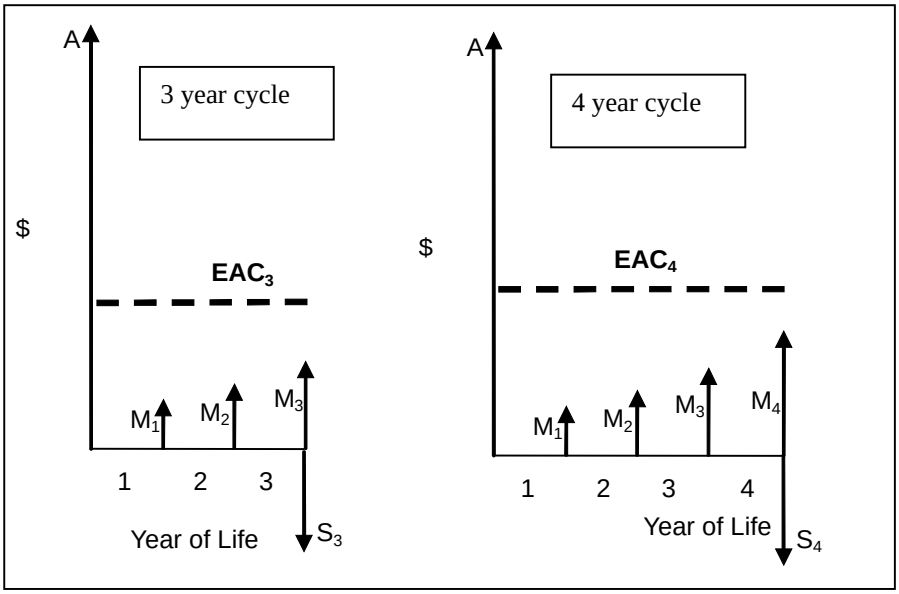


Fig. 15.7 Cash flow for 3 and 4 year lives

Figure 15.8 shows the calculation of the equivalent annual costs of the four life cycle options, with the interest rate at 15%. The Excel functions NPV and PMT are used in the spreadsheet. By inspection we see that the minimum cost replacement age is now 3 years, the EAC being $130,364 per year. This illustrates how raising the interest rate, from zero in the undiscounted case to 15% in the discounted case has the effect of making it optimal to postpone replacement. This is an example of how raising the interest rate dampens economic activity. However, solutions to problems of this type are not always sensitive to moderate changes in the interest rate, or, indeed to other data items. One of the potential applications of this type of model is to test the sensitivity of the solution to changes in the data.

	A	B	C	D	E	F
1	Year, Y	0	1	2	3	4
2	Acquisition cost, A	$300,000				
3	O&M Cost EOY, M		$30,000	$45,000	$65,000	$117,500
4	Resale value EOY, R		$235,000	$190,000	$160,000	$127,500
5	Interest rate %	15%				
6	NPV of Cumul O&M		$26,087	$60,113	$102,852	$170,033
7	PV of Resale Value		$204,348	$143,667	$105,203	$72,899
8	NPV of Cumul Cost		$121,739	$216,446	$297,649	$397,134
9	EAC		$140,000	$133,140	$130,364	$139,102
10	NPV=Net Present value	EAC=Equivalent Annual Cost			PV=Present Value	

Fig. 15.8 Economic life analysis with discounting

	A	B	C	D	E	F
1	Year	0	1	2	3	4
2	Acquisition cost	300000				
3	O&M Cost EOY		30000	45000	65000	117500
4	Resale value EOY		235000	190000	160000	127500
5	Interest rate %	15%				
6						
7	NPV of Cumul O&M		26087	60113	102852	170033
8	NPV of Resale Value		204348	143667	105203	72899
9	NPV of Cumul Cost		121739	216446	297649	397134
10	EAC		$140,000	$133,140	$130,364	$139,102
11						
12	Depreciation rate %		18.75	0.8125		
13	WDV at end of yr		243750	198047	160913	130742
14	Depreciation in yr		56250	45703	37134	30171
15	Company tax rate%		30			
16	Tax credit OMD EOY		25875	27211	30640	44301
17	O&M tax credit		4125	17789	34360	73199
18	NPV cumul after tax OMD		3587	17038	39630	81482
19						
20	Tax credit on resale EOY		2625	2414	274	973
21	Resale + tax credit		237625	192414	160274	128473
22	NPV after tax RS		206630	145493	105383	73455
23						
24	NPV after tax		96957	171545	234248	308027
25	EAC after tax		111500	105520	102595	107891
26						
27	BOY = Beginning of Year					
28	OMD = Operating+Maint Depreciation.					
29	RS = Resale or Trade in value EOY					
30	WDV = Written Down Value					

Fig. 15.9 Economic life analysis with depreciation and tax

15.7.3 Economic Life with Discounting and Tax

Tax can be allowed for using the tax credit analysis described in paragraph 10.5. Figure 15.9 shows this in spreadsheet form. Depreciation is based on the declining balance method at a rate of 18.75% per year and the company tax is at 30%. The optimal life cycle remains at 3 years, so that in this case company tax has not affected the practical decision.

Chapter 16
Equipment Replacement Decisions

Chapter Aim: The aim of this chapter is to present the various reasons for considering replacement of equipment, and to show how replacement decisions can be analysed. Replacement analysis based on increasing maintenance cost with age is presented, covering both steadily and unevenly increasing costs. The use of spend-limits as replacement control mechanism is presented and also the role of risk analysis in replacement decisions.

Chapter Outcomes: After reading this chapter you will be aware of the factors which influence equipment replacement decisions. You will know that financial analysis of replacement policy is based on comparing the future cumulative cost of the existing equipment with the life-cycle equivalent-annual-cost of the challenger, cumulated over the same period. You will know about spend-limits and their role in the setting of replacement policies and how risk can taken into account.

Chapter Topics:

- Replacement planning
- Reasons for equipment replacement
  - Technical
  - Commercial
  - Regulatory
- Technical assessment
- Data analysis
- Cost analysis
- Like-with-like replacement
- Equivalent annual cost of the challenger
- Steadily increasing cost
- Savings
- Unevenly changing cost

N. A. J. Hastings, *Physical Asset Management*,

- Formulas
- Spend-limits
- Risk
- Risk-cost

16.1 Replacement Planning

H.M. Barker in his book "Camels and the Outback" reports that in 1923 he was carting material from Nullagine to Marble bar in Western Australia when his wagon, for which the journey took three days, was overtaken by a motor lorry – the first one in the region. He thought that the lorry was a novelty that would never seriously compete with his camels, but by the time he got to Marble Bar the lorry had passed him three more times, and the mine manager had sent word that his wagon would not be required any more.

Organizations need a systematic approach to the development of replacement plans. Flexibility must be retained as priorities may change, but a backlog of replacements should not build up to a point where losses or serious risks are occurring. The magnitude of such losses or risks is often a more important factor than the achievement of precise cost optimality in replacement planning.

Those who wish to wins friends and influence people never bring bad news, as the reaction of senior people is often to shoot the messenger. Replacing existing equipment is rarely the glamour side of business management and this creates a dilemma for asset managers whose job entails replacement planning.

The best approach is to have a rolling plan in which all forward replacement requirements are indicated, the costs are built in to the capital budget and the acquisition lead times are allowed for. The asset manager can then become an occasional bringer of good news if some items turn out to be in better condition than originally anticipated as their forecast replacement date approaches. Risk assessments should be included, so as to provide senior management with information on relative priorities. However, it is important to avoid crying wolf or being too smart after event. Putting forward reasoned proposals with an associated risk assessment will often produce better results than a more confrontational approach.

Lack of sufficient focus on equipment condition within an organization can lead to the procrastination driven tragedy. The asset manager requests finance for equipment replacement but is asked to prove that it is essential. This is hard to substantiate, and eventually a significant failure occurs. The asset manager is then criticized for "not warning" senior management about the problem. A more extreme version is the asset death spiral mentioned earlier. In this scenario, maintenance and replacement budgets and technical infrastructure are reduced creating short term savings. Routine maintenance becomes minimal or non-existent. Eventually a catastrophe occurs.

16.2 Reasons for Equipment Replacement

As equipment ages there are many reasons why we eventually need to replace it. Key factors influencing replacement decisions include the following; in many cases more than one factor will come into play at the same time. As well as the actual existence of a factor, risk is also a general issue, so that, for example, increased environmental risk may influence a decision even though an actual event has not occurred.

Technical Reasons

- Actual equipment failure
- Reduced reliability, increased risk of failure, long term deterioration e. g. corrosion, fatigue, insulation deterioration
- Reduced availability
- Lack of logistic support, e. g. spares not available

Commercial Reasons

- Operationally obsolete (though still working) e. g. penny farthing bicycle
- Capacity needs changed, increased or decreased

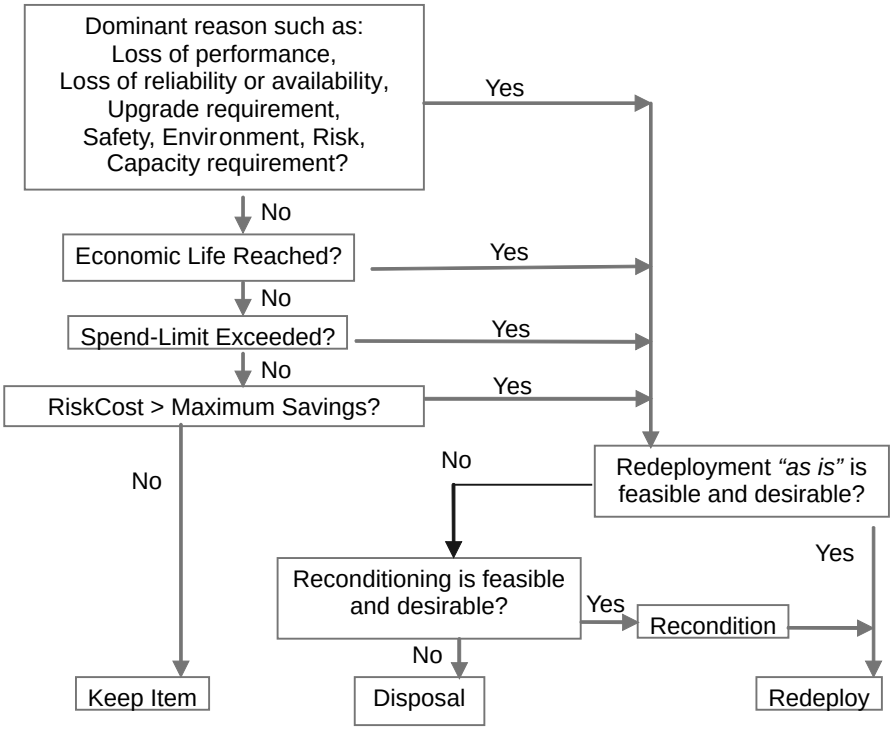


Fig. 16.1 Replacement analysis flowchart

- Operating value low compared with new
- Costs high compared with new

Regulatory Reasons

- Safety or health issues
- Environmental issues
- Government regulator's rules favour replacement
- Technical regulations changed e. g. increased fuel efficiency mandated

Figure 16.1 shows a flow chart covering the logic of replacement decisions. The flow chart was developed for items with a focus on service provision and cost minimization, rather than on profit generation. In a profit focused case, net operating value would be an issue, rather than cost alone. The box at the top left summarizes physical or operational reasons for equipment replacement. Financial issues may include economic life as considered in the chapter on life cycle costing, the spend-limit considered in a later section, and risk-cost, that is the probability of incurring an excessive cost as a result of a risk eventuating. In some cases it may be possible to redeploy or refurbish equipment and these possibilities are covered in the flow chart.

16.3 Technical Assessment

An awareness of criticality and the identification of high risk items are important in the overview of technical condition and replacement analysis. The condition of the existing equipment, particularly in regard to things which deteriorate with age and are not readily remedied, should be monitored. Condition monitoring techniques should be deployed to obtain indications of equipment state, and this can give an advance indication of when replacement will be required. Factors to be considered include corrosion, insulation deterioration, embrittlement of plastics, moisture penetration, fatigue, erosion, wood rot, surface degradation, cracking and movement of structures.

The performance of existing equipment should be monitored in regard to operational efficiency, reliability, availability and maintainability, and the results assessed in relation to the needs of the organization. In some cases, older equipment can be deployed to less critical tasks or to standby roles rather than being discarded. Degradation in performance or in regard to risk of failure often forms the basis for equipment replacement.

16.4 Data Analysis

Replacement decisions are generally based on assessment of changes in performance, reliability and risk as equipment ages. Data relating to these factors is often

present in the form of operating and maintenance records, but in order to use this data, suitable reports need to be generated from it. These should highlight changes in operating performance, failure rate and maintenance costs, forming the basis for sound decisions for replacement of equipment. Experience and gut feel can also play a role, but data analysis is the best approach.

16.5 Cost Analysis for Replacement

Whatever the reason for replacement of equipment, a supporting financial analysis will normally be required, and we now consider the types of analysis needed.

16.5.1 Like-with-Like Replacement

In the chapter on life cycle costing we considered the determination of an optimal life cycle based on cost analysis, and we obtained this by minimizing the equivalent annual cost over the life cycle. In the case of like-with-like replacement, the optimal life cycle determined from that analysis provides the cost guideline for our replacement decision.

An important fact to recognize is the acquisition cost of a new item is always likely to be greater than the current year cost of keeping an old item; but to minimize long run costs we need to replace an old item when its current year costs exceed the *annualized* life cycle cost of the new item, not the acquisition cost. This principle underlies all replacement cost analysis, although there are variations to allow for differing circumstances.

16.5.2 Equivalent Annual Cost of the Challenger

In practice we are likely to find that we are making decisions about replacing equipment of an earlier type and design with equipment of a newer type and design. This may give rise to a need to replace for broader reasons than direct equipment cost, and these reasons, have already been discussed. We now consider the case where the "competition" between existing equipment and new equipment is based on cost grounds.

We can refer to the existing equipment as the old equipment and to the potential replacement as the new equipment. Another form of nomenclature is to refer to the potential new equipment as the "challenger" and the existing equipment as the "defender".

Consider a situation where we are considering buying a new car to replace an existing one. The new car is the challenger and the old car is the defender. The price of the challenger will be a factor in our decision, since if prices have tended lower,

we will be likely to make the changeover sooner than if they have tended higher. In the current year, the acquisition price of the challenger will be almost sure to exceed the maintenance cost of the defender in that year, and if we based our comparison solely on the immediate year's costs we might postpone our decision for a very long time. The correct approach is to consider the equivalent annual cost of the challenger over its lifetime and compare this with the equivalent annual cost of the defender over its estimated remaining life. This analysis requires us to make an estimate of the equivalent annual cost of the challenger, so that life cycle costing analysis is required for the new equipment. Previous expenditure on the existing equipment is a sunk cost and not relevant to our decision. Indirectly though, previous expenditure may be a factor influencing the current condition of the existing equipment, which is a consideration.

16.5.3 Steadily Increasing Cost Case

If the cost of the old item increases steadily year by year, the decision to replace is based on comparing the cost of keeping the old item for one more year, as against the annualized cost of the new, or challenger, item. The annualized cost of the new item is the equivalent annual cost, as estimated by life cycle costing.

The cost of the old item includes the maintenance cost, any decline in resale value, and costs associated with declining performance relative to a new item. For example, if the old item incurs relatively high downtime we should include an estimate of the cost involved, compared with the corresponding life time average downtime of the challenger over one year.

Figure 16.2 illustrates the increasing cost case. The equivalent annual cost of the new item is referred to as EACnew. The old item should be replaced at the end of the second year from now, as in the third year ahead (and subsequently) the annual costs of the old item will exceed EACnew.

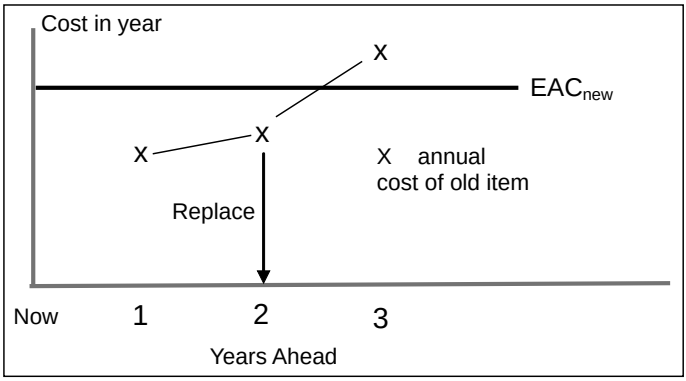


Fig. 16.2 Replacement analysis – steadily increasing costs

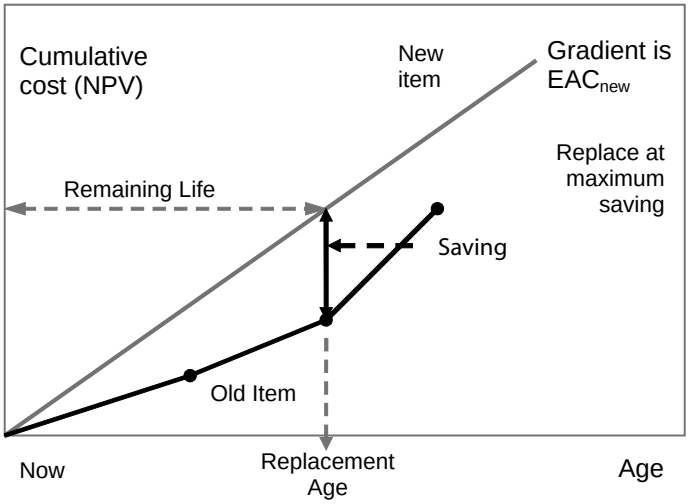


Fig. 16.3 Cumulative cost graph

16.5.4 Savings

Another way of representing the cost comparison is by means of a cumulative plot as shown in Fig. 16.3. The cumulative cost of the old item is the lower solid line. The upper solid line has gradient equal to the equivalent annual cost of the new or challenger item. In the cumulative plot the gap between the "new" and "old" lines represents the savings accumulated by continuing to use the old item. In Fig. 16.3 the optimum replacement age is where the difference between the new and old lines is a maximum. The extent of the savings can be considered when assessing risk or other intangible aspects of the replacement option. Thus if the total savings are quite small in relation to a possible risk, we may decide to replace before the theoretical minimum cost point.

As time goes by the origin of the graph shifts to the new "Now" and the potential savings decrease.

16.5.5 Unevenly Changing Cost Case

The cumulative plot analysis also covers the case where the cost of the old item does not increase steadily, but can vary, for example due to deeper maintenance taking place on a cyclic basis. In this case the cost in the deeper maintenance year may be above the EAC of the new item, but then falls in the rest of the cycle. The point of maximum savings on the cumulative plot gives the optimal replacement age. The same analysis applies where a one-off significant repair is required now; or where a refurbishment that will subsequently lower costs is being considered.

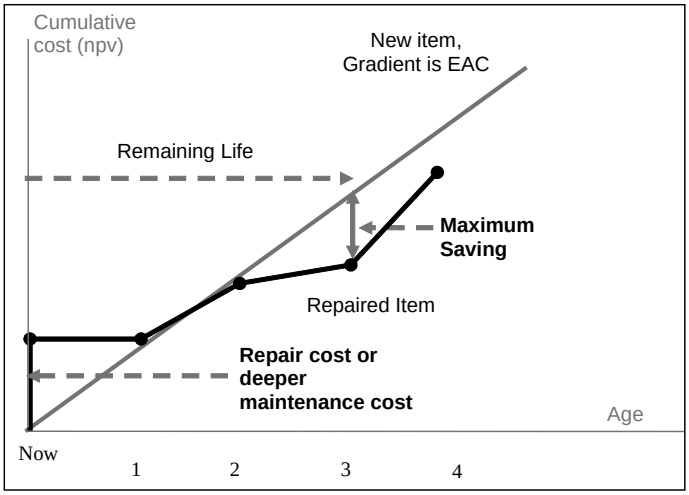


Fig. 16.4 Variable cost case

Figure 16.4 shows a case where an equipment requires a major repair now, and a forecast has been made of subsequent costs based on the expected need for assembly replacements. No costs are expected in the year 1. In year 2 there is an expected higher cost, in year 3 there is a lower cost and then higher costs in year 4 and subsequently. The cumulative cost curve for the old item (repaired item) falls below the cumulative cost line for the challenger (new) item yielding savings. The optimal remaining life occurs when the saving is a maximum.

If the repaired item line did not fall below the new item line, then it would not be worthwhile to carry out the repair. This analysis can be used to indicate the whether a proposed repair or refurbishment is financially worthwhile. The magnitude of the potential savings can be used as a judgment factor in deciding whether to undertake the repair, and also in risk analysis.

16.5.6 Formulas

Let:
NPVold(n) = The estimated NPV of costs of the old item over the next n years
p = discount factor
M(i) = old item operating and maintenance cost in year of life i
S(i) = resale value of old item at end of year of life i
EACnew = The equivalent annual cost of the new item
AN(n) = The n year annuity factor
NPVnew(n) = new item comparative cost over n years

If we keep the old item for n years and then sell it the NPV of the cost is:

$$NPVold(n) = pM(i + 1) + p^2 M(i + 2) \ldots + p^n M(i + n) - p^n S(i + n) \quad (16.1)$$

If we sell now, the NPV of the cost over n years is:

$$NPVnew(n) = -S(i) + AN(n) \times EACnew \quad (16.2)$$

The difference between the two expressions is the saving by replacing after n years:

$$Saving(n) = NPVnew(n) - NPVold(n) \quad (16.3)$$

To find the replacement year, which is the one that gives the maximum savings, we evaluate the previous expression for a range of values of n and find the year which gives the maximum savings and also the value of the maximum savings, MaxSaving

$$MaxSaving = Maxn[NPVnew(n) - NPVold(n)] \quad (16.4)$$

If there is no positive value of MaxSaving, replacement should take place immediately.

16.6 Spend Limits

We can sometimes find that excessive amounts are spent on uneconomic repairs unless rules preventing this are put in place. Such rules are known as spend-limit rules or repair-limit rules. A spend-limit is a limit on the amount which it is permitted to spend on repair or refurbishment of an existing item. The value of a spend-limit will depend on the type of item, its age and the replacement options and costs. The operation of a spend-limit system depends on the availability of replacement items. As such it is typically applicable to items of intermediate value, such as vehicles, radio sets, common user motors or pumps, where there is access to a replacement pool.

Logically, no more should be spent on the repair of an item than the item is worth. As a quick guide, the book value of an item acts as a limit on how much may be spent on repair at any point. The book value may not accurately reflect the value of the item to the business and in this case the spend-limit should be the deprival value, which is the maximum savings from retaining the old equipment, as given by Eq. 16.4. An item which requires a repair whose cost exceeds its spend-limit should be replaced.

The "spend limit" concept can be illustrated by the following common application. If a vehicle incurs accident damage which exceeds its second-hand value, then the company which insures the vehicle will normally specify that the vehicle is written off and is not repaired. The second-hand value acts as a limit on the amount which it is worthwhile spending on the repair. This reflects a basic principle that no more should be spent on the repair of an item than the item is worth after repair. The value after repair is a "spend-limit" for an item.

16.6.1 Spend-Limit Example

A bus company has a number of old buses which are used only on days of high demand. Repair/replacement decisions are controlled by spend-limits. The spend-limit for old buses is set to a level which allows buses with “no problems” or requiring very minor repairs to be retained, but repairs involving major assembly replacement or major bodywork are ruled out.

16.7 Risk with Ageing Equipment

Equipment replacement decisions often need to take account of risk. Costs per unit time may decrease over time, as shown in Fig. 16.5, but then, rather than tending slowly upwards, they may have a sudden jump due to major failure. This type of behaviour occurs with items whose maintenance costs are low relative to their capital cost, but which can experience catastrophic failure. Power transformers provide an example. In such cases it is essential to take account of risk as equipment ages.

Senior management should be involved in the assessment of the risks and consequences arising in any such situation, as their estimate is likely to be the best available, and their ability to make a sound judgmental decision in terms of the business as a whole may save needless and possibly inaccurate analysis.

Where suitable data is available we can estimate levels of risk. For example, an electricity transmission company with complete data on all failure history and maintenance history of its transformers estimated the probability of major failure of transformers and related this to age and to other measures of transformer utilization and condition. From this it was able to draw up guidelines for preventive replacement polices which kept the probability of major failure to low levels. It is generally not possible to eliminate all risk. Where less data is available we may need to rely on technical judgment to guide our replacement policies.

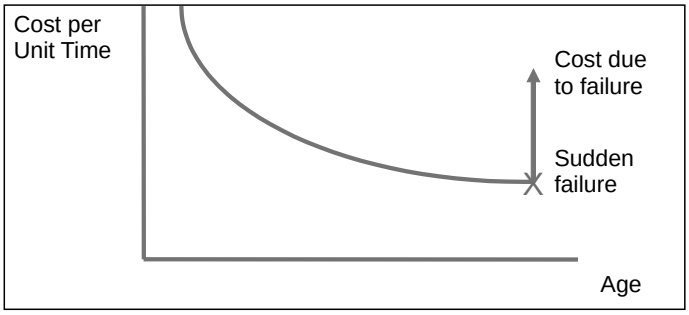


Fig. 16.5 Long life equipment with risk

16.7.1 Risk-Cost

Risk-Cost is the probability that an adverse event occurs multiplied by the cost if it does. Although risk-cost can be a useful guide to our thinking, the product of a very low probability multiplied by a very high cost does not always result in a meaningful value when related to conventional financial analysis.

For example, the probability of an old transformer failing in the coming year was estimated at 1% and the cost of this event at $1,000,000. The product of these numbers gives a risk-cost of $10,000. $10,000 is too small an amount to warrant replacement, but in practice the senior management made the decision based on the probability of failure and its potential impact at the overall business and political level, with the result that the transformer was replaced.

16.8 Exercises

16.8.1 Water Pump Replacement Exercise

A water pump currently has a resale value of $25,000 and is estimated to have a resale value of $18,000 in one years time. The operating and maintenance cost of the pump for the coming year is $3,500, assumed to be incurred at the end of year.

The life cycle EAC of a new pump is estimated at $10,000 per year. Should the old pump be replaced now?

a. assuming zero interest; and
b. assuming interest at 10% p.a.

16.8.2 Transformer Replacement Exercise

An electricity transmission company has a transformer which is currently 40 years old. The operating and maintenance costs for this item for the next four years have been assessed as follows. Assume that these costs are incurred at the END of the respective years. Assume that the old transformer will not be kept for more than four years.

Year	1	2	3	4
Cost	14,250	14,200	24,000	45,450

A new transformer of modern design can be purchased for $300,000. The new transformer can be assumed to have a 40 year life. The cost of capital is 8% and the 40 year annuity factor at 8% per annum is 11.9246. The annual operating and

maintenance cost for the new transformer is estimated at an equivalent annual cost of $2,700 per annum.

a) On the basis of this data, at what age should the old transformer be replaced? Show your working.
b) If the old transformer needed a repair, costing $30,000, should this repair be carried out or should the old transformer be replaced now? Assume that the old transformer has no net disposal value. Assume that this repair will not affect the future costs shown in the table. Show your working.

Transformer replacement solution template:

1. Calculate new transformer EAC

Capital cost	
Life in years	
Annuity factor	
Capital Cost EAC	
Maintenance cost EAC	
Total EAC	

2. Calculate new transformer cumul NPV

1	**Year**	1	2	3	4
2	New Trans EAC				
3	Discount factor	.9259	.8573	.7938	.7350
4	New Trans NPV				
5	New Trans Cumul NPV				

3. Calculate old transformer cumul maint cost, rows 6 to 8
4. Calculate savings from keeping old transformer, row 9

6	Old Trans Maint	14,250	14,200	24,000	45,450
7	Old Trans Maint NPV				
8	Old trans Cumul Maint NPV				
9	Savings row 5 – row 8				

Answer (A) Replacement Age = (B) Repair Yes / No

16.8.3 Spend-Limit Exercise

A company has a machine which requires a reconditioned engine at a cost of $25,000, but is otherwise satisfactory. We estimate that the machine will last for three more years if it gets the new engine, and that its expected maintenance cost over this period will be $3,000 per year. The Life Cycle Equivalent Annual Cost (EAC) of a new machine is $10,000 per year.

Should we replace the engine or scrap the old machine? Assume zero resale value if the machine is scrapped. Ignore discounting over the three year period.

Chapter 17
Outsourcing

Chapter Aim: The aim of this chapter is to outline the main things to be considered by management in regard to outsourcing of maintenance work and other asset management tasks. Both positive and negative aspects of outsourcing are indicated, with the aim of helping managers to get the best value from their outsourcing options.

Chapter Outcomes: After reading this chapter you will know what type of tasks to outsource and what type are best kept in-house. You will learn about the types of outsourcing contract and about the points to watch for in creating and management outsourcing contracts. You will also read about outsourcing from a contractor viewpoint, which will assist both parties to an outsourcing contract to achieve a favourable outcome. You will also read about forms of contract such as Build Own Operate Transfer and Public Private Partnerships.

Chapter Topics:

- Introduction
- Non-core activities
- Owner/Operator model
- What not to outsource
- Benefits of outsourcing
- Costs of outsourcing
- Types of contract
- Outsourcing risk avoidance
- Audit
- Contractor viewpoint
- Build own operate transfer
- Public private partnerships

N. A. J. Hastings, *Physical Asset Management*,

17.1 Introduction

Civilization is based on specialization and specialization involves outsourcing of tasks to those who specialize in specific types of task. Specialization enables an organization to be equipped, trained, skilled and experienced in a chosen range of tasks, and potentially to execute those tasks efficiently. This is the rationale for outsourcing. At the same time, outsourcing introduces communication, negotiation and pricing activities which must be set against the advantages of specialization.

Outsourcing of maintenance activities from utilities and large scale enterprises has occurred on a substantial scale in recent years. To some extent this is a political issue, since large scale enterprises suit the bargaining power of labour organizations. However, our concern here is with the practicalities rather than the politics of outsourcing.

17.2 Non-Core Activities

The activities required to support a capability can be divided into core and non-core activities. For example, in running a power station, the operation of the power plant itself and of immediate engineering support or feeder functions can be regarded as core, whereas site activities such as:

- gardening
- cleaning
- security

are non-core. Non core activities are ready candidates for outsourcing to organizations which specialize in the relevant functions, and which are likely to take on similar contracts with a range of organizations whose core businesses can vary widely.

17.2.1 Minor Player

Outsourcing also makes good sense for technical activities where our organization is a relatively minor player. Examples can include:

- Electric motor repairs
- Oil condition analysis
- Heating, ventilating and air conditioning maintenance

17.2.2 Peak Load Resources

Another common area for the use of contract resources is in the meeting of peaks in activity, such as maintenance personnel required for shutdown work.

17.3 The Owner/Operator Model

Another scenario is for an asset owner to appoint an operator who runs the entire operation. For example, a government entity may own a railway, but contract the operation of the railway to an operating company. We often find a multiple level structure in which the operator then sub-contracts some functions to more specialized organizations. The general principle here is that a prime contractor should be responsible for his sub-contractors. In what follows we refer to the owner or prime operator as an "outsourcer" and the organizations which are contracted to undertake particular types of task as "contractors".

17.4 What NOT to Outsource

It is best not to outsource activities which are central to the business, or where the business has more specialist knowledge than the potential contractor. It is important to ensure that the potential contractor knows the business for which they are bidding.

Another area where companies should be cautious about outsourcing is for functions with high customer impact. It is best to keep a close watch on these activities and to be able to pick up feedback and respond effectively and quickly to problems.

It is best not to outsource activities which are currently causing a problem. Solve the problem in-house and then outsource once a satisfactory working solution has been found. Alternatively, if this is not possible, outsource the problem solving activity on its own and then consider your position once a proven solution has been found.

A paper manufacturer outsourced the maintenance of its overhead cranes to a maintenance organization. But it turned out that the contractor, although competent in maintaining mobile and construction cranes, had no experience in heavy factory overhead cranes of the type used by the paper manufacturer and did not understand the necessity of maintaining strict alignment of the running rails, nor were they equipped to do this. After a couple of near accidents the company brought the maintenance of the overhead cranes back in-house.

In another example, a large insurance company was alarmed to find that only two people had a full understanding of the workings of their computer systems, and that both were contractors. They subsequently developed in-house skills and a succession plan.

17.5 Benefits of Outsourcing

Concentration on core business tends to benefit an organization, resulting in less direct employees, fringe activities cut and less birthdays to celebrate. Historically, a reason for outsourcing has been to redress imbalances in the workforce. Large organizations may have taken on workers whose numbers, skills and flexibilities are out of step with current requirements. Outsourcing provides an opportunity to review the workforce position from a zero base. Subsequently it provides greater flexibility in meeting the needs of a changing business environment.

From the workers point of view, outsourcing can mean the loss of jobs. But many workers benefit from pursuing new lines of activity, and some find employment related to their original tasks, but on a basis that, given the increased flexibility involved, provides benefits for them as well as for their original employers.

Outsourcing can also have the benefit of moving fixed costs into variable costs with equipment, including maintenance and support equipment, which is now provided by the contractor as an operating expense to the outsourcer. Keeping this equipment up-to-date is now an issue for the contractor, but as this is part of the contractor's main business, it is likely to be well managed and give economies of scale.

In the maintenance area, outsourcing provides an opportunity to review and update maintenance practices. Formalizing a contract can create a clearer definition of tasks and responsibilities. The contractor, who is likely to have responsibilities across a range of plant, can bring in economies of scale across the maintenance function. Paradoxically, it can be easier for an asset manager to get good performance from a contractor, whose tasks are well defined and whose performance is under routine scrutiny, than it is to get the same performance from an in-house group.

17.6 Costs of Outsourcing

17.6.1 Formalization

One of the main reasons for establishing companies in the first place is to form a team with a collective aim and identity. Within the team, all are working for the same main ends. Co-operation between members of the team is the norm and requires minimal formalities. By contrast, outsourcing means that work is assigned to an outside organization and this means a contract relationship which requires formalization to cover such things as:

- work scoping and specification
- costing
- identification of potential contractors
- tendering process

- selection process
- contract negotiation and agreement
- legalities
- contract management, including variations, cost control
- progress management and on-site activity control
- auditing of contractor performance.

17.6.2 Intangible Effects

Outsourcing can also have impacts of a less tangible nature. One such aspect is the loss of ability to direct workers, who now work for the contractor. For example, the manager of a hydro-electric generating utility, which operates a number of small plant scattered over a mountainous area, reports that, prior to outsourcing he was readily able to identify and dispatch suitably skilled personnel to deal with problems at any site. Now he has to refer such problems to a contractor resulting in a loss of time and flexibility and an increased likelihood that the person dispatched will be unable to solve the problem.

17.6.3 Other Potential Negatives

Other negatives can include:

- Loss of critical skills and technical knowledge which go to the contractor and then to competitors
- Loss of employees that you didn't intend to lose
- Loss of internal communication
- Less opportunity for knowledge growth and development of internal expertise
- Loss of links with suppliers – suppliers are now dealing with the contractor
- Hidden costs emerge – things that you didn't realize your employees were doing
- The contractor looks good initially, but then shifts the best people to the latest client.
- Delays in resolving crises, response time factors
- Lack of availability of particular necessary skills
- Loss of control over work timing
- Loss of control over work standards
- Cost of monitoring work done
- Inhibits continuous improvement
- Lack of commitment by contract personnel
- Lack of responsibility by contract personnel who will disappear and not be answerable for problems
- Potential for conflict between in-house and contract workers.

- Security
- Access rights
- Insurance
- Handover of tasks / equipment between contractors and in-house personnel
- Ownership of items on site
- Contractors profit motive conflicts with main company's overall interest.
- Termination of contracts
- Ownership of improvements, developments.

This list may appear formidable, but airing the potential problems may go some way towards solving them. Ultimately, the benefits of outsourcing need to be sufficient to more than offset these many factors.

17.7 Types of Contract

Labour Only. Labour is hired in and works as directed by in-house staff.

Time and Materials. The time taken and materials used are recorded and paid for at agreed rates. The contractor has no specific motivation to be economical, but this is not to say that he will be needlessly extravagant.

Survey and Quote:
The contractor estimates the work required and then quotes a price for doing it. There will be checking by technical experts on behalf of the outsourcer. Often the same contractor then goes on to carry out the work.

Work Package:
Labour, tools, spares, are provided to execute defined work,
Examples: Building contracts; Inspection and routine maintenance of fire safety system.

Lump Sum:
The contractor agrees to maintain a system in return for an agreed sum of money. The maintenance policy details are left with the contractor. Level of service standards are defined. See also the performance based contract considered next.

Performance Based:
Similar to Lump Sum except that the payment is adjusted (up or down) in accordance with agreed performance standards, such as:

- Availability of plant,
- Response time,
- Keeping to schedule,
- Turnaround time for rotables.

The maintenance policy details are up to the contractor. This is suitable for situations where the performance criteria can be readily defined. This is generally the preferred type of contract for operational situations.

Alliance:
The outsourcer and the contractor work in an integrated way to achieve a target result. This type of contract may be necessary for projects involving technological development and/or systems integration. It is important that the outsourcer and the contractor agree on:

- Project target outcomes,
- Commercial incentives
- Intellectual property rights.

Conflicts can easily arise in these areas and on-going co-operative goodwill is necessary for success. Risks tend to revert to the outsourcer – be careful of this.

17.8 Contract Features

Some common features of outsourcing contracts are as follows:

- Performance criteria
- Level of service
- Incentives, bonus for good performance, malus for poor performance
- Availability of equipment or service by time and duration
- Security
- Access rights
- Continuous improvement – and partnering for improvements.
- Ownership of intellectual property
- Insurance cover
- Contract termination options, procedure, handover
- Ownership of equipment used
- Prime contractor to remain responsible for sub-contractors, however, health and safety liabilities cannot be contracted out.

The contract must allow the contractor sufficient funds to cover costs, deliver a reasonable profit and allow for contingencies. The nature and range of services must be well defined, and also the performance level. Consider a contract for lawn mowing and edge trimming. The performance level, should state how high the grass is to be in terms of a range! The choice of frequency of mowing is with the contractor, provided that the range of height is maintained, and may vary with the weather. Some fine details will need to be ironed out, for example, who is responsible for clearing the lawn of toys, and what rules govern the disposal of clippings.

Emergency response issues are covered in some contracts. Factors to be considered include the following.

- range of situations to be covered, definition of the emergencies,
- period for which covered
- nature of response
- time to respond,
- acceptable cost rules for dealing with emergencies
- exclusions.

17.9 Outsourcing Risk Avoidance

- The contractor must have necessary skills and management competence.
- Address sources of potential problems at the contract stage.
- Be prepared to stay with in-sourced solutions, or to revert to in-sourcing if necessary, particularly to cover urgent tasks, critical machines or critical services.
- Keep links with affected employees
- Use more than one contractor
- Keep contracts to moderate length
- Use performance based contracts
- Have contract provisions allowing you to react to an emergency by funding overtime, extra resources or specific direction of resources to the emergency on hand.
- Primary contractor to have responsibility for their sub-contractors. However, when problems occur, the contractor will still blame the sub-contractors. It is advisable to involve the sub-contractors in meetings and ensure that their opinions are heard and that they are party to all necessary information, without letting the contractor pass off the risk.
- Create and retain in-house strength in:
  - Highly skilled technicians – have a minimal number and look after them
  - Asset management
  - Technical specialists
  - Contract negotiators
  - Contract managers and performance auditors
  - Customer support resources
- Succession planning is needed for all of the above.

17.9.1 Audit

An audit system should be established to check and report on contractor performance. This should compare actual service levels and other performance indicators against targets, and should check on performance of equipment in terms of reliability and availability.

17.10 Outsourcing Result

Outsourcing means that the outsourcer becomes an Asset Manager rather than a maintainer. There will be a need to continually deal with issues related to service delivery. *So hat jener seiner Sorgen,* to quote a German proverb.

If problems arise you can invoke the contract, but if the arrangements fail the problems revert to the outsourcer. You can outsource the task, but you cannot outsource the (ultimate) responsibility.

The Victoria State Government outsourced the operation of part of its suburban railway network to a contractor, who later walked away when they decided that they could not make a profit from the arrangement. The passengers still needed to be carried, however, so the problem landed back with the government. Fortunately they had used another contractor for another part of the railway and they were able to get that contractor to pick up the slack. In these circumstances the outsourcer may realize that the original contract did not allow enough profit margin and may make a more generous deal the second time around.

17.11 Contractor Viewpoint

Avoid sovereign risk, that is, situations where someone else (e. g. a regulator or government entity) can change the rules after your costs are fixed. Contract for a known service at a known cost. For example, contract for delivering system availability, rather than for actual sales revenue, or for any measure which depends on factors outside your control.

The contract must be sufficiently profitable in terms of the usual investment criteria and contain adequate provision to cover contingencies and to encourage further investment and growth. Identify risks, and ensure that the contract protects you against these as far as possible. Remember that politics can change, and that public servants are interested (like the chicken providing the breakfast egg) but not involved (like the pig providing the bacon).

17.12 Build Own Operate Transfer (BOOT)

A contractor bidding to build a building will aim to provide value in terms of $ per square metre. However, if the same contractor was also going to operate the building (e. g. residence, warehouse, prison) the design would take more account of operational and maintenance factors. The owner should focus on through life costs of the entire operation and not just initial costs. BOOT contracts can assist in this process.

17.13 Public Private Partnerships (PPP)

Public Private Partnerships are arrangements whereby government and industry get together to work on a major project. Examples include roads, railways, desalination plants. The reasoning behind these arrangements is that the public sector and the private sector each have different areas of strength, and bringing them together can produce an effective and timely result. The strengths which the different parties bring to a public-private partnership are summarised in **Fig. 17.1.**

An example of a public-private partnership is the building of the cross-city toll tunnel in Sydney. The tunnel was duly completed and the government and contractors were happy, but the public became resentful, because the government closed some alternative road routes. Public opinion forced the government to back down on some closures and charges, leading to legal conflict with the contractor. The positive side of public private partnerships is that the project generally gets built! Without the cooperation of both sectors, the combination of political, financial and technological delays can drag a project out over many years.

Expertise	**Public Sector**	**Private Sector**
Cost management		☺
Construction		☺
Technology		☺
Operation and Maintenance		☺
Finance	☺	
Land availability, access and approvals	☺	
Legislative changes	☺	
Environmental	☺	
Political	☺	

Fig. 17.1 Organizational strengths in public private partnerships

Chapter 18
Know Your Assets

Familiarity breeds

Chapter Aim: The aim of this chapter is to draw attention to the need for asset managers to be familiar with their assets in a technical, business and operational context. The role of the asset manager involves being well informed across the application of the assets, although this does not mean that the asset manager will be the ultimate expert on any one functional aspect. The asset manager will also have an integrated view of the assets as a whole and will understand the relationships, interdependence and degree of criticality among the deployed assets.

Chapter Outcomes: After reading this chapter you will be aware of the importance of understanding the range of assets which are used in the business, their roles, the technologies involved and the relative criticality of particular assets. You will be aware of the value of expert teams which have in depth asset knowledge and of the significance of bottlenecks which can occur particularly in flow process businesses.

Chapter Topics:

- Awareness of Key Assets
- Block diagrams
- Criticality
- Expert teams
- Bottlenecks
- Backlogs

N. A. J. Hastings, *Physical Asset Management*,

18.1 Awareness of Key Assets

Successful asset management is dependent on managers having a clear understanding of the assets required to physically sustain the business and to keep it profitable. There is value in having a *register of key assets* of the organization which includes information on their leading specifications and age. Having a high standard of awareness of the key assets promotes good asset management. In particular it focuses the attention of employees at all levels on the role and significance of the assets on which the organization depends. It is also valuable to promote an awareness of the range of assets and their inter-relationship in providing essential capabilities.

Asset management information systems contain a vast amount of detailed information. In order to see the wood for the trees, the register of key assets, which is essentially a report generated from the full asset register, lists the main items at a senior management decision level. The register of key assets is a vital document in capability development planning and capital budgeting. This document will incorporate information such as:

- Asset/Capability title
- Brief configuration detail
- Location
- Age
- Estimated remaining life
- Cost
- Replacement cost
- Recent history e. g. last overhaul or upgrade date
- Known issues
- Known plans

There is also value in having maps, plans, satellite images, photographs and surveillance images at various levels of detail, making it as simple as possible to understand the location and nature of assets and their current condition.

An indication of the range and complexity of industrial assets is given by Fig. 18.1, which shows the assets at a mine site. The actual mining operation is not in the picture, and requires a further range of assets in the form of mining machinery and supporting services. Most industrial complexes involve a wide range of types of asset.

A statement of the quantity of assets under management, of the budget involved and of the work carried out annually is valuable as an indicator to staff, to senior management and to the public of the scale of the asset management task. Table 18.1 gives an example.

At a large electricity transmission company the CEO arranged for video screens in the head office to display, on a real time basis, the electricity throughput of each of the company's major transmission lines. This drew the attention to the fact that the important action was happening out there in the field, and that the activities of the office staff were essentially in support of the physical transmission process.

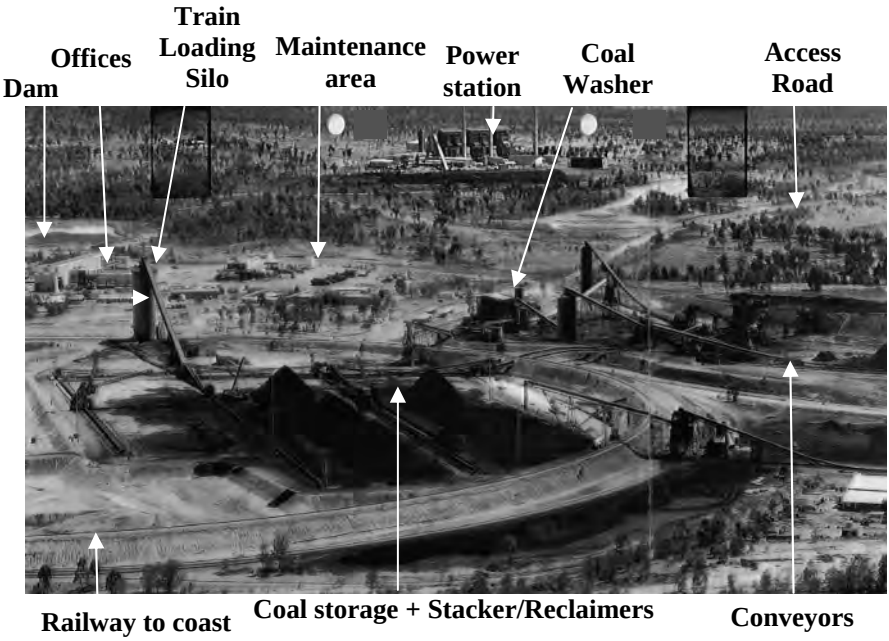


Fig. 18.1 Mine site assets

Table 18.1 A major asset summary

Asset	Quantity
Track	1,800 kilometres
Electrification system	1,600 kilometres
Turnouts	4,715
Signals	3,683
Train services per day	2,500
Customer journeys per day	2.7 million
Annual capital budget	$1 billion
Annual maintenance budget	$1 billion
Annual track reconstruction	42 kilometres
Annual rerailing	74 kilometres
Annual overhead wiring rebuild	16 kilometres
Turnout renewals	60
Track circuit renewals	155

Source: RailCorp New South Wales Asset Management Group

The combination of asset knowledge and business knowledge is not easy to acquire. Operations and maintenance personnel acquire asset knowledge in the course of their work. Engineers working close to the action acquire technical asset knowledge, and their training provides an understanding of the fundamental principles of operation of the asset and they are then able to combine this with practical experience, but they tend to be weak in relation to business understanding. The ideal is someone who comes up through the ranks but has the ability to handle the overall business; Captain Cook for example. The stratification of education tends to prevent the emergence of such people. It is unfortunate that university business schools grew up independently of engineering schools, and give overwhelming prominence to finance, marketing and human resource management with asset and operations management hardly appearing on the curriculum.

18.2 Block Diagrams

System block diagrams help in the understanding of role and criticality of assets. A very simplified block diagram based on a power station is shown in Fig. 18.2. The following are some rules for creating block diagrams.

1. The *function* of each component or block should be identified
2. Each block should be *physically* identifiable
3. The blocks should be mutually independent (as far as reasonably possible)
4. Links, e. g. pipes, wiring, couplings should be assigned to specific blocks, or form their own block where justified
5. Each block should preferably focus on one main technology e. g. mechanical, electrical, hydraulic, PLC.

18.2.1 Information Required Per Block

The following points give an indication of the type of information required in relation to each block.

- Function of block and basic operating principles
- Inputs
- Outputs
- Structure, e. g. assemblies, components and functions and operation of these
- Operating norms, e. g.
  - Production or Flow Rate
  - Yield
  - Pressure
  - Temperature
  - Other gauge settings

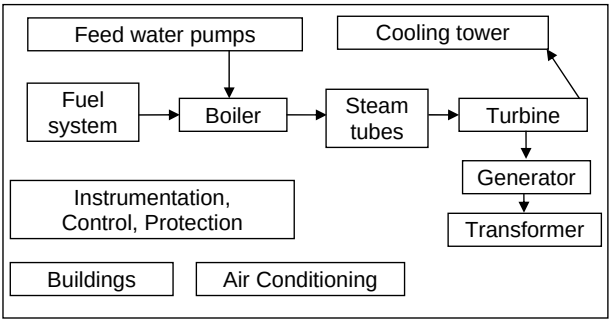


Fig. 18.2 Power station block diagram

18.3 Criticality

For asset planning we need to understand the *criticality* of the various items. This will be in terms of potential production losses if they fail, and also reflect safety and environmental issues. Criticality analysis helps us to prioritise maintenance work and also provides a basis for designing-in redundancy. There are many examples where the loss of a production unit has caused major disruption on a state-wide basis, such as the Varanus Island gas terminal in Western Australia, where a failure cut off one third of the state's gas supply. A similar example is the Longford gas plant in Victoria where a failure cut off the gas supply to Melbourne for several weeks; subsequently, other sources of gas supply were expanded so that risk was reduced.

In the example of Fig. 18.3 from a chemical plant, the heat exchangers were identified as the most critical assets as they are not duplicated and can only be repaired off-line, a time consuming process involving extensive delays. To offset the criticality we need to prioritise these items and ensure that they meet fitness-for-service criteria at a standard sufficient to sustain them over a defined planning and inter-inspection period.

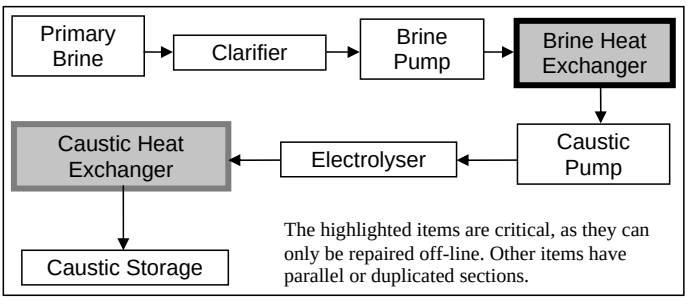


Fig. 18.3 Block diagram and criticality – chemical plant

In the example shown in Fig. 18.4 from a mining site, criticality is based qualitatively on the following factors:

- Failure Category (Unlikely, Adequate Warning, Sudden)
- Failure Impact (Low, Medium, High)
- Ease of Repair (No shutdown, Shutdown area, Shutdown plant)
- Mean downtime (Low, medium, High)
- Cost of Breakdown (Repair cost only, Minor production loss, Major production loss)

18.3.1 Expert Teams

An expert team is a group of people with specialized knowledge of the working of a particular functional area or of a particular type of the plant. The technical nature of the equipment and processes make it essential to have people who understand the plant in order to make sound decisions. Forming expert teams gives plant personnel status and motivation. They take their expertise seriously and it is taken seriously by management.

In some cases the expert team may be formed by linking experts across sites. For example, a mining company may have an expert team with knowledge of a particular type of process or machine, such as draglines. Technical problems relating to draglines, such as root cause analysis of failures, would draw on the knowledge of this group.

	A	B	C	D	E	F	G	H	I
1	Equipment Name	Number off	Failure rate 1=Low 2=Medium 3=High	Safety Enviro impact 1=Low 2=Medium 3=High	Ease of repair 1=No shutdown reqd 2=Shutdown of area 3=Shutdown of plant	Mean Down Time 1=Low 2=Medium 3=High	Cost of Breakdown 1=Repair cost only 2=Minor production loss 3=Major production loss	Criticality = 3* C*(D+E+F +G)	Comment
2	Drilling rigs	2	3	2	1	2	1	54	Can lease if critical
3	Dragline	1	2	1	2	2	1	36	
4	Coal loaders	8	2	1	1	2	2	36	6 out of 8 reqd
5	Dump trucks	14	2	1	1	1	1	24	10 out of 14 reqd
6	Transport	12	1	1	1	1	1	12	
7	Main conveyors	2	2	3	3	3	3	72	
8	Subsidiary conveyors	12	2	2	2	2	2	48	
9	Stacker reclaimer	1	2	1	2	2	2	42	
10	Blender	1	2	1	2	2	2	42	
11	Coal washer	1	1	3	2	2	2	27	
12	Loading silo	2	1	1	2	2	2	21	Old silo retained as standby
13	Rail track	1	1	3	2	2	3	30	Contractor
14	Rail system	1	1	3	2	1	2	24	
15	Rail locos	6	1	1	2	2	2	21	Contractor
16	Rail wagons	248	2	2	2	2	2	48	More redundancy reqd
17	Unloading bay	1	1	1	2	2	3	24	
18	Port stacker reclaimer	1	1	3	2	3	3	33	
19	Dozers	1	1	3	2	3	3	33	
20	Port conveyer	1	2	1	2	2	3	48	
21	Ship loader	1	2	1	2	2	3	48	

Fig. 18.4 Criticality analysis of mining assets

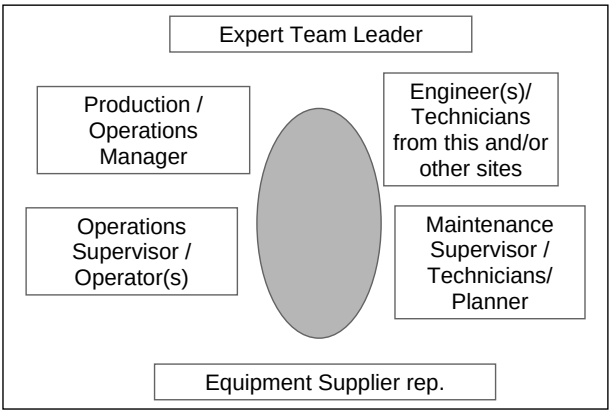


Fig. 18.5 Expert team

18.4 Bottlenecks

A bottleneck is a part of a process which has limited capacity, and therefore constrains the throughput of the system as a whole. In systems involving simple flow processes, effective improvements can only occur at bottlenecks. In non-bottleneck areas, increasing capacity will not improve overall throughput, but will simply generate more spare capacity in the non-bottleneck area. However, bottlenecks are not always constant, but may depend on the production or product mix. For example, in a production facility, if we receive a very large order for product requiring heat treatment, then our heat treatment plant will become the bottleneck, whereas with a normal mix of orders, we may have plenty of heat treatment capacity. We should therefore consider how demand on machines varies with the product mix before focusing on a current bottleneck. Also, if we act to remove an existing bottleneck, the effect may be limited by causing a new bottleneck to appear in a different part of the process.

De-bottlenecking involves making investments which are cost effective in increasing product flow or reducing costs by relieving bottlenecks. As part of our asset knowledge we should be aware of existing and potential bottlenecks, if any, and seek to relieve bottlenecks where this can provide the most cost effective improvements. The following steps are recommended for this purpose:

1. Flow chart the process, identifying operations, queues, storages.
2. Identify demand drivers (e. g. customer pull), demand rates and translate into average required throughput rates for each part of the process. Take account of average and peak loads.
3. Identify capacity constraint areas – potential bottlenecks
4. Calculate maximum throughput rate of areas, using averages, then allowing 25% for queuing effects, then taking maintenance into account.

5. Recognize areas as (a) complete bottlenecks, (b) occasional bottlenecks, (c) excess capacity.
6. Consider variability in service times. A high degree of variability (as opposed to consistent, even performance) leads to longer queues and/or larger stockpiles.
7. Treat bottlenecks by adding capacity, reducing variability or prioritizing flows.

18.5 Backlogs

The build-up of backlogs of work in particular areas is relatively easy to identify, but is often ignored by management. Backlogs are a simple indicator of lack of resources in particular areas, whereas lack of a backlog indicates adequate resources, unless there is some deliberate attempt to distort the picture. Management should respond to the build-up of backlogs by checking the reason and taking steps to reduce the backlog, or to contain it to reasonable levels.

18.6 Plant Criticality Exercise

The senior management of a process plant wants to increase production. They are considering adding another product line and have a cost estimate of $750,000. You are a plant engineer and are asked to comment on the proposal. You know that the standard of reliability of the equipment is not high and that downtime is significant, particularly for the furnace and blower.

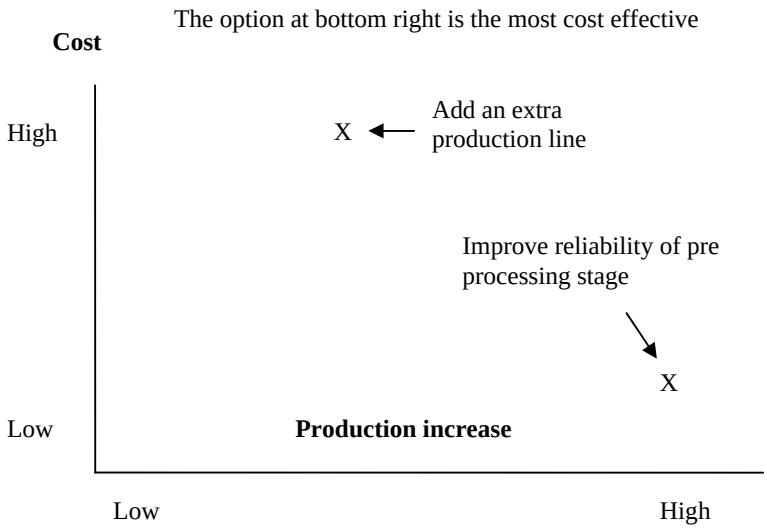


Fig. 18.6 Cost-effectiveness of de-bottlenecking – example

The plant produces intermediate plastic products. Raw material is fed from any of three hoppers into either of two feeder lines. The feeder lines pump material via a flow controller, through a furnace and then into a blower where it is formed into continuous sheet. There is a pump for each feeder line. From the blower, the material can be fed to any of five existing product lines. Give answers in dot point form to the following questions.

- Draw a block diagram of the process.
- Which stages of the process are critical from an operational point of view.
- What do you suggest to management?
- How would you back up your recommendations?

Chapter 19
Asset Management Information Systems

Chapter Aim: The aim of this chapter is to outline the functions of an asset management information system and to consider issues relating to the use, resourcing and operation of the system.

Chapter Outcomes: After reading this chapter you will know the main applications for which an asset management information system is programmed and the type of coding systems which are used to identify equipment, locations and activities. You will be aware of the need for adequate resources to maintain the system and for user training in its use. You will see the structure of the data flows and be aware of the role of the system in the on-going management of current tasks.

Chapter Topics:

- Information system role and applications
- Base data and the need for coding
- Functional locations
- Mobile plant coding
- Location code structure
- Activity and trade codes
- Resourcing and managing the system
- Data administration
- Users
- Features
- Implementing changes
- Reports and their uses.

N. A. J. Hastings, *Physical Asset Management*,

19.1 Information System Role and Applications

An asset management information system is a computer based system which is designed to assist the user to create and maintain documentation for the asset management function. These systems are sometimes referred to as Computerized Maintenance Management Systems (CMMS), as many of them had their origin in the maintenance side of the application. Applications covered by these systems include those listed in this section. Although the software systems will normally have capabilities in these areas, to actually make practical use of the features requires initial data setup, on-going data input, working methods which are consistently applied, training and implementation support. On a more positive note, there is no doubt that computer systems are essential to handling the considerable mass of information associated with asset management, and that experience shows that in most cases, the more extensively a computer system is used, the greater the value that is derived from it. The applications list follows:

- Asset Register including listing of maintainable assets
- Routine Maintenance Lists
- Routine Maintenance Prompts
- Work Requests
- Work Order Management
- Data Logging
- Estimating, Costing and Cost Reports
- Budgeting, budgetary reports
- Spare Parts and Consumables Inventory Management.
- Suppliers, Purchasing.
- Global Positioning Systems.

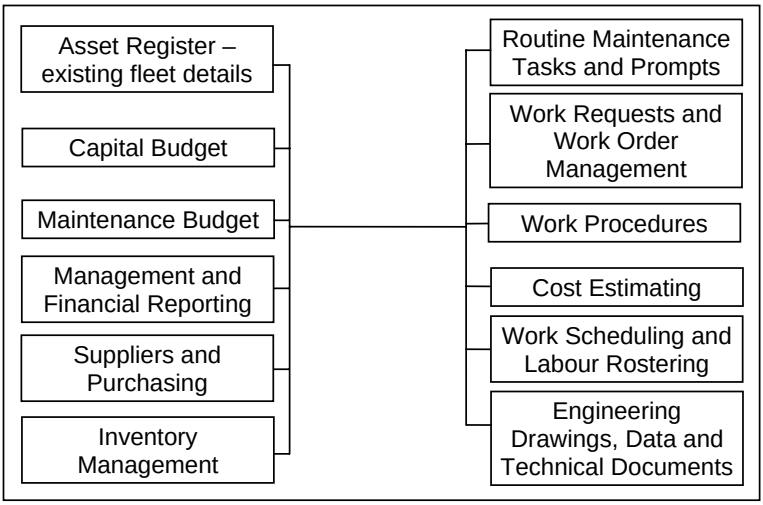


Fig. 19.1 Asset management information system

- Work Procedures including safety.
- Tools and Equipment Inventory.
- Planning and Scheduling.
- Labour categories, personnel, availability, rosters, assignment.
- Work history and analysis.
- Management Reports.

19.2 Base Data and the Need for Coding

When a company buys a Computerized Maintenance Management System it buys an *empty* data base. To use the system, it must populate the data base with data from its own business. This requires the company to establish a system for designating and coding all the entities involved in the various applications listed in the previous section. Systematic structuring and coding is essential. The codings required for financial purposes and for maintenance purposes are generally different, and it is therefore usually necessary to have both Account Codes and Functional Location codes within the system.

19.2.1 Functional Locations

A functional location is a place where an item is located in order to carry out a given function. The functional location enables us to identify locations for operational and maintenance purposes. The functional location is to be specified on Work Requests, Work Orders, Inspection Plans and related documents such as safety or emergency plans.

In static plant or buildings, a functional location corresponds to a place and the function of the item located there. For example, in a house, the different rooms would be different functional locations. Further breakdown of locations would identify such functional locations as the kitchen sink, cooker, refrigerator. The specific item at a functional location may change, but the functional location remains the same. Thus, if the refrigerator at a given functional location changes, the functional location remains the same. If we wish to track the history of a particular refrigerator, we will need to record information which specifies the serial number.

As a further example, consider a large hospital. The hospital will have different areas and different buildings within those areas. Functional location coding system would have a structure that identified the general areas, and then identified the individual buildings within each area. Within a particular building there may be several kitchens. Each kitchen has a functional location code. Within a given kitchen there are two cookers. Each cooker location has a functional location code. If maintenance is required to a cooker, we identify where the maintenance is needed by its functional location code. Some judgment is required in order to achieve clarity, but to avoid an excess of detail.

If a specific cooker requires replacement, the new cooker will have a different serial number from the old (and may be of a different type), but the functional location remains the same.

19.2.2 Mobile Plant Coding

For mobile plant, such as motor vehicles, railway wagons or aircraft, the vehicles themselves will be identified by serial number. Functional locations will be defined for the constituent internal locations. These location codes will apply to all similar types of plant. Major assemblies for which individual tracking is required will also be identified by serial number.

A type-of-item, such as a particular model of diesel engine, will identified by:

- Type Code
- Description
- Manufacturer
- Technical characteristics e. g.
- Power rating
- Number of cylinders and layout
- Size and weight…
- Bill of Materials / Spares catalogue reference

A specific item, such as a particular diesel engine, will identified by:

- Serial Number
- Type Code
- Date of Manufacture

Serial number tracking is necessary for major assemblies which may move between functional locations, if their life history is to be traceable. Thus, in a Model T Ford, the functional location for the engine might have the code “E”. A specific vehicle has serial number “1234”.

The engine “location” of the specific vehicle will be identified by a combination of the vehicle serial number and the functional location code = 1234E. A specific engine would be identified by its engine serial number. If an engine was replaced, the functional location 1234E would be unchanged, but the serial number of the engine in that location would be different.

19.2.3 Location Code Structure

Keep identifier sub-strings to uniform length to facilitate report generation. The following example relates to an electricity transmission system. The system covers

a number of geographic areas, labelled A, B, C, etc. Within each area there are a number of substations. In area A the substations are labelled A01, A02 and so on. The substring which identifies the substation is long enough to cover the possibility of up to 99 substations in an area.

Within each substation there are a number of circuit breaker bays. In substation A01 there are bays A01-01, A01-02 and so on. Then within a particular bay there

```
Area A
   Substation A01 00 000
      Bay A01 01 000
         Circuit breaker A01 01 CB1
            Current transformer A01 01 CT1
            Voltage transformer A01 01 VT1
         Circuit breaker A01 01 CB2
              Current transformer A01 01 CT2
            Voltage transformer A01 01 VT2
         Bay A01 02 000
            Circuit breaker A01 02 CB1
```

Fig. 19.2 Functional location coding – electricity substation

Area	Location
100	Administration
110	Administration General
111	Management and Supervision
130	Supply
131	Storage
132	Fuel
150	Accommodation
154	Site Camp
160	Site Maintenance
162	Buildings
170	Services
171	Power
172	Water Supply
173	Portable Water
200	Mining
220	Dewatering
221	Groundwater
222	In Pit Water
290	Environment
300	Concentrator
310	Concentrator General
311	Management and Supervision
312	Buildings
313	Spares
316	Smelting
318	Cobalt Study

Fig. 19.3 Plant area location coding example (part)

01 ELECTRICAL SYSTEM
- 0101 AC Breaker Panel
- 0102 AC Auxiliary Control Panel
- 0103 Door Supply
- 0104 Battery Charger
- 0105 Battery System
- 0106 DC Breaker Panel
- 0107 DC Auxiliary Control Panel
- 0108 Grounding System

02 PNEUMATIC SYSTEM
- 0201 Air Compressor
- 0202 Air Control Package
- 0203 Brake Control Package
- 0204 Auxiliary Release Package

03 AUTOMATIC TRAIN CONTROL SYSTEM
- 0301 Automatic Train Protection
- 0302 Automatic Train Operation
- 0303 Automatic Train Supervision

04 PROPULSION AND DYNAMIC BRAKING SYSTEM
- 0401 Propulsion System Devices
- 0402 Dynamic Braking System Devices
- 0403 Traction Motor
- 0404 Motor Control Box
- 0405 Brake Resistors
- 0406 Brake Transformer
- 0407 Brake Interposing Relay Box
- 0408 Propulsion Monitor Panel

Fig. 19.4 Functional location coding for an electric train (part)

are individual circuit breakers, and for any circuit breaker there are important components which include Current Transformers and Voltage Transformers (these are instrument transformers which are part of the circuit protection system). The coding system is illustrated in Fig. 19.2. The system enables us to identify any item down to the coded level of components. Also, in analysing historical data, for example, all work orders relating to Current Transformers can be extracted by selecting on code "CT" in positions 8:9.

19.2.4 Activity and Trade Codes

Examples of activity type and trade type codes are shown in **Fig. 19.5**.

ACTIVITY CODES - EXAMPLE

I	Inspect
R	Repair
X	Replace
A	Adjust
L	Lubrication, Fluids
C	Condition Monitoring
F	Fabrication, Manufacture

TRADE CODES - EXAMPLE

M	Mechanical
E	Electrical
W	Welder
T	Textile
I	Instrument
A	Air Conditioning
L	Laborer

Fig. 19.5 Activity codes and trade codes

19.3 Resourcing and Managing the System

19.3.1 Data Administration

Maintenance data administration must be a recognized activity. A combination of staff abilities is required, since technical knowledge is needed for part of the work, but data handling skills are a predominant requirement in other phases of the application. Adequate and consistent resources must be allocated to creating and maintaining the data other wise it will quickly become worthless. This includes keeping up-to-date the register of maintainable assets, the maintenance policies and supporting data such as work procedures and safety procedures.

19.3.2 Users

All trades personnel should be familiar with the system. This familiarization must be part of the training requirement for all potential users. It is highly desirable to get those who enter data, typically the trades persons who carry out work, to make use of some reporting features of the system. This will provide motivation for maintaining the quality of the data input. The more extensively the system is used, the greater are the benefits.

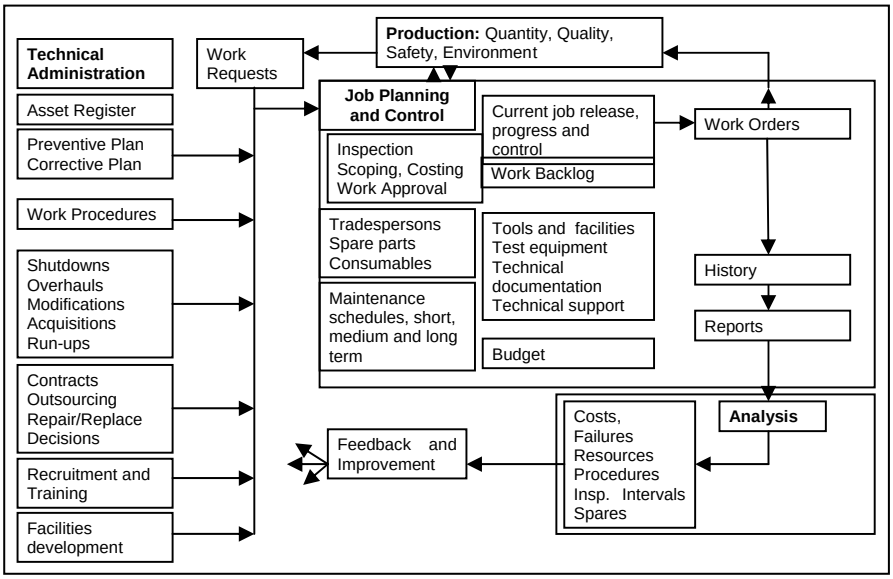


Fig. 19.6 Data flows in a CMMS

19.3.3 Features

The system must provide and readily maintain:

- list of current tasks;
- up-to-date status knowledge of current tasks;
- roster of resources – who is on duty when;
- schedule of assigned resources – who is doing what now and in the immediate future; and
- a rapid, secure, reliable, simple message passing system.

Figure 19.6 shows the data flows which are routinely handled in a computerised maintenance management system. The asset management system as a whole will also incorporate inventory management, costing and budgetary management.

19.4 Implementing Changes

A factor in the management of computer systems is the need to make changes, but at the same time to exercise control over the validity of changes. Anyone who has tried to notify their bank of their change of address will be aware of the problem. **Figure 19.7** shows the steps involved in implementing a data change in a computer system. Data integrity can only be achieved at the expense of a considerable number of checks.

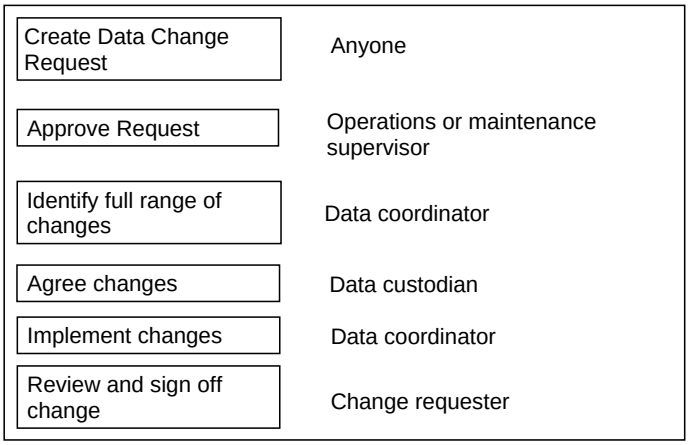


Fig. 19.7 Steps in implementing data changes

19.5 Reports and their Uses

The following are examples of the type of reports which can generally be generated from the asset management computer system, and some of the uses to which these reports are put.

- Operational loss reports. Check causes and follow up to improve performance and reliability.
- Unscheduled work orders. Check causes and follow up to improve performance and reliability. Check history to see if job is recurring, if so investigate, improve – Pareto analysis. Review downtime and seek reductions using rotables, repair kits, better diagnostics, training, spares and support equipment availability. Update job procedures and job requirements. Review inspection and replacement intervals.
- Budget expenditure year to date by account code, by equipment type, by location. This report helps with current budgetary management, and with the assessment of future resources.
- Man-power utilization by trade; by equipment type; by location. This report helps with the allocation of staff by location, and with determining staff requirements
- Maintenance cost by item type by year of life. This report provides a basis for the replacement planning.
- Spares utilization by part number. This report provides the basic input into stock control parameter setting and reorder decisions. Use forecasting and reorder analysis to review spare parts holdings.
- Failure frequency by failure mode and year of life. This report is provides a basis for determining optimal component replacement and inspection policies
- Assembly replacement events and odometer readings. This provides a basis for planning and monitoring policy regarding rotables provision and repair services.

19.6 Exercises

19.6.1 Asset Data Setup Exercise

This exercise relates to a part of a Chlorination Blower. Chlorination Blowers are used in oil refineries as part of the catalytic reforming process. Initially you are setting up the asset register. A small section of the Bill of Materials for the blower is shown in **Fig. 19.8** and **Fig. 19.9**. Use this to:

- Create a coding system for the components shown.
- Create coding systems for the trade and activities shown.

In the following exercises indicate only the brief descriptions and related codes for the key tasks.

- An operator carrying out a shift inspection sees that the casing of the blower is loose and leaking fluid. Create a work request indicating the fault location by code and the fault description.

Chlorination Blower Reformer A
- Mechanical System
  - Housing
  - Casing
  - Fan Shaft
    - Seals
    - Guards
  - Coupling
    - Guard
  - Impeller
    - Bearings
    - Seals
- *By part number:*
  - Plugs
  - Fasteners

Fig. 19.8 Chlorination blower bill of materials

Trade: Mechanical

Activity Types:
Inspect
Lubrication
Replace
Repair
Adjust
Vibration Monitor
Fabricate/Manufacture

Fig. 19.9 Trade and activity types

- A site check indicates that a casing bolt is broken. Create a work order to replace the bolt and to carry out vibration monitoring of the fan.
- Vibration monitoring indicates that an impeller bearing needs replacing. Create a work order for this job.

19.6.2 Pacific Earth Moving Part 4 CMMS

The senior management of Pacific Earth Moving is assessing the need to introduce a comprehensive Computerized Maintenance Management System (CMMS) to sustain its activities. Your group has been retained to advise on the desirability or otherwise of such a system and the support which such a system would require in order to implement and maintain it.

a) List in dot point form the functions which a CMMS can be expected to support and indicate their value to the company.
b) List in dot point form the resources needed to implement and support a CMMS system.
c) Briefly summarize the case for and against such a system for presentation to a company board consisting predominantly of lawyers, financiers and entrepreneurs.

Chapter 20
Maintenance Organization and Budget

Chapter Aim: To describe the features and organizational structures used in asset management and maintenance from good housekeeping through first line and second line maintenance. To show how maintenance budgets can be created and managed.

Chapter Outcomes: After reading this chapter you will be aware of the main features of maintenance activity, ranging from the operator level to workshop level. You will understand the importance of good housekeeping and basic maintenance and how to organize the workplace so that these are well managed. You will know about maintenance organization, including the role of maintenance services, and about workflow management and maintenance budgeting.

Chapter Topics:

- Introduction
- Total productive maintenance (TPM) or asset basic care.
- Basic maintenance
- Performance recording
- Management support
- Maintenance organization
- Maintenance layout
- Maintenance work management
- Maintenance budgeting
- Costing
- Budget cost control
- Budget reports
- Activity based costing

N. A. J. Hastings, *Physical Asset Management*,

20.1 Introduction

An essential requirement of successful asset management is taking care of assets. This involves activities at several levels, ranging from cleanliness and good housekeeping by the user or operator, to first line maintenance activities such as servicing, lubrication and adjustment, to second line maintenance involving repairs and assembly changes, and on to deeper maintenance or overhaul. In addition, there are many technical factors in maintenance, including condition monitoring.

Determining the right level of maintenance activity and hence of expenditure is not an easy task. The role of asset managers is to be aware of available techniques both in terms of management and technology and to apply them appropriately to the benefit of the business. It may be tempting to senior managers to demand more production or to cut maintenance budgets as a response to problems, but such actions quickly become counter-productive if the care and maintenance of assets is neglected.

20.2 Total Productive Maintenance or Asset Basic Care

At first-line level, in a manufacturing context, the process of caring for assets is referred to as *Total Productive Maintenance* (TPM). A more general term is *Asset Basic Care*. Asset Basic Care/TPM involves workplace employees, such as operators and first line maintenance staff in achieving a high standard of care of assets as an integral part of their normal work. Asset Basic Care / TPM is *non-heroic maintenance.* The major elements include:

- Cleanliness and good housekeeping;
- Routine inspection, lubrication and adjustment;
- Focus on machine knowledge, machine performance, quality of output and elimination of losses;
- A sense of ownership by operators and first line maintainers.

The concepts in Asset Basic Care / TPM are summarised in Fig. 20.1.

20.2.1 Workplace Tidiness and Organization

The first essential of asset basic care is a tidy workplace. Some areas have never been tidied up since the industrial revolution. Remove unused or inessential items, especially:

- old or imperfect product
- surplus materials,
- obsolete or unnecessary tools,

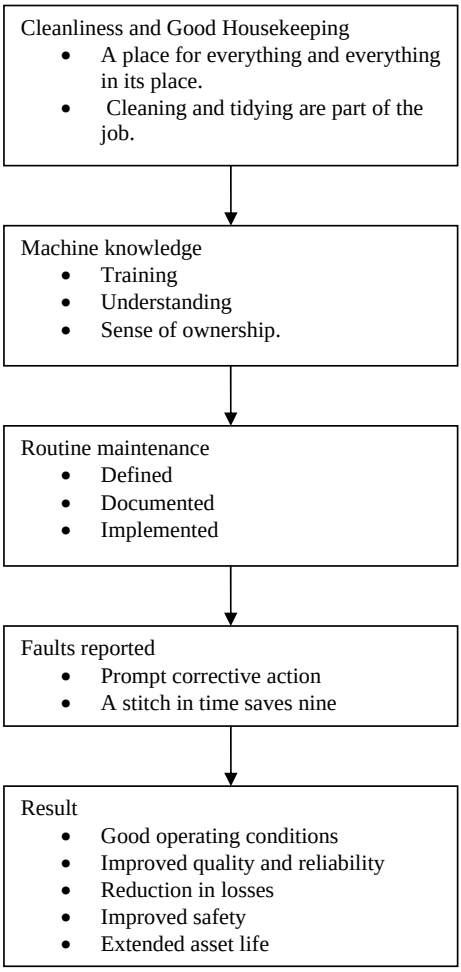


Fig. 20.1 Asset basic care or total productive maintenance

- obsolete fixtures,
- obsolete or inessential documents,
- horse drawn wagons unless it is a theme park.

Having tidied up, get organized. For each workplace list all required:

- tools and instruments,
- implements,
- accessories,
- consumables.

Determine a place for all essential items and provide:

- shelves,
- containers,
- holders,
- labelling.

Use simple indicators, e. g., marks on the floor, coloured shelves to show placement of essential items. Use these facilities and keep items visible.

20.2.2 Maintain Standards

- Take countermeasures against dirt and dust.
- Determine how everything is to be kept clean.
- Provide equipment such as brushes, cloths, vacuum cleaners, dish washers.
- Design out systematic uncleanliness, using shields, covers, waste disposal methods, etc
- Make cleaning up a standard part of every job.

Set cleaning and tidying standards and routines.

- Assign responsibilities.
- Rotate tasks among operators and allow them to agree on who does what.
- Specify cleaning time e. g. Five minutes at end of each shift and half hour per week, plus if idle
- Assign responsibilities for all aspects of supply, storage and disposal of work place items.

20.2.3 Training

Create the training material for:

- correct operating conditions and procedures
- machine knowledge
- basic maintenance procedures
- fault reporting procedures
- knowledge of existing losses

This is done by supervisors and experienced maintenance personnel, initially for a pilot area, later extended to all operations. Training facilities are needed e. g. training room next to shop floor, white board, projector, training materials.

20.2.4 Machine Knowledge

Develop and display machine information on notice boards beside the machines.

- Name of machine
- What it is intended to do
- How it works – without going into unnecessary technical detail … simple flow chart
- Written, step by step details of all necessary procedures, including operating conditions, e. g. temperature, pressure, vibration and alignment checks …
- Troubleshooting guide.

The creation and maintenance of this material is a worthwhile learning task for young graduates.

20.3 Basic Maintenance

Asset performance and sustainment are greatly improved if equipment is kept in good condition. To achieve this, basic maintenance must be carried out on a regular basis. Besides cleanliness, this includes lubrication, adjustment of things that are intended to be adjusted, and tightening or replacement of loose or missing nuts and bolts. In Asset Basic Care / TPM we organise basic maintenance with the aid of the following steps:

- Identify and document lubrication points, adjustment points, checks for nut or bolt tightness and anything else that the operators or first line maintainers need to know about.
- Colour code lubrication points and adjustment points by interval, e. g. daily, weekly, monthly checks.
- Create basic maintenance procedures, standards and routines.
- Specify maintenance and inspection intervals and times
- Identify abnormal conditions in specific terms, e. g., pressure or temperature gauge readings, measurements, flow rates.
- Define basic inspection procedures and corrective actions which the operator can take.
- Specify action to be taken from inspection results, including immediate corrective action, and the raising of work requests for activities which can be deferred. Define how to report conditions which are outside the operator's scope of activity.
- Train workforce personnel in basic maintenance, diagnostics and reporting
- Assign responsibilities.
- Rotate tasks among operators and allow them to agree on who does what.

Task Type	Assign to
Cleaning/housekeeping	Cleaner or operator
Operating	Operator
Servicing	Operator or lubricator
Minor set up	Operator or technician
Minor repair	Operator or technician
Skilled maintenance	Technician

Fig. 20.2 Assignment of basic care tasks

20.3.1 Assign Housekeeping and Basic Maintenance Tasks

Appraise tasks and assign them as you think best, with input from those involved. The essential thing is that all tasks are assigned, **Fig. 20.2** shows examples of possible assignments.

20.3.2 Routine Maintenance by Technicians

More technical maintenance activities will normally be assigned to technicians. Particular attention must be paid to the carrying out of maintenance activities which are required by law or by good practice, such a boiler or pressure vessel inspections.

20.3.3 Accredit Workers

After training, test the competency of workers on machine knowledge, operation and basic maintenance. Recognise their achievements by accrediting them to operate the relevant machines; give them a certificate. This may involve upgrading and higher pay, but an overall payoff can be expected.

The workers closest to the equipment, operators and first line maintenance technicians, have the greatest level of involvement and the greatest degree of equipment knowledge at the user level. This knowledge can be leveraged by empowering the workers to take a wide range of actions in support of production operation and maintenance. In addition to good housekeeping and basic maintenance, these actions can include the replenishment of work place equipment, contact with second line maintenance, participation in quality and condition monitoring activities and performance recording and analysis. Participation in continuous improvement activities and root cause failure analysis activities should also be encouraged.

20.4 Performance Recording

Collect and display simple statistics, e. g.

- Machine downtime by weeks (time lost to operators).
- Machine lost time by weeks (time machine available but not effectively used by operators).
- Quality losses by weeks, numbers of sub-quality product.
- Unplanned maintenance activity by months, showing type of breakdown/repair.
- Time spent on (particular) setups.
- Causes of losses sequenced by frequency of occurrence.
- Causes of losses sequenced by cost significance.
- Trend over time to show improvements and opportunities.

20.4.1 Performance, Quality and Reliability Improvement

The high standard of housekeeping and maintenance, and the recording of performance data and identification of losses and their causes, as promoted by TPM, provide a basis for the improvement of performance, of quality and of reliability. In the production context the potential for and methods of improvement are well documented in works on Total Productive Maintenance and Total Quality Control, such as those of Hartmann, Ishikawa and Suzuki listed in the references section. These advantages should also be carried over to non-manufacturing asset management situations. Operations information regarding losses and data from inspections and routine maintenance form an important source of knowledge regarding equipment condition, and a basis for improvements in performance and reliability of equipment.

20.5 Asset Basic Care / TPM – Management Support

Maintenance must be recognized as important by senior managers and all employees – the Plant Manager needs to commit to this. This recognition includes ensuring that routine maintenance is carried out and is not neglected due to pressure from operations staff or accountants.

Management should assign specific equipment to specific operators or small groups, giving them responsibility and empowerment. As an example, it it's a practice in the United States Air Force to assign management of each aircraft to an individual. This individual follows the aircraft when it goes for servicing or repair and ensures its security, integrity and priority are maintained.

Have a clear chain of technical expertise and use it. Do not remove all expertise from site. Have a fully functioning work request, job scoping, job planning, work order, job scheduling and progress / result reporting system.

20.5.1 Asset Basic Care / TPM Summary

- Cleaning and housekeeping
- A place for everything and everything in its place.
- Visible, documented procedures.
- Lubrication skills.
- Diagnostic skills.
- Minor adjustments.
- Minor setup changes.
- Routine maintenance (technicians)
- Minor repairs (technicians).
- Operator/maintainer certification.
- Sense of ownership.
- Continuous improvement.
- Create routine maintenance schedules on a calendar.
- Balance the workload.
- Publish the schedule, working with production to ensure agreed program.
- Stick to the routine!
- Work request and work management systems in use for non-routine work

20.5.2 Asset Basic Care /TPM Benefits

- More production through reduction in losses
- Improved product quality
- Improved working conditions
- Improved safety
- Overtime reduction
- Reduced absenteeism
- Environmental and legislative compliance

20.6 Maintenance Organization

Logistic Support Analysis as described in section 14.4 and Level of Repair Analysis as described in section 14.4.3, when aggregated across the asset portfolio, provide the basis for determining the size and structure of the maintenance organization as a whole. In the case of a substantial in-house maintenance organization, the structure will be as illustrated in Fig. 20.3 Maintenance organization. Further detail of the maintenance services function is indicated in Fig. 20.4 Maintenance Service.

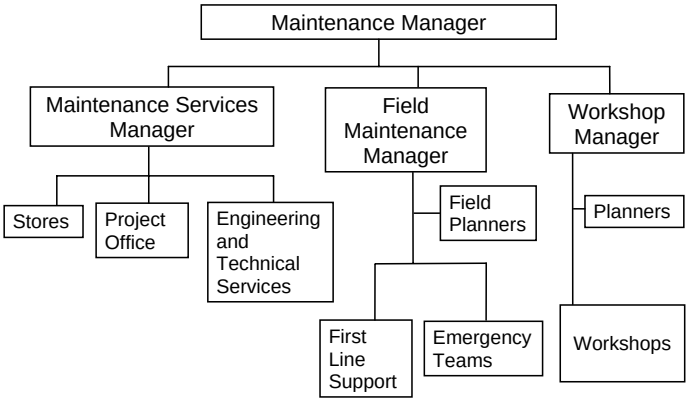


Fig. 20.3 Maintenance organization

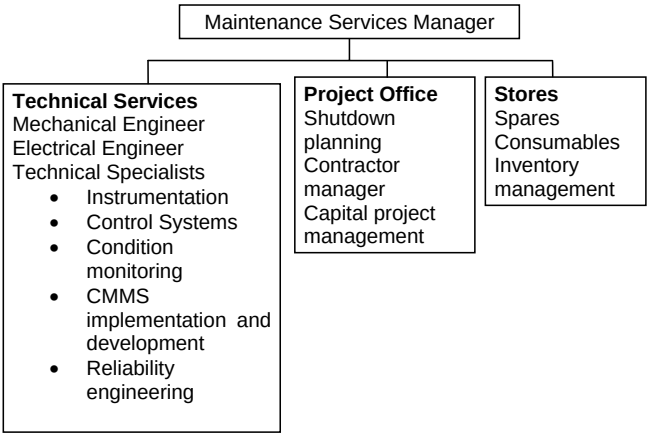


Fig. 20.4 Maintenance services

20.6.1 Maintenance Layout

A typical physical layout of a maintenance organization is shown schematically in Fig. 20.5. At first line, this shows some maintenance personnel assigned to production areas A and B and some shown as supporting all areas. The split will depend on whether the production locations are widely separated, or have similar or different technology. Unless there are reasons to the contrary, it is advisable to have most of the maintenance support placed centrally to support all areas as this provides the most efficient use of the resources. Good planning, scheduling and communications are important contributors to the efficiency of maintenance.

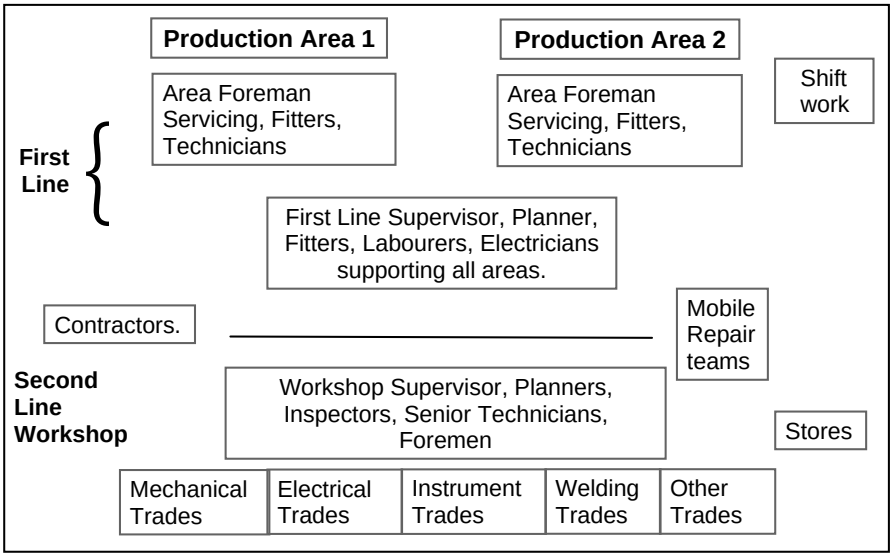


Fig. 20.5 Maintenance layout

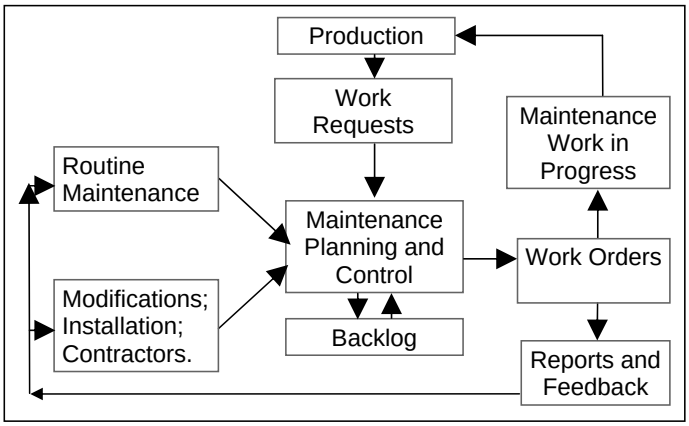


Fig. 20.6 Maintenance activity and information flows

20.6.2 Maintenance Work Management

A useful reference on maintenance work management is D. Nyman and J. Levitt, "Maintenance Planning, Scheduling and Coordination", Industrial Press Inc. The flow of information and of activity in the maintenance process is shown in Fig. 20.6. Figure 20.7 shows the roles of personnel in the management of maintenance work. Figure 20.8 shows the sequence of events in the maintenance job planning and control process. Figure 20.9 shows a scheme of job priorities. Figure 20.10 shows the sequence of activities in creating and managing the schedule of maintenance work from week to week.

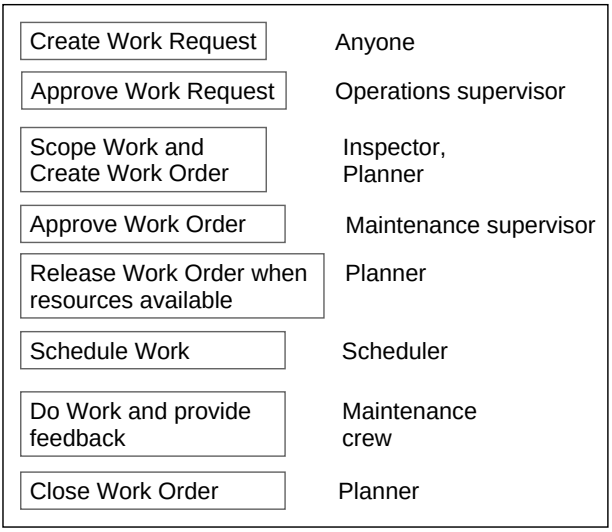


Fig. 20.7 Work management activities and typical roles

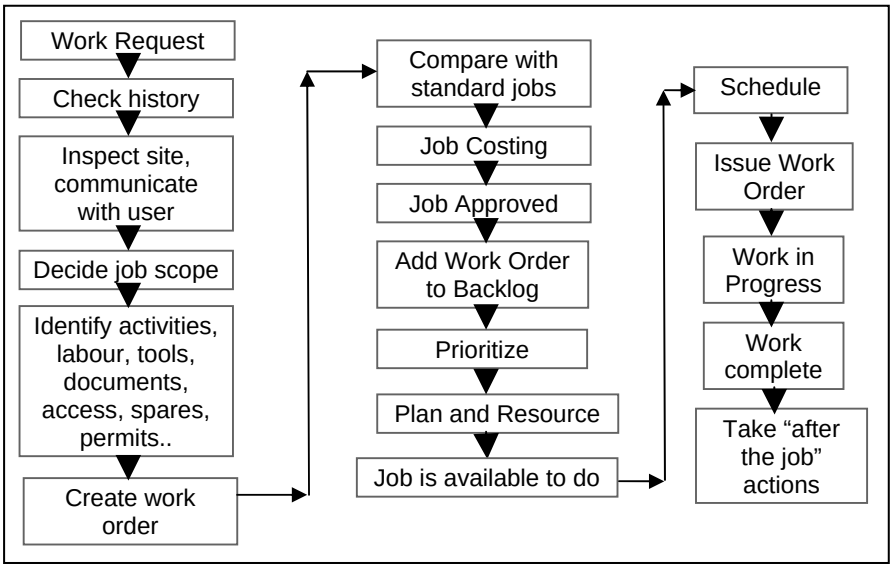


Fig. 20.8 Job scoping, planning, scheduling, controlling

1. Emergency immediate
   - Immediate safety hazard
   - Serious impact on production or service
   - Actual or potential serious plant damage
   - Infringes environmental safeguards
2. Current within 1 week
   - Potential to become priority 1 if unattended
   - Reduces standby or backup capability
   - Note: Routine maintenance slots in here.
3. Short term within 1 month
   - Desirable modifications to benefit personnel or efficiency
   - Likely deterioration in short term if not performed
4. Medium term within 2 months
   - Likely deterioration in medium term if not performed
5. Long Term
   - Seen as advantageous but not essential in short or medium term.

Fig. 20.9 Job priorities scheme

1. Each week the scheduler produces a schedule of work for the following week.
2. Assuming a week of Monday to Sunday, the schedule is produced on Thursday for the following week.
3. There is daily feedback on the schedule. The scheduler provides updates where needed but schedule stability is regarded as of considerable importance.
4. Some work will usually carry over into the next week.
5. The scheduler takes jobs on a basis of priority, drawing primarily from the available to do work in the backlog, and adds them into the schedule, until the available resources are committed.

Fig. 20.10 Weekly scheduling process

20.7 Maintenance Budgeting

20.7.1 The Business Plan

The starting point for maintenance budgeting is the business plan. In a mining operation, for example, the business plan will provide a production plan at each mine, and will give a planned number of tonnes of material to be moved in the year, in various categories such as overburden, ore and processed material of various types. The plan will often be structurally similar to that for the previous year, but the quantities will vary to a greater or lesser degree. An increase or decrease in the mined and processed quantities will affect the maintenance workload, as will variations in such factors as the distance from the ore body to the processing units. In

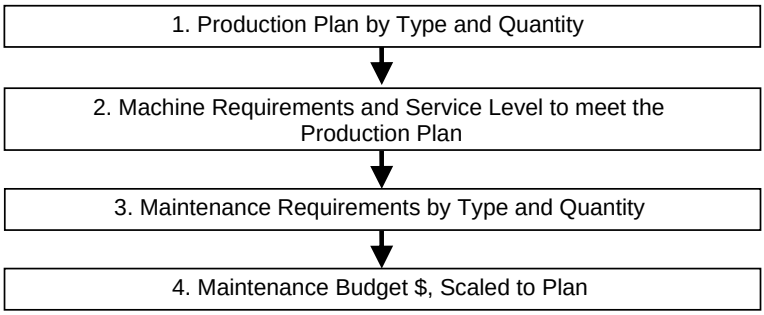


Fig. 20.11 Basic logic of the maintenance budget

addition to the basic processes there will be many subsidiary activities which must be taken into account.

The fact that changes from year to year are often marginal is both a blessing and a curse. It is a blessing in that the maintenance workload, and hence the maintenance budget may then be derived by marginal changes, but it is a curse in that a considerable drift in the maintenance resources from those actually required can occur over time. Indeed, it is not uncommon to find that quite drastic changes in the maintenance workload by quantity and type are not responded to in the maintenance budgeting process. The basic logic is summarised in Fig. 20.11.

20.7.2 Creating the Budget

The first step in **Fig. 20.11**, the production plan by type and quantity, must be provided as part of the overall operational planning process. In step 2 of **Fig. 20.11**, the maintenance manager analyses the production plan to determine the corresponding machine requirements. The service level required by the business plan is a factor in determining the machine requirements. For example, in a railway operation, the timetabling plan will determine the requirement for available trains. In step 3 of **Fig. 20.11** we determine the maintenance workload in order to meet the planned machine availability. This should be done as part of the total planning process, as the success of the production plan will be dependent on the ability of maintenance to service it and the implications of the plan for maintenance must be taken into account. The process continues over the range of maintainable assets summarized to major blocks, with considerations of criticality and required availability. Finally, the maintenance plan is used as a basis for creating the maintenance budget.

20.7.3 Using the History

Useful reference points at this stage are the operational loss data and work order data from the previous year. By analysing operational loss data as an indicator of

shortfalls in the past (such as cancelled trains), and the work order data by trade, equipment and location we can establish maintenance load per machine hour and in total. To be able to use, the history data in this way, we must have been be tough about requiring all jobs and hours to be reported. The analysis may make use of Pareto charts and pie charts to highlight where and how the money has been spent. This can turn up surprises, as the work done in particular areas may well be considerably out of kilter with expectations and with allocated resources. The operational loss data is useful as an indicator of achieved availability, as an aid to focussing on loss reduction, to help justify the budget to operations and to senior management.

20.7.4 Walking Around

In addition to data analysis it is important to see the situation on the ground, particularly in regard to backlogs and equipment condition. Local management should be able to pinpoint areas of required capacity or surplus capacity on the basis of direct experience. Of course, local management will wish to have a generous allowance of resources and this must be aimed off for.

20.7.5 Sources of Maintenance Work

In developing the maintenance requirements consider the sources of maintenance work such as the following.

- Routine servicing
- Condition monitoring.
- Inspect/check/adjust including corrective work arising at first line
- Existing backlog
- Corrective work at second line (workshop) following from inspections.
- Breakdowns and work requests. Subsequent repair/ replace at first line
- Breakdowns and work requests. Subsequent repair/ replace at workshop level.
- Field repair teams if separate from previous categories
- Job scoping, costing, planning and scheduling
- Technical supervision and support at tools level
- Technical support at engineer and specialist technician level including trouble-shooting and reliability improvement
- Data management, setup, routine, analysis
- Modifications,
- Installation and commissioning
- De-commissioning and disposal.
- Shutdowns / turnarounds, overhauls planning.
- Shutdowns / turnarounds, overhauls implementation and management
- Ancillary and miscellaneous work – e. g. painting the Brownies toadstools.

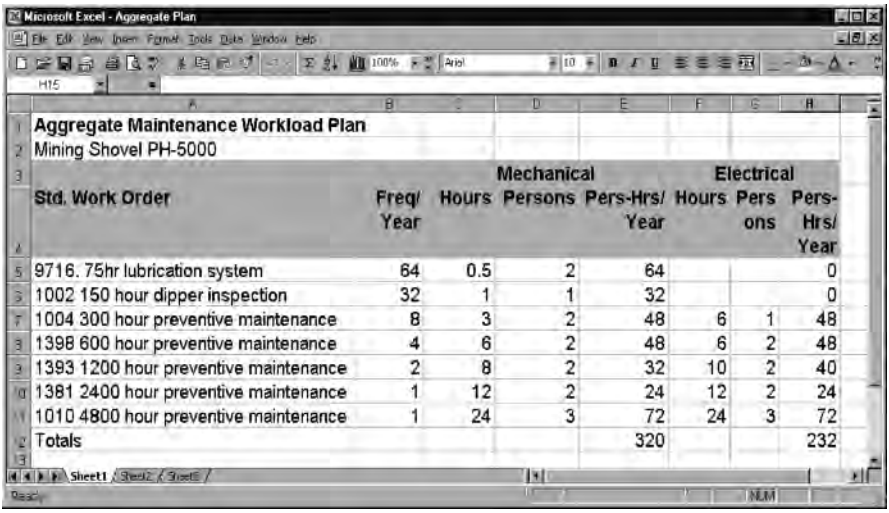
- Personnel management
- Proactive maintenance e. g. failure analysis, root cause analysis, conditioning monitoring development.

20.7.6 Forecast Demand

The considerations just outlined allow us to forecast demand for the planning period. In practice a certain amount depends on how much the workload has changed from the current year and on how accurate we regard the current year's budget in the first place. If the workload has changed little and the current budget is seen as accurate then minimal changes will be needed. But we should clearly allow for changes as the equipment level and workload vary in the following year as compared to the current year. For example, if 10 trucks work 8 shifts per week this year, and 14 trucks will be working 10 shifts per week next year, then increase the budget in proportion. These analyses and observations should be used as a guideline for calculating the maintenance load for the coming year. We should not simply equate this year's load to last years load, but should scale the result for changes in the machine hours required, and for any other changes.

20.7.7 Direct Labour Estimates – Routine

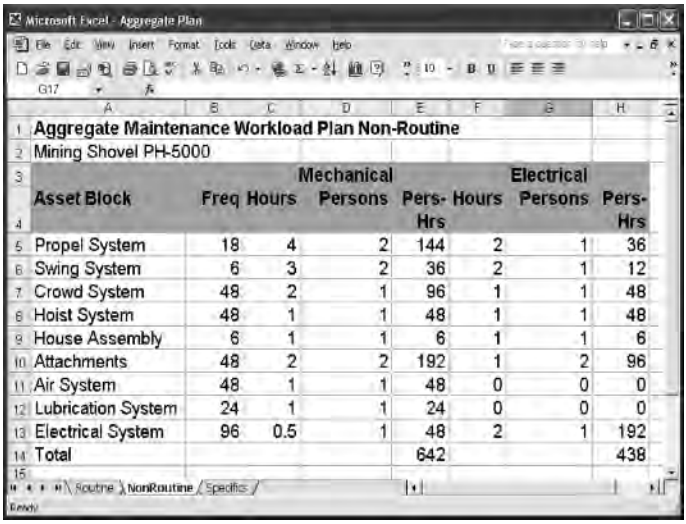
The requirement for direct labour for routine maintenance can be estimated from the labour content and frequencies of particular routine maintenance activities. Figure 20.12 illustrates this.



Aggregate Maintenance Workload Plan
Mining Shovel PH-5000

Std. Work Order	Freq/ Year	Hours	Mechanical Persons	Mechanical Pers-Hrs/ Year	Electrical Hours	Electrical Pers ons	Electrical Pers-Hrs/ Year
9716. 75hr lubrication system	64	0.5	2	64			0
1002 150 hour dipper inspection	32	1	1	32			0
1004 300 hour preventive maintenance	8	3	2	48	6	1	48
1398 600 hour preventive maintenance	4	6	2	48	6	2	48
1393 1200 hour preventive maintenance	2	8	2	32	10	2	40
1381 2400 hour preventive maintenance	1	12	2	24	12	2	24
1010 4800 hour preventive maintenance	1	24	3	72	24	3	72
Totals				320			232

Fig. 20.12 Labour estimates for routine work



	A	B	C	D	E	F	G	H
1	Aggregate Maintenance Workload Plan Non-Routine							
2	Mining Shovel PH-5000							
3			Mechanical				Electrical	
4	Asset Block	Freq	Hours	Persons	Pers-Hrs	Hours	Persons	Pers-Hrs
5	Propel System	18	4	2	144	2	1	36
6	Swing System	6	3	2	36	2	1	12
7	Crowd System	48	2	1	96	1	1	48
8	Hoist System	48	1	1	48	1	1	48
9	House Assembly	6	1	1	6	1	1	6
10	Attachments	48	2	2	192	1	2	96
11	Air System	48	1	1	48	0	0	0
12	Lubrication System	24	1	1	24	0	0	0
13	Electrical System	96	0.5	1	48	2	1	192
14	Total				642			438
15								

Fig. 20.13 Labour estimates for non-routine work

20.7.8 Non-Routine and Breakdown Labour Estimate

The labour estimates for non-routine work, which includes emergency breakdown and deferred non-routine work, is estimated by reference to history, changes in forecast demand and by judgment. Additionally, breakdown costs can be estimated by considering the major failure modes, the mean time between such failures and the labour requirements per failure. The failures referred to here may combine chance events with cyclic events such as major assembly changes, the need for which can be predicted in broad terms, although the exact time of occurrence will not be known in advance. Figure 20.13 shows an example of non-routine labour estimates for the various areas of a large mining shovel.

20.7.9 Specific Items

We then make estimates of the workload by trades and other roles for specific activities such as those shown in Fig. 20.14.

20.7.10 Indirect Labour

Indirect labour covers supervision, administration, training, stores and technical personnel. Requirement for indirect labour must be estimated. Typically there will

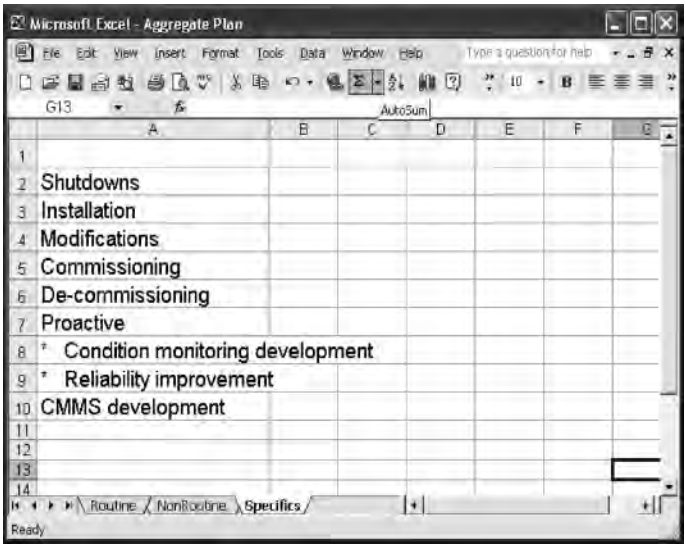


Fig. 20.14 Specific items (headings only shown)

be about 4 indirect positions per 10 direct positions. Other examples of indirect labour activities are:

- Training, trade and technical, equipment, systems, permits
- Induction, safety
- Systems development e. g. CMMS implementation
- Documentation development and maintenance
- Equipment appraisal for acquisition, replacement
- Failure analysis
- Sub-contractor management

20.7.11 Overheads

Identify requirements for facilities and working and office space, consumables, telephone costs.

20.7.12 The Maintenance Iceberg

Many things in maintenance remain hard to quantify. For this reason, a *zero-based budgeting* approach, that is working the budget out by estimating the work to be done from first principles, is less effective than one would wish. Factors in the hard-to-quantify category include:

- Peaking of workloads for valid operational reasons
- Standby capacity to cover emergencies
- Standby capacity to mitigate against expensive down-time of key equipment
- Travel to and from jobs
- Acquiring and awaiting spares and consumables
- Acquiring tools and instruments
- Awaiting the completion of preceding work
- Sub-contractor liaison, communication, management
- Acquiring permits
- Awaiting inspections
- Accessing documentation
- Gaining access to equipment
- Delays in bringing mixed trades together
- In-job training
- Diagnostics
- Resolving technical snags
- Obtaining technical advice
- Absenteeism
- Weather delays
- Seasonal variations
- Non-maintenance activities of maintenance people
- Operator degree of care. Expensive consumables which can be wasted by careless operators should be moved to the production budget. Examples are tyres, bucket teeth.

The marginal value of changes in the maintenance budget is hard to quantify on the down-side as well as on the up-side. Given more money, technical people can always find a use for it. On the other hand, the accountants' tendency to try to increase profits simply by making across the board percentage cuts can only work up to a point.

20.7.13 Arrive at the Resource Requirement

From the steps given in this section, arrive at a required capacity for each resource at each line of repair and at each location. The following categories of staff will typically be required.

- Tradesmen
  - Mechanical
  - Electrical
  - Civil, building, rigging
  - Instrument, air conditioning, etc.
  - Labourers

- Planners
- Storemen
- Inspectors
- Supervisors
- Engineering and technical support personnel
- Clerical staff
- Managers
- Data systems support staff
- Contractors

20.7.14 Correct the Imbalances

Organizations may find that they have evolved into a situation where the workforce is out of balance with needs in terms of numbers, skills, flexibility and location. So in spite of the reference to comparing the planned budget with the current year budget as discussed in preceding paragraphs, it is important to take a hard look at what may be significant imbalances between current maintenance capacity and planned workload. Relate required work to required capacity by:

- Location
- Trade
- Shift
- Equipment type

Where imbalances occur – and they may not be small imbalances – reassign, reduce or increase capacity. *Correct the gross imbalances.* Putting this another way, it means that while a totally zero-based budget approach may have its limitations, it is still good to be able to take a zero-based viewpoint in particular areas where there is reason to regard the resources as significantly out of balance. Build the result into the next year's budget.

20.8 Costing

The accounting department will help in converting the resource budget into a financial budget. This will involve identifying the cost rate for various labour categories including on-costs, such as:

- holiday pay,
- sick pay,
- payroll tax
- workplace insurance
- superannuation.

Indirect, operating and overhead costs must then be added for such categories as:

- Vehicles,
- Tools and Equipment
- Spares
- Consumables
- Freight
- Rent
- Rates
- Electricity and gas
- Telephone
- Facilities maintenance
- Insurance
- Office consumables
- Depreciation

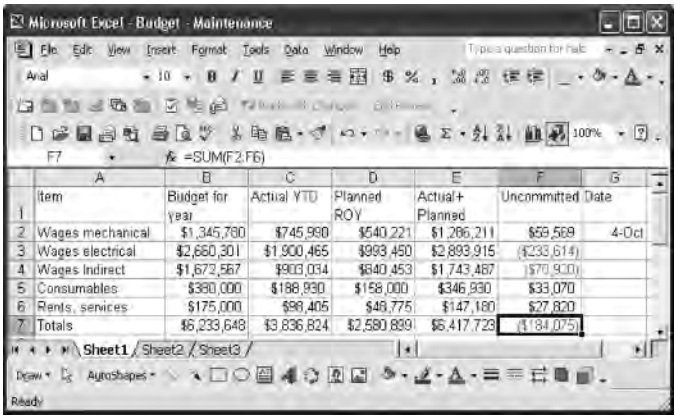
When indirect costs and overheads are taken into account it is not unusual to find that the total cost of maintenance is in the region of three times the wages cost of the direct labour.

20.9 Survey and Quote

When a major item needs extensive work, a Survey and Quote approach can be used. The extent of work needed is assessed, possibly involving some disassembly, and a scope of work is determined. This is then costed, and included in the budget. There must be adequate allowance for contingencies and for materials and overheads.

20.10 Budget Cost Control

1. Create a budget in a spreadsheet (or other established system) indicating the various cost categories and the amounts allocated. Figure 20.15 shows an example.
2. Record actual expenditure year to date (YTD) as it occurs.
3. Calculate planned expenditure for rest of year (ROY). In the absence of other information, this can be done as a proportion of the original budget, but it should be adjusted to allow for known factors of future expenditure. These may be increases or reductions relative to the original plan.
4. Calculate "uncommitted" money = Budget – (ActualYTD + PlannedROY). This will be a positive amount if there is a projected budget surplus and a negative amount if there is a projected budget shortfall.
5. Take steps to remain within budget, or discuss situation with management if an unavoidable shortfall or surplus is emerging.



	A	B	C	D	E	F	G
1	Item	Budget for year	Actual YTD	Planned ROY	Actual+ Planned	Uncommitted	Date
2	Wages mechanical	$1,345,780	$745,990	$540,221	$1,286,211	$59,569	4-Oct
3	Wages electrical	$2,660,301	$1,900,465	$993,450	$2,893,915	($233,614)	
4	Wages Indirect	$1,672,567	$903,034	$840,453	$1,743,487	($70,920)	
5	Consumables	$380,000	$188,930	$158,000	$346,930	$33,070	
6	Rents, services	$175,000	$98,405	$49,775	$147,180	$27,820	
7	Totals	$6,233,648	$3,836,824	$2,580,899	$6,417,723	($184,075)	

Fig. 20.15 Monitoring budget expenditure

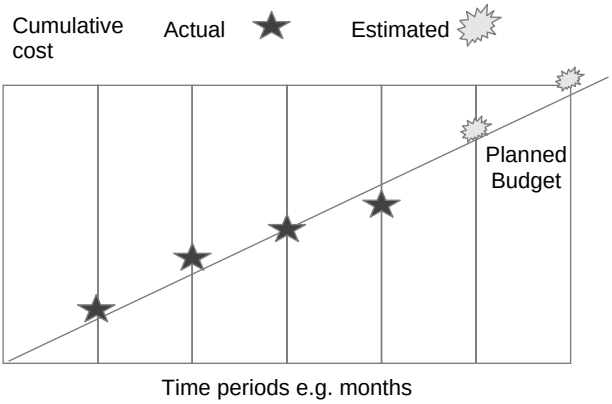


Fig. 20.16 Budget actual versus planned

Figure 20.16 shows the budget monitoring process in graphical form. The expenditure planned in the budget is shown as the straight line (though in practice a variable slope may apply if expenditure over the year was not expected to be uniform). As time goes by the actual cumulative expenditure is plotted and the estimated cumulative is also shown, indicating projected expenditure in relation to budget.

20.11 Budget Reports

The following budget reports should be created and monitored on a regular basis, such as monthly.

1. Actual versus planned expenditure to date
2. Estimated commitments versus remaining budget, giving projected *under-spend* or *over-spend*.

3. Risk analysis, i. e. significant costs which may occur, and also contingency which may not be required. Finance likes a realistic assessment of how much money will be needed. An over-spend is a problem, but an under-spend is also needs to be addressed, and may relieve problems in other areas.
4. Although not specifically a budget report, backlogs in maintenance activity should be reported and monitored as part of the budget management process.

It is important to react in response to the information provided by the reports. Budget changes may be required due to significant changes in commitments. Backlogs should be acted upon, either by increasing resources in backlog areas or reducing resources if backlogs disappear. Contingency allowances should be retired if risks do not eventuate. Do not cry wolf but be prepared to make a balanced statement regarding risk. Use the unfolding information to refine the budget for next year.

20.12 Activity Based Costing

Activity based costing means relating costs for a product, service or machine closely to the activities needed to support it. This is in contrast to a broad brush approach which allocates overheads in proportion to direct labour, even when a particular overhead may not apply to a particular activity. Thus activity based costing is essentially a more accurate way of allocating of overheads.

In activity based costing we

- Identify the "cost drivers" of each activity.
- Relate costs, and hence budgets and prices for these activities to the drivers.

As an example, consider a plant in which only one section, the boiler system and related pipe-work, uses ultrasonic condition monitoring. Ultrasonic condition monitoring is a *cost driver* for that part of the plant. The cost of ultrasonic condition monitoring should be part of the budget for that section only. Spreading the cost evenly over the whole plant (e. g. by absorbing the cost as a general overhead) can lead to poor decision making, for example by wrongly inflating the cost of products which make no use of the boiler system.

Internal invoicing between cost centres can provides a mechanism for assisting with activity based coating. For example, in a power station which is close to a coal mine it is important to monitor the stability of the foundations of the buildings. Initially, the workgroup monitoring stability of foundations was regarded as a general overhead. When internal invoicing was introduced, the monitoring workgroup invoiced the maintenance workshop for monitoring their foundations. The maintenance workshop was in an area that was not subject to instability and did not have its foundations monitored. They refused to pay and their refusal was ultimately upheld by senior management. Had they been required to pay for the monitoring of foundations as a general overhead, it would have artificially inflated their costs and made it hard for them to compete for outside work with other workshops in the area.

20.13 Revision Questions

1. What is a budget?
2. What are OPEX and CAPEX
3. What are fixed and variable costs
4. What steps form the basic logic of maintenance budgeting
5. What are the main sources of maintenance work
6. What is backlog and what part does it play in budgeting?
7. What factors in addition to direct labour, go into the cost of maintenance?
8. How would you monitor budgetary expenditure?
9. How would you manage and revise a maintenance budget?
10. What is Activity Based Costing?

20.14 Exercises

20.14.1 Maintenance Budgeting Exercise

Pacific Plant Management maintains a large fleet of earth moving equipment. You are creating a maintenance budget for the coming year. The following data are available for the current year.

Equipment Type	Routine labour hours	Non-routine labour hours	Spares and consumables
Trucks	30,000	10,000	$195,000
Loaders	25,000	12,000	$185,000
Excavators	28,000	15,000	$205,000

The direct labour cost rate is $30 per hour with a multiplier for on-costs and overheads of 2.75. For next year an increase in activity of 24% has been forecast for all equipment types. A contingency allowance of 15% is applied to the basic budget. What should the total maintenance budget be for the coming year.

20.14.2 Pacific Earth Moving Part 5, Maintenance

Pacific Earth Moving is in the process of acquiring a substantial amount of additional plant. The company has identified an area of profitable business in supporting mining and oil and gas industries. This involves providing equipment on contract, with full logistic support to major companies operating in remote and rugged terrain. The company needs to boost its maintenance support activities to meet this

challenge. Your group has been retained to provide recommendations on the following issues:

a) What organization is needed to manage the maintenance of the equipment?
b) What functions will the maintenance organization need to provide?
c) How would you establish a budget for this maintenance activity?

Present your answer using charts and dot points.

Chapter 21
Reliability, Availability, Maintainability

Chapter Aim: To introduce key elements of reliability, availability and maintainability from an asset management perspective.

Chapter Outcomes: After reading this chapter you will be aware of the need to specify and check for reliability, availability and maintainability (RAM) requirements for asset acquisitions and developments. You will learn about how reliability, availability and maintainability are measured, and about the factors that lead to successful management of assets in regard to RAM considerations.

Chapter Topics:

- Specification and testing
- Reliability
- Design for reliability
- Reliability management
- Operator logs and incident reports
- Failure reporting and corrective action (FRACAS)
- Pareto analysis
- Failure mode and effects analysis (FMEA or FMECA)
- Root cause analysis (RCA)
- Condition monitoring
- Failure patterns and causes
- Availability
- System availability
- Cost of downtime
- Availability when needed
- Availability related to total time
- Maintenance effectiveness
- Maintenance load
- Maintenance regime

N. A. J. Hastings, *Physical Asset Management*,

- Maintainability concept
- Design for maintainability
- Maintainability measure

21.1 Specification and Testing

The specification of an asset should include parameters for reliability, maintainability and availability (RAM). At the acquisition planning stage we carry out tests of prospective equipment to check whether the RAM specifications are met. Performance and RAM characteristics must be also checked prior to specific equipment acceptance. Otherwise the equipment may fail to deliver a reasonable level of service.

The specifications for reliability, maintainability and availability, will be based on technical input and judgement from knowledge of the type of equipment concerned and the service conditions and requirements involved. The tests will involve operating the equipment for a trial period during which equipment performance, faults, failures and maintenance activities are recorded and analysed. The results should then be compared with the required specifications, and to compare competing equipment. Faults may be reduced and performance improved as trials proceed, but finally a judgement is made as to whether the equipment is satisfactory in relation to the specifications, and meets criteria for quality and safety.

Trials also provide information regarding logistic support requirements including maintenance and replacement policies and spare parts planning. It is important to make data supported decisions on all these topics wherever possible.

21.2 Reliability

Reliability is important because failures reduce the effectiveness of service and undermine the organizational objectives which the assets are intended to support. Failures may also have safety and environmental implications. The cost of failure is generally disproportionately high when considered against the costs of sound maintenance, repair and replacement policies. The most commonly used measure of reliability is the Mean Time Between Failures or MTBF. This is defined as follows.

Mean Time Between Failures (MTBF) is the average time for which an equipment operates between failures occurring.

To apply this concept it will be necessary to decide what constitutes a “failure”. A failure is a sudden or gradual deterioration of an item such that it is no longer able to perform its required function. However, as some failures may have minor impact on equipment operation, it is common to adopt the concept of critical failures, that

is, failures which are considered to be important enough to stop the show. We may then use the term Mean Time Between Critical Failures. To be acceptable, an item must reach the target MTBF for critical failures at the reliability trial.

21.2.1 Design for Reliability

The design of equipment should reflect the level of reliability required by the application specification. Besides the design of the equipment itself, the reliability of a system is influenced by the degree of *redundancy*. In systems where high reliability is required, this is often achieved by having components, assemblies or units working in parallel, or on standby, so that if one item fails the system remains operational. A design has N-1 redundancy if the failure of one element can be tolerated without loss of service. This type of redundancy is common in electricity generation and transmission systems.

21.3 Reliability Management

Beyond the initial acquisition stage, where reliability will depend largely on design factors, reliability should be managed throughout the life of an asset. Many techniques have been devised to assist in this process and some of these are outlined in this section. Figure 21.1 gives a flowchart relating to the management and improvement of reliability. Fuller details are given in books dedicated to reliability, such as O'Connor.

21.3.1 Operator Records and Incident Reports

Operator logs or records form a useful source of information about equipment performance and condition. The frequency and extent delays, losses or faults can be determined directly and in a timely manner from these logs. Following up on the data from operator logs can lead to the determination of causes of problems and to action to eliminate or mitigate problems. Data from work requests and work orders are also valuable and form the normal basis for failure investigation, but operator logs are relatively neglected as a source of useful information for reliability improvement.

The reporting and management of incidents forms a basis for managing the performance and reliability of assets. There is a saying that 30 incidents become one accident and 30 accidents become one fatal accident. The causes of losses and incidents should be investigated and steps taken to prevent future occurrence and to mitigate the consequences.

21.3.2 Failure Reporting and Corrective Action System (FRACAS)

FRACAS is a formal system in which a range of specified parameters are reported when a failure occurs, and a specified systematic approach to corrective action is taken.

21.3.3 Pareto Analysis

Pareto analysis, as applied to equipment failures, means ranking failure modes by frequency and cost. The most frequent and highest cost failure modes can then be addressed.

21.3.4 Failure Mode and Effects Analysis (FMEA or FMECA)

FMEA also known as Failure Mode, Effects and Criticality Analysis (FMECA) is a technique used mainly in the design or manufacturing of product. It consists in assessing all the potential ways in which a product may fail, assessing the causes and effects of failure, and carrying out a numerical risk ranking. Recommendations to correct the failures or mitigate the effects are then made and acted upon.

21.3.5 Root Cause Analysis (RCA)

Root Cause Analysis (RCA), also known as Root Cause Failure Analysis (RCFA) is a formal approach to determining the root causes of failures, with the intention of preventing future occurrences. It involves assessing immediate or *action causes* and *condition causes*, which relate to background conditions.

21.3.6 Condition Monitoring

Condition monitoring involves continuous or periodic checking of the operating condition of machines. For example, rotating machines when running correctly will have a particular vibration signature, that is they will run smoothly, but have moderate levels of vibration at certain frequencies, rather like a human heartbeat. Significant variations form the normal vibration pattern can be detected by instruments and warn that failure is imminent. Action can then be taken to check the machine and avoid a catastrophic failure.

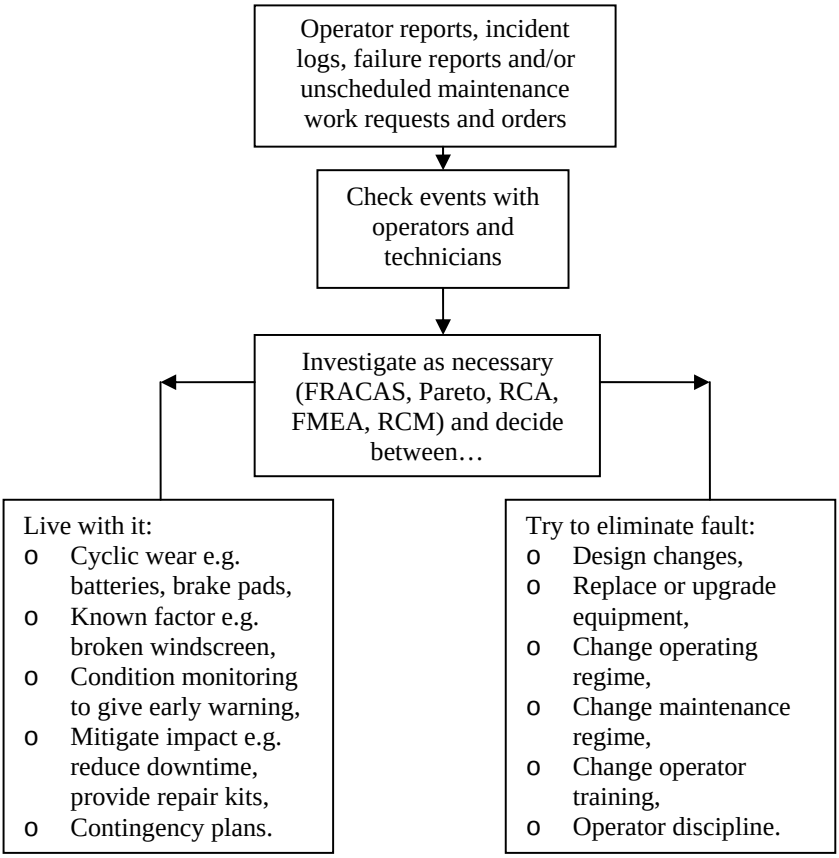


Fig. 21.1 Reliability improvement

Machine	**Human Being**
Human senses	Appearance - looks ill
Vibration analysis	Pulse, ECG
Thermographics	Temperature
Oil analysis	Blood sample
X-rays	X-rays
Ultrasonics	Ultrasonics
Pressure gauge	Blood pressure,
Performance monitoring	Stress test
Borescope	Endoscope
Megger insulation testing	Angiogram
Strain gauge movement of buildings or structures	Sprain

Fig. 21.2 Condition monitoring techniques and medical parallels

Asset and maintenance managers need to be aware of the condition monitoring techniques which are most appropriate to the assets under their care. An early work which describes many condition monitoring techniques is R.A. Collacott, "Mechanical Fault Diagnosis". Over recent years there have been many advances in these techniques, particularly in terms of cheaper and more effective versions of the diagnostic tools. Figure 21.2 shows a list of condition monitoring techniques and the analogous technique used in medical diagnosis.

21.3.7 Failure Patterns and Causes

Reliability analysis involves a recognition of patterns and causes which commonly arise in relation to equipment failures. Common failure rate patterns start with early life or burn-in failures which occur with new items and are typically due to manufacture or installation defects. These failures decrease as defect free items survive the early period. Then there are random, or constant rate failures, which can occur at any time and may be caused by external factors such as overloading or a nail in the tyre. Finally, failure rates increase in a wear-out phase due to ageing or degradation, involving wear, fatigue, embrittlement, corrosion, cracking, insulation breakdown or movement of structures. Awareness of the failure pattern can assist in identifying and eliminating the cause.

21.4 Availability

The simplest concept of availability applies when we have a single machine which is required continuously and which has an associated repair crew. The state of the machine is either Up, that is running or available to run, or Down, that is, failed. When the machine fails the repair crew repairs it. Figure 21.3 illustrates the situation. Availability of the machine is defined in the following terms.

Availability is the proportion of time for which a machine is available for use.
Downtime is time when equipment is not operable.
Up Time is time for which equipment is operable.

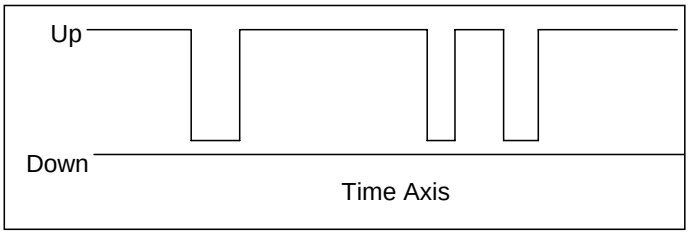


Fig. 21.3 Availability

Availability = Up Time / (Up Time + Downtime) = Up Time / Total Time

Given the Mean Time Between Failures of the machine (MTBF) and the Mean Time to Repair (MTTR), then the Availability, A, is given by:

$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

To achieve a high availability, the MTTR must be much shorter than the MTBF. Availability can be improved by increasing the MTBF or decreasing the MTTR.

21.4.1 System Availability

Most practical situations are more complex than the single machine case. Also, the time taken to get a failed machine running is not just the active repair time, but can include many elements, such as those in **Fig. 21.4**. Besides these specific types of delay, general factors which contribute to the achievement of availability are shown in Fig. 21.5.

21.4.2 Cost of Downtime

The potential types of cost associated with failure are indicated in Fig. 10.8. The cost of failure and of downtime is the basic driver for maintenance and influences priorities for maintenance. The cost of downtime is hard to quantify, and varies considerably with circumstances, but awareness of the cost of downtime is important to good management, because it provides a sound basis for evaluating the trade-off between maintenance costs, capital equipment expenditure and business profitability. If managers are not aware of the cost of downtime they may see maintenance as purely a cost element which can be cut without regard to flow on effects.

21.4.3 Availability When Needed

Many systems do not require 100% availability all of the time. Preventive maintenance can be scheduled to take place in times of low demand. Breakdown maintenance can continue in low demand periods, such as weekends or holidays. Repair support can be increased in periods of high demand so as to minimise the effects of outages.

For example, in electricity generation, demand fluctuates with time of day and season of year. Capacity required can be forecast, and individual generators brought on stream at particular times. Equipment shutdowns are scheduled for periods of

Element of Downtime	Downtime Reduction Activities
Diagnostic delays	Improved operator training. Improved instrumentation.
Reporting delays.	Improved communications.
Travel time for maintenance person to breakdown location.	Improved transport. Repair person located nearer to breakdown location..
Travel time for machine to repair facility.	Better transport arrangements.
Inspection, diagnosis, repair cost estimating and documentation.	Staffing, equipment, training, documentation, troubleshooting techniques.
Repair decision.	Delegation of authority. Speed of response.
Hazard analysis. Obtaining permit to work	Hazards documented. Good liaison between production and maintenance.
Awaiting spares.	Inventory control. Resupply and purchasing policy.
Awaiting labour. Awaiting repair facilities, tooling, technical information.	Vary staffing by trade, shift, sub-contract, training, multi-skilling. Reassign jobs to another maintenance area.
Active repair time.	Improve maintainability. Study repair methods and procedures, equipment.
Inspection and testing.	Staffing, instrumentation.
Travel to required location.	Transport arrangements.
Installation time. Run up time.	Staffing, training, multi-skilling, methods, procedures.

Fig. 21.4 Elements of downtime

low demand. Available capacity is normally designed to cover the unexpected loss of the largest generator currently running. Similar considerations apply in transmission systems. This approach is known as n-1 *redundancy*, indicating that the loss of one component should not cause a loss of supply.

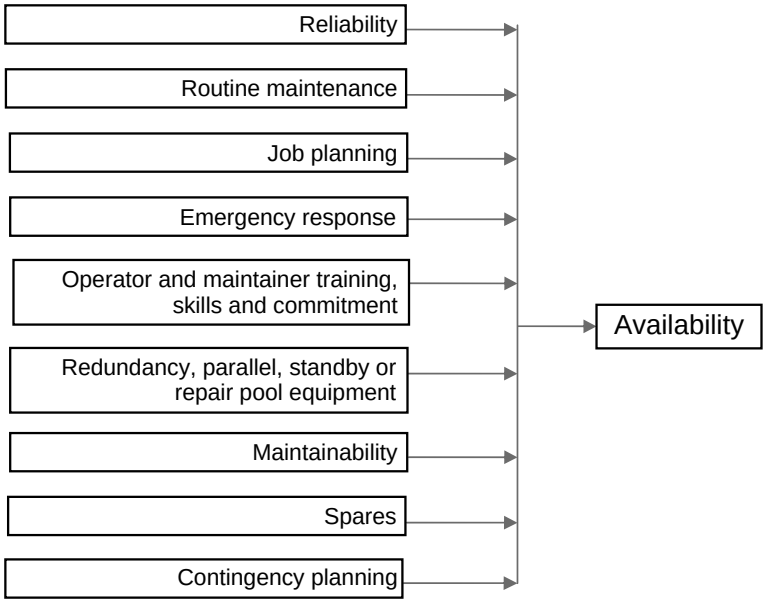


Fig. 21.5 Inputs to availability

21.5 Availability Related to Total Time

Most equipment does not operate on a 24 hours 7 days a week basis, and there are scheduled times of non-use, scheduled maintenance times and other times when machinery is not required. The definition of availability in these circumstances

<table>
<tr><td colspan="7">Total Time, T</td></tr>
<tr><td colspan="6">Scheduled Time, S</td><td>Non-scheduled time</td></tr>
<tr><td colspan="5">Scheduled Production Time, SP</td><td>Scheduled Maintenance Time, M1</td><td>Non-scheduled time</td></tr>
<tr><td>Actual Production Time</td><td colspan="2">Lost Production Time, LP</td><td colspan="2">Production Not Required Time, NR</td><td>Scheduled Maintenance Time</td><td>Non-scheduled time</td></tr>
<tr><td>Actual Production Time</td><td>Lost Prod Time due Maint. M3</td><td>Lost Prod Time due Other, LO</td><td>Not required other</td><td>Opportunistic Maintenance Time, M2</td><td>Scheduled Maintenance Time, M1</td><td>Non-scheduled time</td></tr>
</table>

Fig. 21.6 Availability related to total time

requires a consideration of how the total time available is partitioned. Figure 21.6 illustrates this.

The following availability measures can then be defined.

Availability (When Required) = 1 – M3 / (SP – NR)
(of equipment from maintenance when required)
Maintenance Effectiveness = 1 – (M1 + M2 + M3) / S
(100% if no maintenance)
Availability (Total) = 1 – (M1 + M2 + M3) / T
(of equipment from maintenance as related to total time)
Availability (When Required) = 1 – LP / (SP – NR)
(all causes)
Relative Maintenance Losses = M3 / LP
(lost time due maintenance as a proportion of all lost time)

There is also a possibility of opportunistic maintenance in non-scheduled time.

21.6 Maintenance Effectiveness

The effectiveness of maintenance relates to how well the effort put into maintenance translates into reliable and available equipment. Figure 21.7 shows factors that influence the effectiveness of maintenance. The skill of the maintenance workforce in relation to the tasks on hand is a key factor, and training and continuity on the job are therefore important. Possibly the most important factor of all is the degree of commitment or motivation of the workforce – an indicator of lack of

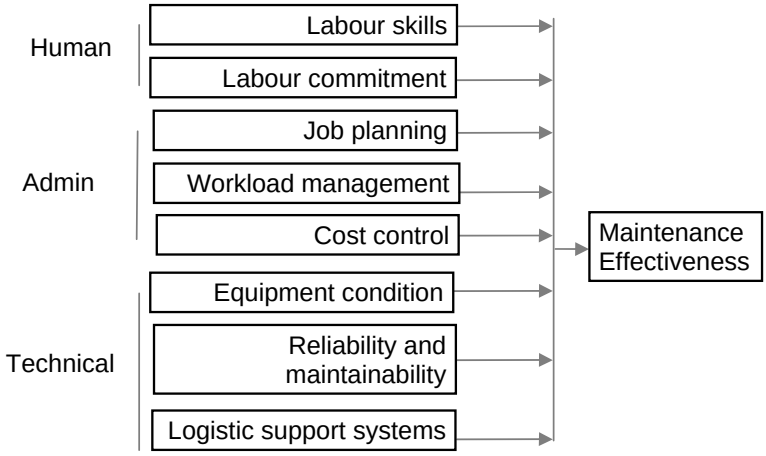


Fig. 21.7 Inputs to maintenance effectiveness

commitment is absenteeism. The degree of commitment is influenced by the other factors in the Fig., since lack of cleanliness, poor planning, inherently unreliable equipment and poor logistic support will lead to poor morale.

Maintenance personnel generally welcome being involved in work on improving reliability and maintainability, such as root cause analysis, diagnosis and condition monitoring. However, too marked a tendency to replace basic maintenance by sophisticated but ineffective activities should be resisted.

21.7 Maintenance Load

The maintenance load generated by a system is the cost and resource requirement for maintenance of the system per unit of service, for example for an aircraft the maintenance hours per flying hour. The maintenance load will consist of routine and non-routine activities, of which the latter can only be estimated on the basis of some operating experience.

21.8 Maintenance Regime

It is important to have an established maintenance regime, and for this to be documented, adhered to and records kept. Conforming to the manufacturers recommendations, meeting all regulatory requirements and staying within warranty claim boundaries are good basic ideas. Variations from this need a reason. Be confident about what you can tell the judge in a court case.

The maintenance regime specifies the details of what maintenance is done routinely, by whom and at what frequency, and the procedures for both routine and non-routine maintenance.

Manufacturers' recommendations make a useful starting point in determining the maintenance regime, but should be kept under review with regard to possible variations required by the current application. An established formal approach reviewing the maintenance regime, or to establishing it in the first place, is Reliability Centered Maintenance (RCM), for which a key reference is J. Moubray, "Reliability Centered Maintenance". This technique is ideal for situations where an in-depth analysis is required. A less comprehensive approach is known as Preventive Maintenance Optimization (PMO), which starts with an existing preventive maintenance plan and reviews the suitability and frequency of the various tasks.

These techniques initially involve reviewing the range of equipment in the organization and identifying items where there is a perceived need for the creation or review of the maintenance tactics. If all items are to be covered, for example where records are to be computerized, then the equipment is prioritized, and high priority areas are tackled first. Sources of information for the review of maintenance tactics include:

- Manufacturers documentation;
- Experienced maintenance personnel, particularly older staff, planners and supervisors;
- Records of previous maintenance activities;
- Maintenance and technical support staff;
- Suppliers;
- Consultants.

The review may lead to the introduction of, or adjustments to such tactical elements as:

- inspection intervals,
- lubrication intervals,
- checks and adjustments
- component or equipment replacement intervals or guidelines
- condition monitoring regimes
- repair pools and rotables provision
- repair kits,
- check lists,
- troubleshooting guides,
- accessibility,
- tools,
- spare parts optimization
- field repair teams provisioning
- workshop facilities provisioning
- level of repair policy

21.9 Maintainability

Maintainability relates to the ease or difficulty with which an item can be repaired when it fails. A basic factor in maintainability is the *Mean Time to Repair (MTTR)*. This is defined as the average length of active time taken to repair an item which has failed. An item which is easy to repair will have a short MTTR, and an item which is hard to repair will have a longer MTTR.

21.9.1 Design for Maintainability

Maintainability is a design factor which competes with other requirements such as low initial cost, good performance and reliability. For example, it may improve the maintainability of a chemical reactor vessel to have an access plate in a certain spot, but this may also increase the cost and reduce performance because of reduced allowable pressure, and may decrease reliability, because of the need for seals which

are less reliable than a solid wall. In designing for maintainability the general aims are to reduce total maintenance load and to reduce downtime when it occurs.

A good design will minimize and simplify maintenance tasks, and provide predictability in maintenance requirements. Specific features which promote good maintainability include ease of access by technicians; visibility; ease of testing; interchangeability of components or modules; provision of good maintenance documentation and diagnostics. Some further details of techniques used to provide good maintainability are as follows:

- Access. Provide good access for maintenance.
  - Access plates.
  - Use hinged panels.
  - Use roll out drawers …
- Modularise. Example: Maintainability of an electronic device may be improved by making it in the form of detachable boards plugged into a base. The plugs, however, may have low reliability when compared with permanent joints.
- Minimise need for special tools.
- Minimise range of tools required.
- Provide failure signals, warning signals, built in sensors
- Provide troubleshooting, diagnostic aids and plans
- Build in monitoring points
- Provide good instrumentation
- Label assemblies
- Provide operation and calibration information on labels.
- Use easily replaceable, expendable components e. g. flywire door.
- Prevent faulty assembly (poka yoke)
- Provide handles or other lifting points.
- Provide castors.
- Lubrication points visible and accessible.
- Adjustment points visible and accessible.
- Provide spare fuses or equivalent reset.
- Provide adequate illumination.
- Redundancy, e. g. standby light bulb with switch.
- Help desk, on-line maintenance support, portable computer with workshop manuals and drawings, etc.

21.10 Maintainability Measure

In order to specify, measure and compare maintainability of items we need a definition of maintainability as a measurable quantity. For this purpose we define maintainability as a probability that an item can be restored to operating condition within a specified interval of time, when maintenance is performed in accordance with prescribed procedures and resources. The following definition is adapted from Society of Automotive Engineers Standard SAE JA1010.

Maintainability is the probability that an item will be repaired within a specified time, referred to as the *maintenance time constraint*.

The Maintenance Time Constraint is set in relation to operational circumstances, such as, aircraft turn around time. As a property of the item itself, maintainability is related to Active Repair Time. As a property of a system, maintainability is related to total downtime.

The average value of the time to repair is known as the Mean Time to Repair (MTTR). If the distribution of the time to repair is negative exponential, the repair rate is constant and is the reciprocal of the MTTR. Define

MTTR = Mean Time to repair

μ = Repair Rate

Then for the exponential model we have

$\mu = 1/\text{MTTR}$

$M = 1 - \exp(-\mu t)$

where M is the Maintainability and t is the Maintenance Time Constraint. Thus, if we have data from which we can estimate the Mean Time To Repair, then we can calculate the corresponding maintainability with reference to our maintenance time constraint.

21.11 Exercises

21.11.1 Pacific Earth Moving Part 6. Reliability and Availability

In addition to routine maintenance activities, Pacific Earth Moving requires an ability to achieve high standards to equipment availability, in order to reach the equipment availability targets set in its contracts with client companies.

Your group has been asked to advise the company on what methods or techniques should be introduced in order to achieve a high standard of reliability and availability for the company's plant. Give your answer in dot point form, stating the features of each approach and indicating the potential benefits and costs.

21.11.2 Cost of Downtime

A single conveyor brings coal from a mine to the surface. The conveyor operates full time, which in this case is 48 weeks per year, 48 hours per week. Extension of

this working period is not practicable. Experience shows that conveyor availability is 87%. The sales value of production is $30,000,000 per year. What is the cost of downtime? The conveyor system uses minimal consumables.

21.11.3 Availability Related to Total Time

A plant makes two types of coiled spring, Small and Large. The standard production times are:
Small 3 minutes per spring
Large 4 minutes per spring

The plant works nine 8 hour production shifts per week, with an additional maintenance shift of 8 hours.

In a given week, the following data are recorded.
Production: Small springs 578
Large springs 492

Unscheduled Downtime
due to Maintenance: 7 hours 30 minutes

Calculate the ratios indicated in previous slide.

How much time is lost during production shifts for reasons other than maintenance? Assume that there is no 'Not Required' time.

21.12 Desert Song

"So where did you go after Norway, Pop?", asked Jock on his next visit to his granddad. Jock really enjoyed hearing his Pop's old stories but it was hard to get him going on them.

"What sort of stuff are you working on now?" said Pop, diverting the question.

"It's about sustaining our in-service assets, but I think you would call it maintenance", said Jock; and after a pause Pop decided there were some things about maintenance that Jock ought to know.

"We were in North Africa", said Pop. "You know those films with John Wayne firing a machine gun from the hip from a moving tank?"

"Yes", said Jock.

"Well it's not like that. The fact is that tanks get stuck or break down pretty easily. There is always soft sand or mud, unexpected gullies, rocks or concrete in the wrong place. It's surprising how easily they can throw a track or strip the final drive or just get into a spot where they can't move. And that's not counting enemy action

or mines. After a day's fighting in the desert dozens of tanks on both sides would be broken down somewhere. But somehow the Germans had most of theirs up and running again by next morning. It had us flummoxed at first."

"We found that they had the field maintenance angle well worked out. They had recovery vehicles with a winch and a spade which could pull a tank out of any spot, and repair teams trained and equipped with all the right tools and spares."

"At that time we didn't even have a mechanical and electrical engineering corps at all. We just had fitters attached to the supply regiment."

"And we loved their petrol cans – jerry cans we called them. Our cans were so flimsy that they would start leaking at the drop of a hat."

"Pretty bad eh", said Jock.

"Before the war our staff blokes must have still been dreaming of the old cavalry days. They finally picked up on it after the Germans looked like they would make it to Cairo. By Alamein we began to get some better equipment through and a mechanical and electrical engineering corps was formed. Later when the Americans came in with the half-tracks we got our forward repair teams running too."

Chapter 22
Inventory

Chapter Aim: The aim of this chapter is to describe the various aspects of inventory management required for asset management. This starts from the initial purchase of spare parts and consumables, and continues to through life support. Inventory control methods are presented for routine demands and for fast and slow moving spares and for insurance spares.

Chapter Outcomes: After reading this chapter you will be aware of the main issues that confront asset managers in regard to spare parts and consumables inventory. You will know everything that is worth knowing about spare parts inventory, but this will not mean that you can solve al the problems.

Chapter Topics:

- Introduction
- Initial spares purchase
- Cataloguing
- Aims of inventory management
- Inventory management basics
- Stock keeping units
- Spare parts basics
- Procedure when item is needed
- Stock control terminology
- Dependent demand
- Independent demand
- MIN and MAX
- Target level
- Forecasting
- Reorder risks
- Lead time
- Reorder rules, fast moving items
- Consignment

N. A. J. Hastings, *Physical Asset Management*,

- Cannibalization
- Returned stores
- Storekeeper personnel
- Repair pools
- Item criticality
- Slow moving items
- Insurance spares
- Performance indicators
- Accounting for inventory

22.1 Introduction

The term inventory is applied to stocks of items such as finished goods, work in process, materials, consumables and spare parts held by an organization in order to carry out its business functions. The management of inventory extends to cover items which are on-order and are known as dues-in, and items which are required by users and known as dues-out as well as to those items which are physically in stock at any given moment. In the asset management area, the items involved are typically:

- Consumables such as fuel, oil, lubricants
- Spare parts
- Repair parts, also known as rotables, which are held as a repair pool; this may include complete equipments
- Insurance spares, that is items which we may never need but which we prefer not to risk being without.

22.2 Initial Spares Purchase

When new equipment is acquired we normally purchase an initial quantity of spare parts. This may be based on the manufacturers recommended spares list, or on input from experienced maintainers. The acquisition budget should include funding for the initial spares purchase. An amount in the range of 5% to 10% of the main equipment budget is typically allocated. The initial purchase or 'scaling' is based on a planning horizon such as three years. Major spares, such as replacement engines and gearboxes, which may go out of production by the time they are needed, should also be included. It is hard to get it right on forecasting demand and some over and under supply must be expected.

22.3 Cataloguing

It is essential to be able to identify spare parts within the organization's inventory management system and it is therefore necessary to catalogue the items which the organization will hold. An agreed system of codification will need to be adopted. The equipment manufacturer will normally provide a parts list for spare parts which will include parts explosion diagrams and part numbers. However, if these are to be incorporated into a company inventory system it will be necessary to catalogue the parts under the company's part numbering system. Resources will be needed for this activity and for maintaining the computerized inventory management system.

22.4 Aims of Inventory Management

The primary aim of inventory management in the field of spares and consumables is to enable the meeting of requirements for equipment availability at minimum cost. This will involve

- Keeping service to the users at a reasonably high level
- Keeping inventory investment reasonably low
- Cost-effective purchasing

A balance must be struck between these conflicting factors. Secondary aims of inventory management are to ensure that:

- Stock is secure;
- Stock identity, quantity and location are known;
- Items are available and accessible when required;
- Purchase orders are placed promptly and goods received effectively.

22.5 Inventory Management Basics

A flow chart of inventory transactions is shown in Fig. 22.1 Inventory system. Inventory management is invariably based on a computer system and will feature as part of any Computerized Maintenance Management System. The following points are counsels of perfection for inventory management.

- Have one person responsible for the inventory management system.
- Provide an adequate computer system and personnel for system support.
- Have an effective coding and cataloguing system with unique part numbers.
- Maintain stores accuracy in regard to, quantities, locations, item descriptions,
- Establish bill of materials and where used data
- Ensure Work Orders contain all spares and materials required for the job

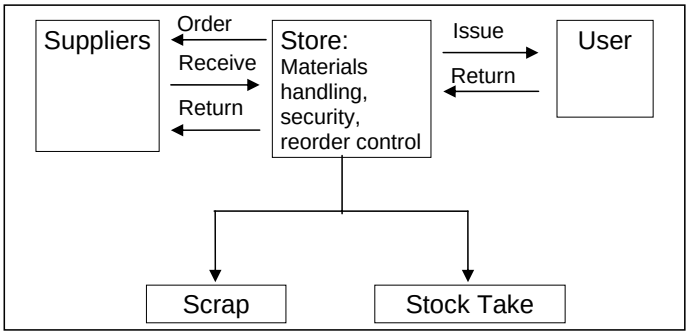


Fig. 22.1 Inventory system

- Establish and use strict procedures for receipt and issue of stores,
- Have a system which allows 24/7 access to spares for urgent maintenance jobs
- Establish and use strict procedures for reordering stock,
- Maintain the computer system in regard to updating supplier and stock records. Ensure staffing is adequate to sustain this.
- Carry out regular stock-takes, usually on a cyclic basis.
- Make stores records visible to users. Extend this company-wide, and have a transfer system between locations.
- Establish data for average demand. Establish item criticality. Have a system for keeping this information up-to-date. Set reorder parameters.
- Eliminate dead stock.
- For fast moving items, establish Just In Time delivery procedures.

22.5.1 Stock Keeping Units or SKUs

An *SKU* is a point at which a given item is stocked. A company may have 10,000 different types of item in inventory, but some of them may be held in more than one place. So if the main store is in Melbourne and it holds all 10,000 types of item and there is a subsidiary store in Upper Wup Wup which only holds a subset, say 4,000 types of item, then the company has 14,000 SKUs. The number of SKUs gives a measure of the total size of the inventory management side of the business.

22.5.2 Spare Parts Basics

Basic elements of spare parts data for engineering equipment are the spare parts explosion diagram and spare parts catalogue listing, examples of which are shown in Fig. 22.2 and Fig. 22.3.

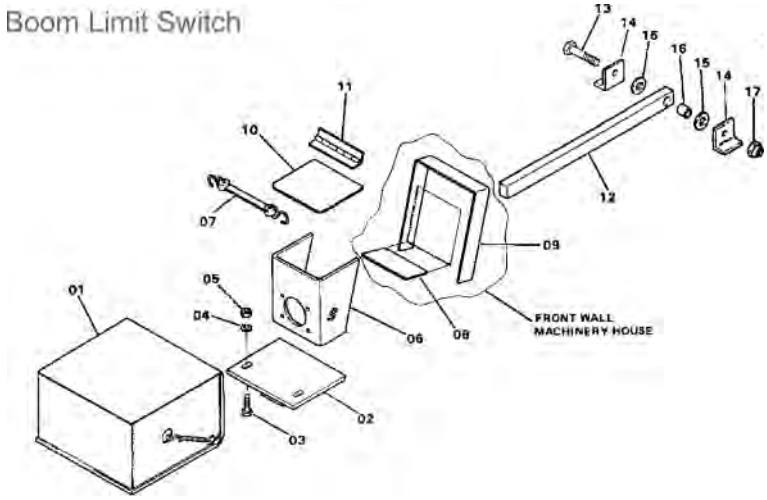


Fig. 22.2 A parts explosion diagram

Ref	Part No.	Description	Qty
0	100J6493F4	Installation, Boom Limit Switch	1
1	979J23F1	Switch, boom limit	1
2	16N3651D1	Bracket, support	1
3	20Q260D329	Screw, Hex Hd Cap ½-13UNC X 1-3/4in	2
4	3616V011	Washer, lock, 1/2in	2
5	20Q270D32	Nut, ½-13UNC	2
6	16N3649D1	Bracket, mounting	1

Fig. 22.3 Extract from a parts catalogue

22.6 Procedure When Item Is Needed

The basic steps involved when an item is needed from inventory are as follows.

a. An item is needed.
b. Get the Part Number. Refer to the Spare Parts Explosion Diagram and the Catalogue
c. Is the item in stock?
d. If so, where is it? Pick the item from the location.
e. Follow the issue procedure, documenting the issue.
f. Do more items need to be ordered? This will be the case if there is insufficient in stock, or if the withdrawal takes the stock level below the reorder point.
g. If so, how many should be ordered? The order quantity may have been set in the inventory system, but enough should be ordered to cover foreseen requirements
h. Follow the reorder procedure. Get the supplier details. Initiate a purchase order.

Date: 18 Sept 97 **Time**: 14:47:05 **Location**: BIN 46

Parent Item: P & H Shovel **Manufacturer**: Hamischfeger

Part Number: 16W316D1 **Description**: BRACKET, Mounting

Manufacturers Ref: BLS06 **Unit**: EACH **Lead Time Days**: 14

Reorder Level: 1 **Reorder Qty**: 2 **Unit Cost**: $153.07

YTD Used: 1 **Last Activity Date**: 30 Aug 97

Current Stock Level: 0 **Net Level**: 0

Dues In			Dues Out		
Date	**PO No.**	**Qty**	**Date**	**WO No.**	**Qty**
3 Sept 97	PO4371	2	12 Sept 97	WO123	1
			18 Sep 97	WO234	1

Fig. 22.4 Inventory status report screen

22.7 Stock Control Terminology

Stock Level The number of items in stock.
Dues In Items ordered but not yet delivered.
Dues Out Items required for use but not yet issued.

Dues out are usually items which have been ordered but not yet received, however, they also include items demanded but not yet ordered and items received but not yet issued. These items may be referred to as "committed", as they are already known to be required for specific users.

Backorder A purchase or production order for an item which is already required by a customer or user. The item is *backlogged*.

Net Level = Stock Level + Dues In – Dues Out.

The net level is the stock level that we shall have if we add the dues in to our existing stock and then subtract the due out. It is the balance of our stock situation allowing for existing planned stock movements. If the result is below the reorder level, or MIN level, a further order should be placed.

22.8 Dependent Demand

Dependent demand is demand which can be estimated or planned, by time and quantity, from the production plan or the scheduled maintenance plan. Examples are:

- The consumption of fuel, for a known vehicle fleet operating to an established production or delivery schedule.
- Spares such as spark plugs or brake pad used in an established scheduled maintenance plan.
- Spares which are ordered for a known repair, or for a shutdown involving planned replacement of known components.

If dependent demand it very regular it can be managed by routinely ordering quantities sufficient to cover the demand. Occasional variations from average will be dealt with by temporarily varying the order.

If demand is dependent but irregular, we use an inventory projection report of the type shown in Fig. 22.5. The item referred to is a type of grease, purchased in multiples of 50 kilograms, which is used in servicing major machines such as mining shovels, draglines and ball mills.

In Fig. 22.5 the rows correspond to planned events in date order. The first row shows the opening stock which is 13 kilograms and this figure appears in the Net Level column. Any existing purchase orders provide data for the Due In column. Row 2 shows that we currently have 50 kg Due-In under Purchase Order

Part No: A43WS582-Grease. Unit: kg; Date: 05Jul Time: 10:15
Lead Time Days: 28 Supply Multiple: 50 Supplier ID: 3427

Row	Date	Note	Due In	Due Out	Net Level
1	06JUL	Stock			13
2	06JUL	PO-123	50		63
3	10JUL	WO-456		25	38
4	19JUL	Dragline Servicing		50	-12 **
5	28JUL	PO-145	100		88
6	01AUG	Ballmill Servicing		25	63
7	10AUG	Shovel Servicing		35	28
8	17AUG	WO-475		45	-17 *

** = Shortage within one lead time. * = Shortage within two lead times.

Fig. 22.5 Dependent demand inventory projection report

PO-123 on 6 July. The Net Level column shows the projected stock after each planned transaction. In row 2 the Net Level is 63, as the 50 kg from the P.O. are added to the stock of 13. The data for the Due Out column is created from the current utilization plan. The next planned event in time is a Due-Out of 25 kg required by Work Order W.O. 456, which will reduce the Net Level to 38 kg. This demand may be an irregular one-off demand, but it is known and needs to be planned for. In practice some unexpected demands may occur, but for "dependent demand" items these should be a small minority.

The report continues projecting forward the Dues-In and Dues-Out, running as far ahead as we choose to plan, usually at least two delivery lead times ahead. In this case the lead time is 28 days so we will plan for 2 months ahead. The Net Level column will eventually show a shortage, represented by a negative net level. This is an indication that we need to take action so that the shortage is prevented. If the shortage first occurs more than one lead time ahead, we can cover the shortage by placing a normal order. If a shortage occurs within the normal lead time we need to take special action. This may be placing a rush order, delaying the lowest priority use, or providing a partial quantity to one or more demands.

Every change in the supply or demand situation requires a revision of the Inventory Projection Report. However, in practice it is usually sufficient to generate a new report at a convenient regular interval such as daily for critical items or weekly for non-critical or slow moving items.

22.9 Independent Demand Items

Independent Demand Items are items for which demands occur on a variable basis, such as spare parts required for breakdown repairs.

22.9.1 Fast Moving Items

For fast moving independent demand items a typical cycle of stock level from order to re-order is shown graphically in Fig. 22.6.

The stock level is shown vertically and time is shown horizontally. The stock level following an earlier delivery starts at some initial value as shown on the left hand axis, and then falls irregularly over time.

The stock level is controlled by setting a *reorder level* represented by the horizontal dotted line in Fig. 22.6. The current net stock position is monitored, and when the stock falls below the reorder level an order for a *reorder quantity* is placed. There is then a *lead time* after which the order is delivered. The stock then increases by the reorder quantity and a similar cycle of events is repeated. Control of the stock is effected by setting appropriate values for the reorder revel and reorder quantity.

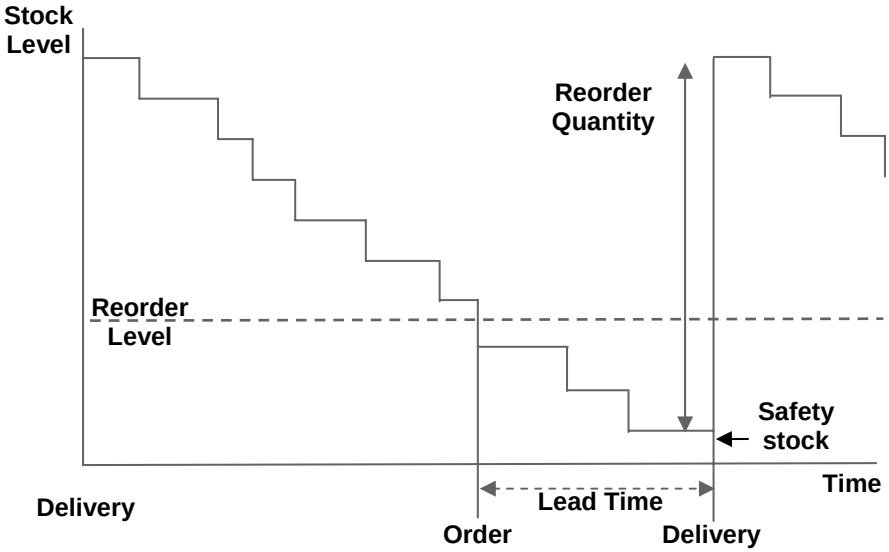


Fig. 22.6 Fast moving items – reorder cycle

22.9.2 MIN and MAX

The stock control process may also be presented in terms of minimum (MIN) and maximum (MAX) values. MIN is the same as the reorder level, so that an order is placed if the net level is below MIN. MAX is a maximum stock level and is conceptually the level which the stock reaches when an order is delivered. This is approximately the same as the reorder level plus the reorder quantity, but can be regarded as giving the stock controller the option of ordering a varied amount if the circumstances call for it, so that we order enough to bring the stock up to the value MAX.

A great deal of statistical analysis has gathered in the literature about stock control, but as a rough guide, the reorder level or MIN should be twice the demand in the resupply lead time and the reorder quantity or MAX should be a convenient ordering and delivery quantity, sufficient to cover demand for a readily foreseeable period ahead, such as one to three months.

22.10 Target Level

A variation on the MIN and MAX method of stock control is the Target Level method. This is equivalent to setting MIN and MAX to the same value and treating this value as a target. If the net level is below MAX then sufficient is ordered to bring it up to MAX. The MAX value acts as a target. This approach is convenient

if routine deliveries occur with the quantity to be ordered being flexible from delivery to delivery. Regular milk deliveries and weekly grocery ordering are examples. With all methods, adjustments may need to be made for exceptional demands or shortages.

22.11 Forecasting

Scientific reorder control for independent demand items depends on estimates of the average demand and the average resupply lead time. These parameters can vary through time and a forecasting system, or more accurately a demand tracking system should be used to track variations in the demand. The simplest systems are based on calculating a *moving average* of demands. The average will rise or fall as demand changes and the reorder level and reorder quantities should be linked so that they follow the changes.

For spare parts, the *exponentially weighted moving average*, or *exponential smoothing* method is recommended. It has the advantage that, in the case of *slow movers*, it will vary gradually, whereas a twelve month moving average, for example, would fall to zero after a year with no demand.

Besides variations in the level of demands, there can be seasonal variations and trends. Changes in trend are particularly difficult to deal with automatically and may require human intervention to correct the forecasts. Another difficulty is outliers, that is, exceptional circumstances which may rarely if ever repeat. A classic in the Australian bush is the demand for fencing wire, for which a bush fire running through a region can cause a once in a lifetime outlier in demand. This is besides being the basis for a stack of novels, films and real life dramas.

Lead time variations are more likely to be caused by administrative changes, for example changes in supplier, in delivery system or communication system, and should be monitored on that basis. Shorter lead times are beneficial in providing a more responsive system.

22.12 Reorder Risks

Risks to the smooth running of the reorder process include:

a. Failure to identify when the net stock level has fallen below the reorder level or MIN.
b. Lumpy demand causes a shortage
c. Failure to place the required order
d. Wrong item ordered
e. Order not received by supplier
f. Order not acted on by supplier
g. Wrong item sent

h. Loss in transit
i. Item wrongly identified
j. Item faulty at receipt quality check
k. Item misplaced or lost on site
l. Item faulty when brought into use

These risks are often more significant in practice than any fine tuning which may be achieved by statistical approaches to reorder level setting. A guideline response to these risks is to set the reorder level to twice the average demand in the lead time.

22.12.1 Safety Stock

The expected level of stock remaining at the end of the lead time is known as safety stock. With the guideline given in the previous paragraph we set the safety stock equal to the average lead time demand. When the lead time elapses we expect the item to be delivered. If it is not, then we should check why. If the order is not on track, we then the safety stock will provide cover for an additional lead time in which to get supply.

22.12.2 Lead Time

The estimate of the lead time should include:

- Time that it takes us to identify the that stock has fallen below the reorder level
- Time taken to place the order
- Time from the supplier receiving the order to delivery
- Time taken from delivery until the item is available to a user, e. g. checked in and placed on the shelf.

22.12.3 Reorder Rules Fast Moving

The following guidelines are suggested:

Reorder Level or MIN = 2 × average lead time demand, rounded up.

Reorder Quantity or MAX = 1 to 3 months demand, rounded to a convenient purchase quantity.

For critical items increase quantities by 25%. Do not order more than will last for the shelf life.

22.12.3.1 Stock Control Example

An item has an average demand of 4 per month and a lead time of 2 weeks. What MAX and MIN values should be set?

Solution: Take the two week lead time as corresponding to half a month. The average demand in the lead time is 2.

We set MIN = 2 × average demand in lead time = 2 × 2 = 4

We choose to set MAX to three months demand, MAX = 12

Thus the control parameters are:

MIN = 4

MAX = 12.

22.12.4 Other Factors

Several factors make stock control complicated and make automated control difficult. These include:

- **Issue Multiple.** Items are issued in multiple quantities, for example spark plugs. The multiple may be different for different applications, e. g. four or six cylinder engine.
- **Issue Quantity is Variable.** The issue quantity varies from job to job, for example when an item is stripped down in some cases new seals may be used but in other cases the existing seals may be left in place or reused or partly so.
- **Reserved Stock.** Items required for a critical machines, specific repairs, specific projects, or for a shutdown, may need to be held in reserve, otherwise, when the breakdown or shutdown occurs the items will no longer be available and a major delay in can occur.
- **Kits.** Some items form part of kits of components which are issued in a set to carry out certain repairs. When a kit is issued, a new kit should be prepared, and this will draw stock from the item store. Kits may sometimes be returned partly used, in which case the kit should be replenished. Kits may be raided for components in an emergency (oh no!).
- **Supply Multiple.** Supply may be in quantity multiples which are convenient for packaging or transportation. A choice between available supply quantities may have to be made. For example, oil in 20 litre cans or 200 litre drums.
- **Price Breaks.** Like supply multiples, price breaks occur depending on order quantities. A decision to increase the reorder quantity to take advantage of a price break may be needed.
- **Shelf Life.** May be an issue. Do not order so much that the shelf life is exceeded. To avoid items lingering in the store, arrange for *first-in-first-out*, or *FIFO*, use of items.

22.12.5 Consignment

Stock on consignment is stock that suppliers provide into store, which is only invoiced as it is used. This can have advantages for the user who is not committed to unused stock. It can also suit a supplier who gets a guaranteed customer and perhaps also gets free storage.

22.12.6 Cannibalization

This term refers to a situation where we have two items of equipment which require different spares, and the spares are unavailable. We can take spare parts from one item in order to get the other one working. This is not an ideal situation but it may be the only practical resolution to return a needed item to production in a hurry.

22.12.7 Returned Stores

Returned stores are generally a curse but may sometimes be a blessing. The condition of returned stores may be hard to assess, and using them may give rise to safety problems. In the case of technical items, expertise is needed to identify them and it is often not practical or economic to provide this. On the other hand, a scrap yard of returned stores or scrapped items may provide the only source of spares for old equipment. Where else will you find an authentic gearstick knob for your 1935 Chevvy?

22.12.8 Storekeeper Personnel

Employ ex-tradesmen in the stores. They understand the equipment, are sympathetic to the needs of operations and maintenance and have the interests of the industry at heart.

22.12.9 Overstocking

Stores people tend to be criticized more for shortages than for over-stocking, so the tendency is to overstock.

22.13 Repair Pools and Rotables

A repair pool is a number of additional machines, assemblies or components which are provided on a standby basis. When a failure occurs, an item from the repair pool is quickly brought into service. The failed item is then repaired and returned to the repair pool. Repair pools can significantly increase system availability at moderate cost. The items are referred to as rotables. Figure 22.7 illustrates the process.

It is important to initiate the repair cycle promptly. Sometimes the rotable is left languishing in a corner, with no replenishment action taken until a crisis occurs.

In some cases only the owner's own assemblies (identified by serial number) are returned to the owner's pool. A repair facility which deals with many customers (e. g. as an OEM) may supply rotables which are not necessarily those which the owner has sent for repair, so that the failed item is really a financial trade-in. In this case the mean time to replenish the repair pool may be less than the time to turn around a specific rotable. A judgement needs to be made regarding the appropriate lead time to use in estimating the size of the repair pool. As a guide line the size of the repair pool should be twice the number of failures expected in the turnaround lead time. For critical items one or two extras may be carried.

22.13.1 Repair Parts

Repair parts are items which are sent for repair to a higher echelon, but no repair pool is kept. The item is out of service while the repair is being carried out. In-between situations can arise if the repair part is replaced from stock or by cannibalization, but normally the user awaits the return of the repair part.

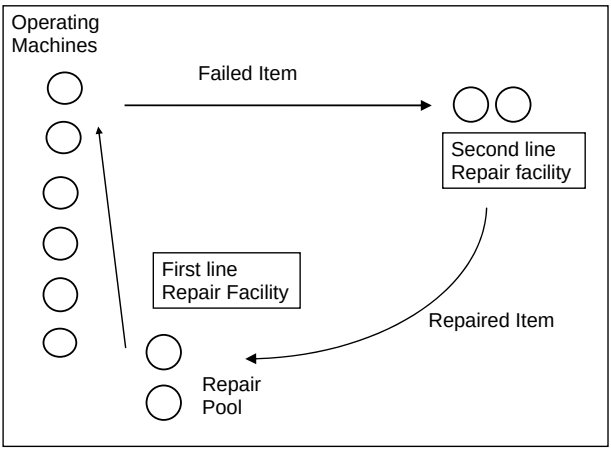


Fig. 22.7 Repair pool and rotables

22.14 Item Criticality

Reviewing item criticality requires a knowledge of which machines and processes are most critical to the business.
Critical items will normally be:

- Consumables that are essential for mainstream operations,
- Spares that are essential to maintain mainstream plant.

Increase reorder levels where criticality is identified. As a guideline, increase the reorder level by 25% and round up to the next integer value. So a non-critical reorder level of 5 will become a critical item reorder level of 7.

22.15 Slow Moving Items

A slow moving item is an item where the mean time between demands is much longer than the lead time. As a guideline, if the mean time between demands is more than ten times the average lead time then the item is slow moving. Thus an item with an average demand of 1 per year and a lead time of one month is slow moving. The *mean lead time demand* is the average demand in the average lead time. An item is slow moving if:

Mean Lead Time Demand < 0.1

For slow moving items, the probability of multiple demands in the lead time is very small. Specifically, it is less than 0.01, assuming that demands are independent. Classify slow moving items into the following categories:

- "*Stock Zero*" items. Do not hold stock. In this case you have to wait for delivery every time. This is also described as Order Only On Demand (OOOD).
- "*Stock One*" items. This is the default. Usually have 1 in stock. Order when stock reaches zero, (MIN = 1).
- "*Stock Two*" items. Items for which extra safety stock will be held. Usually have two in stock. Order when stock reaches 1. (MIN = 2).

The choice of category for any given item is based on the following factors:
Demand Probability. Low values reduce the holding. A mean lead time demand of less than 0.01 will usually result in a "Stock Zero" decision, that is, orders are only placed when a demand for an item eventuates. But consideration should be given to holding the item as an insurance spare, in which case we will have a "Stock One" decision.

Item Cost. A high cost reduces the holding, for example a high cost may result in a stock-two item being reduced to the stock-one category.
Shortage Cost. Higher values of shortage cost will increase the holding

Lead Time. A long lead time increases the holding
Safety and Environment. Potential problems under these headings increase the holding

22.16 Insurance Spares

An "insurance spare" is one where the probability that it will be needed is low, but the consequence of not having it is high, so on balance we decide to hold it. The item need not be high cost. In fact, low cost is an argument in favour of holding a spare.

For high cost and high shortage-cost items, have a contingency plan. This may involve:

- holding a spare equipment, this is an insurance spare,
- sharing this with others,
- arranging air freight as a contingency plan for an emergency,
- making a contingency agreement with the supplier
- having a contingency plan which provides an adequate short term solution, if feasible
- pre-creating inventory file entry …

22.17 Performance Indicators

22.17.1 Service Level

The *service level* is the proportion of items supplied at the time required. The service level is a performance indicator. However, the service level only measures performance from the consumer's point of view and if it is the only performance indicator used, it will encourage overstocking.

22.17.2 Days Supply

Consideration of the number of days supply of items can help to highlight stocks which are excessive and ones which are in short supply:

Days Supply = Net Stock × 365 / Annual Demand

Days Supply > 730 is more than two years supply, which normally indicates dead stock or possibly an insurance spare
Days Supply > 365 is excessive stock or slow moving
Days Supply < 365 is normal
Days Supply = 0 is out of stock

Part No - Description	Net Stock Level	Av. Monthly demand	Days Supply
158904 - Bearing	356	0	9999
235611 - Flange	75	2.3	978
SR-24 - Hose	3900	25	156
7034452 – Seal	2	6	10
56902 – Desiccant	23	150	4.6
78/45WY6002 - Pipe	0	5	0
AD670013 – Valve	-3	2	-45

Fig. 22.8 Days supply report

Dead stock is likely to be for items which are no longer used. Correct gross anomalies by transferring, writing off and disposing of stock which is of no further use at a given location. But be careful not to overreact. Some items may be insurance spares or may only be required at long intervals. Figure 22.8 shows an example of a days-supply report.

22.17.3 Value Turns

Another performance measure is *value turns*. This is the annual demand value divided by the stock value. A low level indicates a low turn over rate of stock, which is inefficient. The cost-benefit of the current inventory can by examined by analysing the cost of the stock and the value of the demand for that stock. Items with high stock cost but low demand value per year are poorly performing. These items should be eliminated unless they are being retained deliberately as *insurance stock* against assessed risks.

$$\text{Stock Cost} = \text{Stock Level} \times \text{Item Cost}$$

$$\text{Annual Demand Value} = \text{Annual Demand} \times \text{Item Cost}$$

$$\text{Value turns per year} = \text{Annual Demand Value} / \text{Stock Cost}$$

The value turns can be calculated for the entire stock or for sections of it. A useful assessment can be made by calculating the value turns for items in various ranges

Days Supply Range	Stock Cost	Demand Value	Value Turns / Year
0 - 90	$257,498	$3,012,543	11.7
91 - 365	$1,752,107	$921,191	0.53
365+	$3,951,228	$142,201	0.04

Fig. 22.9 Inventory value turns

of days supply. Insurance spares, however, are a special case and should be kept out of the value turns calculation.

The example in Fig. 22.9 is based on a vehicle importer which had substantial amounts of dead stock, due to model changes. The dead stock items are those with 365+ days supply. These items also have very low value turns. Similar results occurred in an oil refinery with spares for obsolete plant.

22.17.4 ABC Analysis

Sort the items by Annual Demand Value (or "turnover").

Annual Demand Value = Annual Demand × Item Value

Group into "A,B,C" classes by Demand Value.

- Class A is items with high demand value (top 20%)
- Class B items with medium demand value (next 40%)
- Class C items with low demand value (bottom 40%)
- Possibly also Class D for zero value = dead stock, but could include some insurance spares. Exclude these from percentages.

Focus most attention on improving the management of the Class A items.

22.17.5 Inventory Improvement Actions

- Eliminate stocks for items no longer in use.
- Retain stock of items which may be needed, even if they are old, slow moving or insurance items
- Eliminate excessive stocks. Stocks above the (reorder level + reorder quantity or MAX) are normally excessive. Old stock can often deteriorate and cause problems when used.
- Reduce lead times e. g. by faster freight service, or more frequent review.

- Consolidate stock holdings and/or stock level information across sites.
- Get the supplier to hold stock or send stock on consignment.
- Use a Just In Time call off system for steadily moving items.

22.18 Accounting for Inventory

Inventory is an asset. Fast moving inventory, with a turnover period of less than one year is a current asset, whereas slow moving inventory is a fixed asset. Categories of inventory include:

Current Assets:
- Finished goods including distribution inventory
- Work in Process (WIP)
- Materials – for use in manufacture
- Consumables e. g. fuels
- Spare parts of a fast moving nature

Fixed Assets:
- Spare parts, slow moving
- Repair parts e. g. rotable assemblies
- Insurance spares – held just in case.

22.18.1 Inventory in the Balance Sheet

Inventory of all types occurs as an asset in the balance sheet. Inventory must be funded, that is we have to have paid for it, and as it does not generate a return merely by sitting there, it is something which we should try to minimize, provided that we can do so without causing losses to appear elsewhere. This is why manufacturers try to minimize inventory through systems such as Just In Time and Lean Manufacturing.

22.18.2 Inventory in the Profit and Loss Account

The cost of the current asset inventory purchased in the year is part of the costs in the profit and loss statement, whilst the difference in the inventory value between the start and end of the year also appears in the profit and loss statement of company accounts.

EBITDA = Revenue – Costs + Closing inventory $ – Starting inventory $

In an operation which runs at a reasonably uniform pace, the difference between the values of closing and starting inventory will normally be small, so that the signifi-

cance of changes in inventory value will not be great. However, an apparent profit arising primarily from an increase in the value of inventory over the year should be regarded with suspicion, as the inventory may ultimately not realize its quoted value. People have been known to lose their jobs when they were found out fudging the profit by overstating the value of inventory. Work-in-process inventory and capital developments partially completed are areas where valuations can be dubious.

22.18.3 Overstocking and Write Downs

For finished goods, an overstocked situation may lead to discounting of the price and hence to an inventory write down which will affect profits. A potential problem, relates to maintenance parts. Fast moving spares are treated as current assets, but if they do not move as quickly as expected – as often happens – they can accumulate in value on the books. If it then turns out that they are subsequently worth much less than their purchase price, due perhaps to being obsolete, then a substantial write down, and hence loss of profit will occur.

As an example, consider a company which has a fleet of vehicles which uses a particular type of tire. The company buys a supply of tires for the vehicles. Tires are an expense item, that is, a current asset, and the value of tires in stock at the end of the year will contribute to profit. Later the vehicles are replaced by a different model which uses different tires. Tires of the original type which remain in stock will remain as a current asset, but may in fact have no value, in which case a write down will be required. On a small scale, this may be unimportant, but experience suggests that, when accumulated over many assets and a long period of time the problem can become substantial. Management will be concerned at the cost and timing of a write down as it will impact on profit in the current year.

A possible solution to the previous problem is to hold spares as capital items and depreciate them. However, another problem may then arise. Often, spares are charged out to a user, possibly an outside customer or an internal cost centre, as they are taken from store. If spares are depreciated, they will be charged out at much less than their purchase price, and the cost will be borne by the store (our company or our cost centre). To avoid this we would need to have a policy of charging out spares at cost. Another thing is that if spares are depreciated the accountants may want to write them off as of little or no value, when in fact they are essential to keep our major assets working.

Thus there are some unresolved issues relating to accounting for slow moving spare parts.

22.19 So How Did We Win?

“Most of your war stories seem pretty negative, Pop”, said Jock.

“Yes”, said Pop. “In fact Hermann, our German storeman in Sennelager after the war, used to tell me that he couldn’t understand how his side lost!”

"One day though, a Polish bloke turned up at the store looking hot and bothered. He had walked about ten kilometers from where his tank transporter had broken down. A brake jumper lead had failed and it wasn't safe to drive with the trailer brakes not working. He had the lead in his hand – he asked if we had a spare."

"We didn't have tank transporter spares and neither did anyone in the area. I took a look at the lead and figured that we could fix it temporarily by replacing the worn section with a piece of metal tube. I told the Polish driver to go over to the canteen and get something to eat and come back in an hour."

"I got Chalky White to turn a length of tube to the right size and to fix it into the lead with hose clips. We tested it on the compressed air machine and it was okay. The Polish driver was delighted, and we had a call later that day saying that he had got to his base safely and thanks."

"It was at a social barbecue later that Hermann said to me that that just wouldn't have happened in his army. They worked strictly in silos, and there was no way that his regiment would have even let a foreigner into the store, much less gone to the trouble of helping him out."

22.20 But Problems Remain

"Nothing that I learnt in my Operations Management class ever seems to work", Veronica complained one day at the water cooler.

I was going to ask what in particular she had in mind, but she went on seamlessly.

"The chlorinator has umpteen types of seal and a different one fails every time. They only cost a few dollars each but any of them can bring the whole system to a grinding halt. Not only that, but you can't get them in this country, they have to be imported, and once we have a particular type in store we never need it again!"

I groaned sympathetically. She was feeling pretty stressed – the chlorinator was off-line again.

"I ordered a whole lot of seals for the annual shutdown, but guess what – some person (I think she said person) took a couple out of the store to use on the other line. Now were waiting for air-freight on two dollars worth of items, at $20,000 an hour down-time."

"Hmm", I said, and edged away from the cooler.

……

A week or so later when things had calmed down I asked Veronica what she meant about the Operations Management class.

"Well the lectures were all to do with the *standard deviation of the lead time demand* which seemed to be the answer to everything, but there is no chance of getting off first base with that in real life."

"The first problem is that the technicians need access to the stores 24 hours per day 7 days per week. That cuts right across a stack of security issues. So the technicians 'expense' a whole lot of stores that they think they might need and squirrel them away somewhere. This completely invalidates any demand data on the computer system."

"Another problem is that the people who work in the store nowadays, and the computer system people, know nothing about the equipment or about maintenance – it is all just part-numbers to them. Of course it's not their fault, but if only they *knew or cared* about what was going on in the plant it would make a lot of difference."

"One thing that we did at Widdecombe", I offered, "Was to employ ex-trades people in the store. They were all ex-mates of the technicians and understood the plant because they had worked there for years.

"In fact, there is a guy called Tom Cobbley who could do with a job right now, and who knows the refinery really well"

"Interesting", said Veronica, "I'll see what Human Resource Management says about that idea".

…….

"I think I know where the academics go wrong", I said, the next time I met Veronica in the tea room.

"Yes?" she said.

I reminded her about her comments about Operations Management lectures.

"What they do." I said "is replace a simple problem with a harder one. For example, if you said to the storeman that it was okay to run out of stock of non-critical items on average once a year, he could probably make a fair shot at the correct reorder level. But if you tell him to set the reorder level to the mean lead time demand plus 1.68 standard deviations then you have created a much harder problem for him."

"I see what you mean" said Veronica, "but to be fair, the analytical types are trying to cope with thousands of items on some automatic basis. A human being can probably get a better answer if he has time to work on a particular item."

…….

"I thought that that consultant that we had was a complete idiot, but I can see what went wrong now", said Veronica a few weeks later.

She knew that I always lent a sympathetic ear to her stories.

"He spent ages setting the reorder levels on the automotive parts inventory, and as soon as he left we began to run out of parts"

"So was he an idiot or what?" I asked.

"As it happened, just after he left we decided to close the warehouses in New South Wales and Queensland and supply the dealers direct from the main store in Victoria. That completely changed all the demand data and made the reorder levels too low. That is why we ran out of parts.

"The consultant wanted to implement a forecasting system which would have updated the demand data, but apparently we were out of budget for consultants and that never happened."

"So what's happening now? I asked.

"We're in a mess", she said.

…….

"I hear that you are leaving, Veronica"

"Yes, we're relocating to Perth.

"And by the way, I've just figured something out on the military maintenance contract"

"You always figure things out just too late… oops, sorry. Nothing secret, I hope"

"Not really. Peculiar though. We often had difficulty getting spare parts for the older army equipment until I met up with a secondhand dealer in Melbourne who always seemed to able to come up with stuff.

"The thing I couldn't get was that it would always take him until 'next Thursday' to supply parts – it seemed odd.

"Then I realized that there was an Army Surplus sale at the depot every Tuesday. He was buying old stores from the Army, extracting what we needed and selling them back to us to sell back to the Army."

"So was he a crook or was he providing a valuable service?" I asked. But Veronica had hurried off into the sunset.

……

I saw Veronica about six months later at the Asset Management Conference.

"All running smoothly in Perth? I asked.

"You'll like this one" she said. "I went to the electrical distribution branch's store to review their stock control procedures. As I arrived a truck pulled up with a couple of technicians in it. The storeman asked what they wanted and then directed them out the back to an open concrete area." – "Probably over on the far left" he shouted.

"They had come to look for replacement connectors for one of the older lines. I asked the storeman if they were easy to get."

"Impossible" he said. "They stopped making them ten years ago, but some of the ones on the old wires are still usable. We never throw anything out."

"Do you have records of what you've got? I asked.

"Naw – ugh" he said.

"I thinking he was expressing a certain contempt for office wallahs."

"Well they had one thing right" I said, "The storeman knew the business."

Chapter 23
Key Performance Indicators

Chapter Aim: The aim of this chapter is to introduce and to give examples of indicators of asset performance.

Chapter Outcomes: After reading this chapter you will be aware of the role of performance indicators and of some of the factors to consider in creating and applying them. You will have available some examples of performance indicators in specific applications.

Chapter Topics:

- Functional performance indicators
- Railway systems
- Water supply systems
- Electricity supply systems
- Overall equipment effectiveness
- Maintenance related performance indicators

23.1 Functional Performance Indicators

Functional performance indicators are used to measure the performance achievements of systems. They are important in that they show how well an asset, or system of assets is meeting its stated purpose. They are therefore a valuable guideline for users, customers and senior management in assessing and comparing performance across time periods and across comparable systems. A range of performance measures suited to public works organizations is listed in the International Infrastructure Management Manual Section 3.1.3. Indicators may be linked to payments or to penalties in performance contracts. Responsibilities for non-conformance and constraints on performance need to be recognized in creating these contracts. At the

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operational level, performance indicators are useful to managers as rapid pointers to how a system is performing and as an indication of areas of strength and weakness.

Performance indicators should ideally be designed so that they do not affect the behaviour of participants, other than in motivating genuine performance improvements. In practice, performance indicators can have a motivating or de-motivating effect depending on how they affect particular people or groups. If maintenance work done while machinery is idle for operational reasons creates "unavailability" which counts against maintenance, then the maintenance opportunity will not be taken. If the cost of tyres is a charged to the maintenance budget, operations will have less motivation to drive carefully than if the cost comes out of the operations budget. Service providers can indulge in what is known as '*pencil whipping*', which means making moves designed specifically to meet or beat the indicator. For example, a performance indicator on completed repair tasks may be circumvented by closing off one job ahead of a deadline and then starting up another job to finish the remaining work. Thus the danger of a performance indicator is that it may substitute for a more effective but less specific requirement for across the board improvement.

Performance measures are subject to random variation, and to decide formally whether a variation is significant or not, statistical analysis is needed. The detail of statistical techniques is outside the scope of this book, but examples are confidence limits for observed measures, control charts as used in quality control, regression analysis and correlation coefficients.

23.1.1 Railway System Indicators

In a railway system, some indicators are:

- % of planned train-kilometres delivered per month
- % of services no more than 5 minutes late
- Passenger-minutes late
- Train cancellations %
- Train-minutes late

23.1.2 Water Supply System Indicators

In a water supply system, performance is measured by such factors as reliability of supply, water quality, water pressure, frequency of burst water mains, sewer collapses, leaks and flooding and response times and time to fix problems. Target levels of service for these parameters are set and performance is measured against them.

The severity of incidents can vary considerably and a severity rating should be established. The rating will also serve to indicate priority in addressing problems at any particular point in time. Examples of high severity events for a water authority are as follows.

- Sewer discharge or overflow
- Missing sewer access lid
- Sewage entering drain or watercourse
- Personal injury or significant health risk
- Damage to buildings or sensitive environments

23.1.3 Electricity Transmission or Distribution

Indicators of performance are:

- Outages frequency
- Outages duration
- System-minutes lost
- Voltage drops

The system-minutes lost is calculated by dividing the number of megawatt-minutes lost in a period by the average megawatt rating in the period. For example, if 40,000 megawatt-minutes were lost in a period, in a system that averaged 5,000 megawatts, the number of system minutes lost would be 8.

23.1.4 Trucks

Examples of indicators are:

- Truck utilization,
- Numbers of used and unused trucks,
- Payload by weight, volume, value
- Distance travelled
- Value per truck-day
- Comparison with a base line

This inference from these indicators is not necessarily that low utilization is a bad reflection on fleet management, as there are potentially many causes.

23.2 Overall Equipment Effectiveness

Overall Equipment Effectiveness = Availability × Utilization × Quality

It is important to identify the sources of shortfalls. Availability may be high, but utilization poor, due to a range of factors, such as shortage of operators, shortage of materials, poor operational planning, lack of demand. Similarly, the problems may lie in the quality area.

23.3 Maintenance Related Performance Indicators

The following are some examples of items which can be used as performance indicators.

a. Compliance with weekly maintenance plan, % of activities completed
b. Planned and scheduled hours as a % of total maintenance hours.
c. Unplanned downtime to be low
d. Occupational Safety and Health injuries to be minimal
e. Preventive Maintenance, Predictive Maintenance, and Condition Based Maintenance hours as a % of all maintenance hours to be high
f. Plant availability to be high
g. Breakdown Maintenance Hours as a % of All Maintenance Hours to be low
h. Production losses due to maintenance to be low
i. Maintenance costs as a % of turnover
j. Maintenance costs as a % of plant replacement value
k. Work Orders reworked/Total work Orders
l. Maintenance overtime/Total company overtime to be less then 5%
m. Inventory turnover to be 2 to 3 times per year
n. Training, proportion of employees/year receiving training to be more then 40%
o. Expenditure on employees to be more then 4% of payroll
p. Store investment as a % of plant replacement value
q. Contractor costs as a % of maintenance costs
r. Maintenance labour utilization to be high, but not so high that response to urgent jobs is inhibited.

Chapter 24
PAS-55 Asset Management Specification

Chapter Aim: The aim of this chapter is to describe PAS-55, the asset management specification published by the British Standards Institute.

Chapter Outcomes: After reading this chapter you will be aware of the scope and contents of PAS-55 Asset Management Specification and will see hoe it relates to techniques used in the asset management field.

Chapter Topics:

- Introduction and references
- Outline
- Asset management manual guidelines
- Outline content of PAS-55 clauses
- Functional gap analysis

24.1 Introduction and References

PAS-55 is a preliminary standard or 'Publicly Available Specification' for asset management, the development of which has been led by the Institute for Asset Management (UK). It is published by the British Standards Institution, London. www.bsigroup.com Tel: +44 (0)20 8996 7070. The document references are:

PAS 55-1 Asset Management. Part 1: Specification for the optimized management of physical infrastructure assets. ISBN: 978 0 580 50975 9

PAS 55-2 Asset Management. Part 2: Guidelines for the application of PAS 55-1. 978 0 580 50976 6

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PAS-55 provides a comprehensive framework for asset management, ranging from the general setting of organizational policy and strategy to the details of planning, documentation, training, risk management and so on. PAS-55 provides the general framework, but not the detailed content of the various techniques and practices of asset management. The adoption of PAS-55 can provide:

- A structured view and understanding of asset management;
- Effective relationships between top management, asset management, operations and maintenance;
- Improvements in asset financial returns;
- Improvements in asset management organization;
- Insurance, health and safety, regulatory benefits;
- Company recognition/marketing;
- Improvements in training and development.

The following tables relate the clauses of PAS-55 to the techniques which are established in the asset management body of knowledge. They can be used to address three issues:

- Assessing competence of the system and of individuals in relation to PAS-55
- As a guide to the techniques required in implementing PAS-55
- As a link between the issues encountered in asset management and the techniques which have been applied in solving these problems.

An outline of PAS-55 is given in the next section, a schematic chart of PAS-55 is shown in Fig. 24.1 and a list of clause headings is shown in Fig. 24.2.

24.2 Outline

PAS-55 has the four introductory sections labelled:

0 Introduction
1 Scope
2 Reference publications
3 Terms and Definitions

These sections deal with general issues such as:

- What is an asset?
- What scope of assets does PAS 55 cover?
- What is asset management?
- What is the aim of asset management?

The remaining section:

4 Asset Management System Requirements

deals with the asset management field, specifying in general statements supported by many dot points, the requirements of asset management.

Section 4 is broken into the following subsections:

4.1 General requirements,
4.2 Asset management policy
4.3 Asset management strategy, objectives and plans
4.4 Asset management enablers and controls
4.5 Implementation of asset management plans
4.6 Performance assessment and improvement
4.7 Management Review

Figure 24.1 shows the structure of PAS-55 in outline. The Policy, Strategy and Information Systems sections have system wide application. The remaining sections are applicable to all areas of a system, but the details will vary from asset to asset.

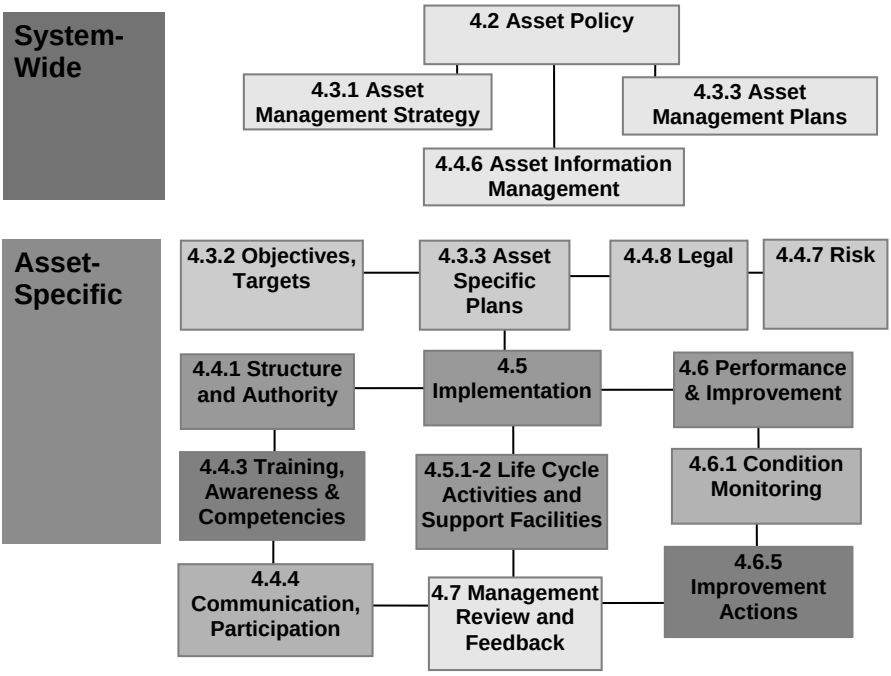

Fig. 24.1 PAS-55 outline structure

24.3 PAS-55 Asset Management Manual Guidelines

This section gives an outline which can serve as a guide in developing a PAS-55 based Asset Management Manual. Figure 24.2 shows the clause headings of PAS 55-1, supplemented by additional sub-headings from PAS 55-2. Some further detail of the outline contents of each clause is then given.

0	Introduction
1	Scope
2	Reference publications
3	Terms and definitions
4	Asset Management System Requirements
4.1	General Requirements
4.1.1	Asset Management System
4.1.2	Review against PAS-55-1
4.2	Asset Management Policy
4.3	Asset Management Strategy, Objectives and Plans
4.3.1	Asset Management Strategy
4.3.2	Asset Management Objectives
4.3.3	Asset Management Plans
4.3.3.1	Asset Management Plans - General
4.3.3.2	Optimizations of asset management strategy and plans
4.3.4	Contingency Planning
4.3.4.1	Contingency Planning - General
4.3.4.2	Contingency Plans
4.3.4.3	Emergency equipment and resources
4.4	Asset Management Enablers and Controls
4.4.1	Structure, Authority and Responsibilities
4.4.2	Outsourcing
4.4.3	Training, Awareness, Competence
4.4.3.1	Training, Awareness, Competence - General
4.4.3.2	Competencies in Asset Management
4.4.4	Communication, Participation, Consultation
4.4.5	Asset Management System Documentation
4.4.6	Information Management
4.4.7	Risk Management
4.4.7.1	Risk management processes
4.4.7.2	Risk management methodology
4.4.7.3	Risk management - Process steps
4.4.7.4	Risk registers
4.4.7.5	Management of asset-related risks
4.4.7.6	Asset criticality
4.4.7.7	Risk identification and assessment
4.4.7.8	Use and maintenance of asset risk information
4.4.8	Legal Requirements

Fig. 24.2 PAS-55 clauses and sub-clauses

4.4.9	Management of Change
4.5	Implementation of Asset Management Plans
4.5.1	Life Cycle Activities
4.5.1.1	Implementing asset management plans
4.5.1.2	Operational control of asset management processes
4.5.1.3	Creation, acquisition or enhancement of assets
4.5.1.4	Utilization of assets
4.5.1.5	Maintenance
4.5.1.6	Decommissioning and disposal
4.5.1.7	Other operational controls
4.5.2	Tools, Facilities and Equipment
4.6	Performance Assessment and Improvement
4.6.1	Performance and Condition Monitoring
4.6.2	Investigation of Asset-Related Failures, Incidents, Non-conformances
4.6.2.1	Investigation - general
4.6.2.2	Investigation - procedures
4.6.2.2.1	Investigation – procedures general
4.6.2.2.2	Investigation – immediate action
4.6.2.2.3	Investigation - recording
4.6.2.2.4	Investigation – investigation !!
4.6.3	Evaluation of Compliance
4.6.4	Audit
4.6.5	Improvement Actions
4.6.5.1	Corrective and preventive action
4.6.5.1.1	Corrective action
4.6.5.1.2	Preventive action
4.6.5.1.3	Follow up
4.6.5.1.4	Non-conformance and incident analysis
4.6.5.1.5	Monitoring and communicating results
4.6.5.2	Continual improvement
4.6.6	Records
4.7	Management Review

Fig. 24.2 (*continued*) PAS-55 clauses and sub-clauses

24.3.1 Outline Content of PAS Clauses

1 Scope

List the range of your assets to which the standard applies. Everyone involved in asset management should have a basic understanding of the main assets which the organization has to manage. *Section 18.1* describes the Register of Key Assets which can be used to indicate the range of assets covered.

2 Reference Publications
List references to related documents, internal and external, that are relevant to your asset management application, e. g. organizational structures, procedure documents, technical standards. A cross reference list between PAS-55 and the health and safety standard OHSAS 18001:2007, environmental standard ISO 14001:2004 and quality standard IOSO9001:2000 is given in Annex A of PAS-55.

3 Terms and Definitions
List the terms and definitions which apply to your application. PAS-55 section 3 contains a list. This section should give a reference to acronyms particular to your organization or industry that are used in asset management.

4.1 General Requirements
The requirement is for a defined system for asset management for the organization. Give an overall statement and/or organization chart of the system. Outsourced functions must be covered.

4.2 Asset Management Policy
An asset management policy statement is required. It must be visibly endorsed by top management.

4.3.1 Asset Management Strategy
Give details of the strategic approach to asset management adopted by the organization. This section is used to describe the structure and procedures for business development planning as related asset capability development, *at top level*. Functional level details are considered at Section 4.3.3.
The organizations systems and methods for managing the following factors are to be documented:

Asset requirements forecasting.
Asset gap analysis.
Financial analysis – procedures and guidelines.
Outsourcing policy.
Planned life, considering age, condition, obsolescence.
Renewal/ replacement planning.
Stakeholder groups liaison policy and procedures.
Asset acquisition and development project evaluation and approval guidelines and procedures.

4.3.2 Asset Management Objectives
Functional level: Business objectives
Functional level: Financial objectives.
Functional level: Cost Benefit objectives.

4.3.3 Asset Management Plans
This section deals with assets at the planning stage. Section 4.5.1 deals with the through life implementation of asset support.

Acquisition plans
Disposal plans
Logistic support analysis.
Level of Repair analysis.
Through life support planning.
Life cycle costing.
Integrated logistic support analysis
Capital Budget,
Outsourcing planning and control.
Replacement planning

4.3.4 Contingency Planning

Emergency response procedures and related equipment.
Contingency plans.
Backup systems.

4.4.1 Structure, Authority and Responsibilities

Asset management organizational structure.
Acquisition project management structure.
Maintenance organizational structure. Maintenance facilities, workshops.
Engineering and Technical support structure and regulations.
Spares and consumables provision and management system

4.4.2 Outsourcing

Covering material in this book chapter on Outsourcing

4.4.3 Training, Awareness and Competence

Competence requirements analysis for asset management related jobs
- Chief Asset Management Officer
- Asset Managers
- Project Managers – Acquisitions
- Project managers – Sustainment
- Logistic Support Analysts
- Technical Support Specialists

Training requirements analysis.
Training resource organization and establishment provision
Training budget.
Training plans

4.4.4 Communication, Participation and Consultation

Stakeholder groups creation, planning and implementation.
Employee communication systems, e. g. newsletters, meetings.

4.4.5 Asset Management System Documentation

Documentation of the asset management system itself

4.4.6 Information Management

CMMS existence
CMMS resourcing.
Asset register, coding,
Configuration Management.
Real time use.
History.
Asset acquisition, location, records and history.
Configuration management
Maintenance policies and procedures (in CMMS),
Renewal/Acquisition procedures and decisions documentation system.
Organization for the security and access to documentation.
Data coordinator to identify full range of changes.
Data custodian to check and approve.
Procedures for the revision of documents

4.4.7 Risk Management

Risk management processes and methodology. AS4360
Risk identification and assessment
Use and maintenance of asset risk information
Risk Based Inspection.
Level of Protection Analysis.
Event and Fault tree analysis.
Safety Integrity Levels.
HAZOP.
Risk in plans and projects.

4.4.8 Legal and Other Requirements

Technical regulation awareness and system for maintaining
Regulation compliance for: High risk plant
Regulation compliance for: Environment;
Regulation compliance for: Health and Safety.
Legal support for asset related acquisitions and contracting

4.5.1 Life Cycle Activities

This section deals with the through life implementation of asset support. Section 4.3.3 deals with assets at the planning stage.
Life cycle costing – can Fig. in this section and in 4.3.3.
On-going strategic role relating to activities of the maintenance organization, covering:

- Through life support
- Asset Basic Care activities
- Reliability Centered Maintenance.
- Maintenance planning, scheduling and control.
- Maintenance actions
- Spares and consumables inventory management
- Shutdown/Turnaround planning and management

Maintenance Budget.
Maintenance Policies and Procedures Development.

4.5.2 Tools, Facilities and Equipment

Planning, acquisition and strategic role in:
Provision of tools, support and maintenance facilities and equipment
Facilities management.
Systems, procedures, implementation
Cataloguing
Spares and consumables management system and resources

4.6.1 Performance and Condition Monitoring

Performance monitoring, procedures, standards, implementation, response.
Technical performance monitoring.
Engineering design criteria.
Condition monitoring economics, methods, targets.
Condition monitoring techniques used.
Condition monitoring personnel, training, procedures and response systems. External technical support.
Reliability standards and performance
Availability,
Maintainability.

4.6.2 Investigation of Asset-Related Failures, Incidents and Non-Conformities

Incident reporting systems.
Incident management systems and practices.
Failure Reporting and Corrective Action Systems (FRACAS).
Suggestion, response and feedback systems. Continuous improvement.
Root Cause Analysis.
Failure Mode and Effects Analysis (FMEA).
Reliability analysis, MTBF, failure rate trends
Maintainability analysis and improvement.

4.6.3 Evaluation of Compliance

4.6.4 Audit

Auditors and procedures established
Audit records
Audit follow-up action procedures. Actions taken and recorded

4.6.5 Improvement Actions

Corrective and preventive actions
Continual improvement

4.6.6 Records

Traceable records to demonstrate conformance to the requirements of the asset management system.

Production records.
Fault and failure records.
Maintenance action and cost records.
Asset history records.
Records of statutory compliance e. g. pressure vessel tests.
Training records
Calibration records

4.7 Management Review
Improvement co-coordinator role and responsibilities. Suggestion, review and feedback systems.

24.4 Functional Gap Analysis

A company can check its competency in relation to the specification, by comparing its systems with those indicated by the clauses of PAS 55. The company is likely to have in place many of the wide range of techniques in recognized use for physical asset management. Figure 24.3 relates the clauses of PAS 55 to some 80 established techniques in asset and maintenance management. The aim of this table is to assist companies to assess their competence in relation to PAS 55.

In Fig. 24.3, the first two columns give the PAS 55 clause numbers and clause headings, and the third column lists related techniques. As an example, consider Clause 4.4.6 Information Management. The requirement for an asset management information system will typically be met by having a Computerized Management Information System or CMMS. Thus Fig. 24.3 shows "CMMS Existence" as the first listed technique relevant to this clause. Here we are asking the question, "Does the company have a CMMS?" The three right-hand columns of the table provide for the user to assess the level of competency targeted and achieved, and whether the targeted level has been attained.

The company's level of competency in relation to any clause is judged by reference to five levels which are listed at the end of Fig. 24.3. These are Mastery (score 5), Professional (4), Foundation (3), Developing (2), Initial (1) and None (0). The fourth column in Fig. 24.3, headed Target, is for the user to select a target level which the company wishes to achieve in relation to a particular technique. Whilst Mastery (5) would be ideal for every competency, not all companies will require the same level of competency in every technique or every clause.

As an example, again consider clause 4.4.6 Information Management. The second competency under this clause is "CMMS resourcing". The target set by the company for this competency might be Professional (4), that is, we wish to have adequate, well trained and professionally competent staff to support our CMMS implementation. If the company has in fact minimal resources in this area, possibly also with system training yet to be completed, then its actual level of attainment might be assessed as Initial (1) or Developing (2). The Attained column would then contain the entry "0" since the target level of competence has not been reached.

PAS 55 Clauses	Related Techniques, Activities, Competencies	Target	Actual	Gap
1. Scope	Broad range of assets to which the standard applies.			
2. References	List of references to related documents, internal and external, e.g. technique standards			
3. Terms and definitions	As in PAS55 or agreed equivalent. Special terms or acronyms related to asset management within the organization.			
4.1 General Requirements	Must have an asset management system Must cover outsourced functions			
4.2 Asset Management Policy	Overall asset management policy visibly endorsed by top management.			
4.3.1 Asset Management Strategy	Capability development organization and system at top level. Asset requirements forecasting. Asset gap analysis. Financial analysis. Outsourcing policy. Planned life. Obsolescence plan. Stakeholder groups. Acquisition project evaluation and approval.			
4.3.2 Asset Management Objectives	Support of business objectives through asset availability and performance. Key performance indicators Financial objectives. Cost Benefit objectives			
4.3.3 Asset Management Plans	Asset acquisition plans Logistic support analysis. Level of Repair analysis. Through life support planning. Life cycle costing. Capital Budget, Maintenance Budget. Maintenance Policies and Procedures Development. Reliability Centered			

Fig. 24.3 PAS-55 gap analysis template

PAS 55 Clauses	Related Techniques, Activities, Competencies	Target	Actual	Gap
	Maintenance. Maintenance facilities planning. Special tools and support equipment. Outsourcing planning and control. Replacement planning Risk in plans and projects.			
4.3.4 Contingency Planning	To mitigate risks			
	Contingency plans Emergency equipment and resources Emergency response procedures and related equipment. Backup systems.			
4.4.1 Structure, Authority and Responsibilities	Asset management organizational structure.			
	Acquisition project management structure. Maintenance organizational structure. Maintenance facilities, workshops. Engineering and Technical support structure and regulations. Spares and consumables provision and management system			
4.4.2 Outsourcing of asset management activities	Contract creation			
	Contract management Audit			
4.4.3 Training Awareness and Competence	Training requirements analysis.			
	Training resource organization and establishment provision Training budget. Training plans Competency analysis methodology Competency analysis for asset management roles Competency analysis of personnel			
4.4.4 Communication, participation and consultation	Stakeholder groups creation, planning and implementation. Employee communication systems, e.g. newsletter, presentations,			

Fig. 24.3 (*continued*) PAS-55 gap analysis template

PAS 55 Clauses	Related Techniques, Activities, Competencies	Target	Actual	Gap
	briefings.			
4.4.5 Asset management system documentation	Documentation of the asset management system itself.			
	Renewal / Acquisition procedures and decisions documentation system.			
4.4.6 Information management	Asset register, coding,			
	Maintenance policies and procedures (in CMMS), Asset acquisition, location, records and history. Configuration management Organization for the security and access to documentation. Data coordinator to identify full range of changes. Data custodian to check and approve. Procedures for the revision of documents Real time use. History.			
4.4.7 Risk management	Risk management. AS4360.			
	Asset criticality Risk identification Risk registers Risk Analysis Risk treatment Risk Based Inspection. Level of Protection Analysis. Event and Fault tree analysis. Safety Integrity Levels. HAZOP. Risk in plans and projects.			
4.4.8 Legal and Other Requirements	Technical regulation awareness and system for maintaining Regulation compliance for: High risk plant Regulation compliance for: Environment; Regulation compliance for: Health			

Fig. 24.3 (*continued*) PAS-55 gap analysis template

PAS 55 Clauses	Related Techniques, Activities, Competencies and Safety.	Target	Actual	Gap
	Legal support for asset related acquisitions and contracting			
4.4.9 Management of change	Procedures for change proposals			
	Authority for change			
	Procedures for introduction of change			
4.5.1 Life cycle activities	System for the management of acquisition and development projects			
	Operational control of asset management processes			
	Maintenance, repair and overhaul			
	Decommissioning and disposal of assets			
	Maintenance planning, scheduling and control.			
	Shutdown/Turnaround planning and management.			
	Spares and consumables operation system.			
	Facilities management.			
	Asset Basic Care. Systems, procedures, implementation			
	Outsourcing management.			
4.5.2 Tools, facilities and equipment	Planning, provision and management			
4.6.1 Performance and Condition Monitoring	Technical performance monitoring.			
	Engineering design criteria.			
	Condition monitoring economics, methods, targets, implementation. Reliability standards and performance Availability,			
	Maintainability.			

Fig. 24.3 (*continued*) PAS-55 gap analysis template

PAS 55 Clauses	Related Techniques, Activities, Competencies	Target	Actual	Gap
	Performance monitoring, procedures, standards, implementation, response.			
	Condition monitoring assessment.			
	Related personnel, training, procedures and response systems.			
4.6.2 Investigation of Asset Related Failures, Incidents, Non conformances	Incident reporting systems.			
	Incident management systems and practices.			
	Failure Reporting and Corrective Action Systems (FRACAS).			
	Suggestion, response and feedback systems. Continuous improvement.			
	Root Cause Analysis.			
	Failure Mode and Effects Analysis (FMEA).			
	Reliability analysis, MTBF, failure rate trends			
	Maintainability analysis and improvement.			
4.6.3 Evaluation of compliance				
4.6.4 Audit	Auditors and procedures established			
	Audit records			
	Audit follow up action taken and recorded			
4.6.5 Improvement actions	Corrective actions			
	Preventive actions			
	Follow up			
	Continual improvement			
4.6.6 Records and Record Management	Production records.			
	Fault and failure records.			
	Maintenance action and cost records.			
	Asset history records.			
	Records of statutory compliance e.g. pressure vessel tests.			
	Training records			
	Calibration records			

Fig. 24.3 (*continued*) PAS-55 gap analysis template

PAS 55 Clauses	Related Techniques, Activities, Competencies	Target	Actual	Gap
4.7 Management Review	Improvement co coordinator. Suggestion, review and feedback systems.			
	Totals			
	% Actual / Target			

Notes
5 Mastery
4 Professional
3 Foundation
2 Developing
1 Initial
0 None

Fig. 24.3 (*continued*) PAS-55 gap analysis template

Assessment of the company's competence in relation to the target levels can be continued across all clauses of PAS 55, with Actual and Attained levels being entered in the Table. Finally a total score can be calculated in terms of both percentage of Actual to Target and of the number of competencies attained.

Figure 24.4 is the inverse of Fig. 24.3 and shows the body-of-knowledge techniques listed in alphabetical order, with the related PAS 55 clause numbers shown against each technique. Figure 24.4 is designed to assist users who are preparing PAS 55 documents and gives an indication as to which sections of PAS 55 are related to particular techniques. For example, Life Cycle Costing is relevant to Clauses 4.3.3 and 4.5.1.

PAS-55 is an overarching document which does not attempt to provide the specific detail of the many techniques involved in asset management. Besides knowing which techniques are relevant to any clause, we need the detail of that technique. Thus, to implement an asset management system, it is necessary to draw on a wide range of techniques and standards. This book, and the references and standards listed at the end of this book, present further details of asset management techniques and procedures needed to implement a PAS 55 based asset management system.

Technique	PAS 55 Clauses		
Acquisition Business Case	4.3.1	4.3.2	4.3.3
Acquisition Project Management	4.5.1		
Asset Development Organization	4.3.1	4.4.1	
Asset Development Processes	4.5.1		
Asset Management Organization	4.4.1	4.4.1	
Asset Requirement Analysis,	4.4.3		
Availability	4.6.1		
Budget, Capital	4.3.1	4.3.3	
Budget, Maintenance	4.5.1	4.5.2	
Budget, Operating	4.5.1		
Business Development and Forecasting	4.3.1	4.3.3	
Capital Investment Analysis, NPV, ROI, IRR, Payback Period, Annualized Cost	4.3.1	4.3.3	4.3.2
Computerized Maintenance Management System CMMS	4.4.6	4.4.5	4.5.1
Condition Monitoring Techniques, Practices, Standards, Decisions	4.6.1		
Configuration Management	4.5.1	4.4.6	
Cost Benefit Analysis	4.3.2		
Disposal	4.5.1		
Engineering and Technical Support	4.5.1	4.5.2	4.6.2
Engineering Design	4.6.1	4.6.2	4.5.2
Environment and environmental regulations	4.5.8	4.3.3	
Event Tree Analysis and Safety Integrity Levels	4.3.2		
Existing capabilities	4.3.1		
Existing equipment condition and remaining life	4.6.1	4.3.1	
Facilities Management	4.5.1	4.5.2	
Failure Mode and Effects Analysis FMEA / FMECA	4.6.2		
Fault Tree Analysis	4.4.7		
Financial criteria	4.2.1	4.3.1	4.3.3
Financial resources	4.2.1	4.3.1	4.3.3

Fig. 24.4 Asset management techniques and PAS-55 clauses

Finance Department	4.3.1		
Forecasting	4.2.1	4.3.2	4.3.3
Gap Analysis – of Capability	4.3.3	4.3.1	
Health and Safety	4.4.8		
Human resources	4.3.1	4.3.3	4.5.1
Inspection Intervals	4.5.1		
Insurance Spares	4.5.1		
Integrated Logistic Support ILS	4.3.3	4.5.1	
Knowledge of business environment	4.2.1	4.3.1	
Legal Department	4.4.8		
Legal Requirements	4.4.8		
Level of protection analysis	4.4.7		
Level of Repair Analysis LORA	4.5.2		
Life Cycle Costing LCC. AS 4536	4.5.1	4.3.3	
Logistic support	4.5.1		
Logistic Support Analysis LSA	4.5.1	4.3.3	
Maintainability	4.6.1	4.5.1	
Maintenance Audit	4.5.1.5		
Maintenance Facilities, Workshops	4.5.2		
Maintenance History Recording and Analysis	4.5.1.5	4.4.6	4.6.6
Maintenance Organization	4.5.1.5		
Maintenance Policies, Plans, Schedules	4.5.1.5	4.3.3	
Maintenance Procedures	4.5.1.5		
Obsolescence	4.3.3		
Operations	4.5.1.2		
Outsourcing Policy	4.4.2	4.3.1	
Outsourcing Contracts	4.4.2	4.4.8	
Outsourcing Management	4.4.2	4.5.1	
Parallel and Standby Redundancy	4.3.4		
Performance Monitoring	4.6.1		
Performance Standards	4.6.1		
Planned Life	4.3.1	4.3.3	
Preventive Replacement	4.5.1		

Fig. 24.4 (*continued*) Asset management techniques and PAS-55 clauses

Reliability Analysis	4.6.1	4.6.2	
Reliability Centered Maintenance RCM	4.5.1		
Repair / Replace Policies	4.3.1	4.3.3	
Replacement Policy – Capital Equipment	4.3.1	4.3.3	
Risk Analysis AS 4360	4.4.7		
Risk Based Inspection RBI	4.4.7		
Risk to plans and projects	4.4.7	4.3.3	4.3.4
Root Cause Analysis RCA	4.6.2		
Rotables	4.5.1	4.5.2	
Safety	4.4.8	4.4.7	
Scenario planning, modeling, analysis	4.3.3		
Shutdown / Turnaround Planning	4.3.3		
Spares and Consumables Management	4.5.2		
Special Tools and Support Equipment	4.5.2		
Stakeholders	4.2.1	4.3.1	
Statutory Requirements	4.4.8		
Sustainment of existing equipment	4.5.1		
Technical Regulations	4.4.8		
Test and Evaluation	4.5.1		
Through Life Support	4.5.1	4.5.2	
Total Productive Maintenance TPM	4.5.1		
Training	4.4.3		
Users	4.2.1	4.3.1	

Fig. 24.4 (*continued*) Asset management techniques and PAS-55 clauses

Appendix A – Tables

Table A.1 Discount Factor

	Interest Rate										
Years, n	5%	6%	7%	8%	9%	10%	11%	12%	13%	15%	20%
1	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091	0.9009	0.8929	0.8850	0.8696	0.8333
2	0.9070	0.8900	0.8734	0.8573	0.8417	0.8264	0.8116	0.7972	0.7831	0.7561	0.6944
3	0.8638	0.8396	0.8163	0.7938	0.7722	0.7513	0.7312	0.7118	0.6931	0.6575	0.5787
4	0.8227	0.7921	0.7629	0.7350	0.7084	0.6830	0.6587	0.6355	0.6133	0.5718	0.4823
5	0.7835	0.7473	0.7130	0.6806	0.6499	0.6209	0.5935	0.5674	0.5428	0.4972	0.4019

Table A.2 Annuity Factor

Years	Interest Rate										
n	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	20%
1	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091	0.9009	0.8929	0.8850	0.8333
2	1.8861	1.8594	1.8334	1.8080	1.7833	1.7591	1.7355	1.7125	1.6901	1.6681	1.5278
3	2.7751	2.7232	2.6730	2.6243	2.5771	2.5313	2.4869	2.4437	2.4018	2.3612	2.1065
4	3.6299	3.5460	3.4651	3.3872	3.3121	3.2397	3.1699	3.1024	3.0373	2.9745	2.5887
5	4.4518	4.3295	4.2124	4.1002	3.9927	3.8897	3.7908	3.6959	3.6048	3.5172	2.9906

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Appendix B – Solutions to Exercises

B.1 Holiday Resort Exercise 1.9.1

The owners of a holiday resort have had a good year, but at times the resort was overcrowded. There are opportunities to develop additional areas for accommodation and leisure activities. Write down half a dozen dot points of factors that they should consider in making plans for the future.

a. History of demand, level, trend, cycles, forecast of customer demand.
b. Demographic pattern of current and potential customers.
c. Possible bottlenecks and easy fixes ? Access roads, parking, buses, airport.
d. Site analysis
e. Scope for new attractions (e. g. theme parks) with considerations of capacity, accessibility, match to customers interests
f. Scope to develop new accommodation
g. Needs for additional utilities and services e. g. power, access routes, parking, staffing, training, staff accommodation.
h. Outline of practical options with preliminary financial analysis
i. Ranking of best return on investment
j. Requirement for government approval and permits if any.
k. Risks e. g. Accuracy of demand forecasts; Attitude to expansion of locals, of government; environmental impact, variability of weather; Risk of the unknown!
l. Competitor analysis
m. Marketing required for selected option.

N. A. J. Hastings, *Physical Asset Management*,

B.2 Pacific Earth Moving Part 1: 1.9.2

- Forecast of demand
- Forecast of revenue
- Asset gap analysis in relation to existing fleets
- Assessment of quantities and types of equipment needed.
- Consideration of commercial competitors
- Proposed volumes and timing of acquisitions
- Identification of prospective suppliers and options e. g. purchase, leasing
- Identification of logistic support requirements and costs
- Financial analysis including sources and cost of funds, return on investment
- Projected Cash Flow, Profit and Loss and Balance Sheet calculations
- Risk analysis including optimistic, average and pessimistic scenarios.
- Acquisition approval.

B.3 Pacific Earth Moving Part 2: 2.7.1

The answer to this exercise is based on Sects. 2.2 and 2.6.

B.4 Capacity Planning Exercise Generators 3.13

The pre-plan gap analysis is shown in Fig. B.1, rows 1 to 4. The total gap of 3.32 GW gives an indication of the minimum additional capacity required over the planning period and can be a useful guide in selecting options for the pre-feasibility analysis. The figure also shows the calculations for Option 1. Figure B.2 shows the

	A	B	C	D	E	F
1	Years from Now, i	5	6	7	8	Total
2	Forecast capacity needed GW.	5.2	5.72	6.29	6.92	
3	Un-augmented capacity available	4.8	4.8	4.2	3.6	
4	Pre-plan Gap	0.4	0.92	2.09	3.32	
5	Capacity before install. Row5(i-1)+Row7(i-1)-(Row3(i-1)-Row3(i))	4.8	5.4	5.4	6	
6	Gap before install. Row2 - Row5	0.40	0.32	0.89	0.92	
7	Install qty GW	0.6	0.6	1.2	1.2	3.6
8	Install cost $billion	1	1	2	2	6
9	Year of decision, i-3	2	3	4	5	

Fig. B.1 Generator capacity planning option 1

	A	B	C	D	E	F
1	Years from Now, i	5	6	7	8	Total
2	Forecast capacity needed GW.	5.2	5.72	6.29	6.92	
3	Un-augmented capacity available	4.8	4.8	4.2	3.6	
4	Pre-plan Gap	0.4	0.92	2.09	3.32	
5	Capacity before install. Row5(i-1)+Row7(i-1)-(Row3(i-1)-Row3(i))	4.8	6.8	6.2	7.6	
6	Gap before install. Row2 - Row5	0.40	-1.08	0.09	-0.68	
7	Install qty GW	2	0	2	0	4
8	Install cost $billion	2.7	0	2.7	0	5.4
9	Year of decision, i-3	1	0	3		

Fig. B.2 Generator capacity planning option 2

calculations for Option 2. Option 2 is cheaper, but Option 1 offers more flexibility in the event that the needs forecast turns out to be inaccurate. A combination of the two sizes of generator might offer a better combination of flexibility and cost.

Additional aspects of capability include; physical site availability and features; fuel supply and handling equipment; cooling water; power transformers; transmission and distribution requirements; …

B.5 Bottling Plant Exercise 3.14

Concept Stage. Formalise the projected demand over a planning period of several years ahead. Consider competition which may affect market share and total revenue. Try to determine the expectations of major customers and potential customers. Estimate the revenue from meeting demand and costs of meeting demand at a concept level. If further analysis seems worthwhile proceed to the next stage.
Pre-Feasibility Analysis. Get data on available bottling machines, new and possibly second hand. Determine acquisition costs, operating costs, maintenance costs and production capacity.
Consider the physical and financial characteristics of options including:

- Continue with existing system, reviewing maintenance policy for possible improvements.
- Replace oldest or most troublesome machines to improve reliability
- Acquire new machines, considering configurations to address the old and new markets.

If the pre-feasibility analysis looks promising proceed to the next stage.

Feasibility Analysis. Review the options and select a preferred option, possibly involving some combination of those outlined. Develop the plan in detail for the preferred option, including acquisition strategy (e.g. supplier options, shortlist of suppliers, tendering procedure if any) installation requirements, staffing requirements, maintenance and logistic support requirements, financial analysis. Bring this together into a business case and seek approval. If the plan is approved proceed to the next stage.
Acquisition Process. Acquire, install, commission, train, introduce into service.
Operational Phase. Operations proceed with new more reliable equipment, reducing the maintenance requirement, increasing production capacity and addressing the new market for screw-top bottles. Enjoy the financial benefits.

B.6 Pacific Earth Moving Part 3: 5.15.1

a. Project team paragraph 5.1.1
b. Project management 5.1.2 and activities detail in chapter, sections 5.1.3 to 5.6
c. Chapter 5, sections 5.9 to 5.12
d. Chapter 12, section 12.5

1. Year, i	1	2	3	4	5	6
2. Vehicles Reqd BOY	10					
3. Disposals EOY	1					
4. Number Owned BOY before purchase = Row 7(i-1) – Row 3(i-1)	10					
5. BOY Shortage(+) or Surplus(-) = Row2– Row 4	0					
6. Purchase Plan BOY	0					
7. Number Owned BOY after purchase. = Row 4 + Row 6	10					
8. Lease Reqt BOY=Row 2 – Row 7						
9. Lease Cost = Row8 x $50k						
10. Capital Cost = Row6 x $200k – Row3 x $15k	-15					
11. Total $k	-15					

Fig. B.3 Vehicle fleet planning template

B.7 Vehicle Fleet Capacity Exercise 7.4

The solution can be developed using the template shown in Fig. B.3. BOY means Beginning of Year and EOY means End of Year.

The analysis can be carried out using the following steps:

1. Calculate the number of vehicles which will be owned at the end of the year after disposals, but before purchases. Row 4.
2. Compare this with the number required next year, to check for a potential shortage. Row 5.
3. Decide how many to buy, if any, make up the rest of any requirement with leasing. Row 6, Row 8.
4. Calculate costs. Rows 9 – 11.

The results are shown in Fig. B.4 and Fig. B.5.

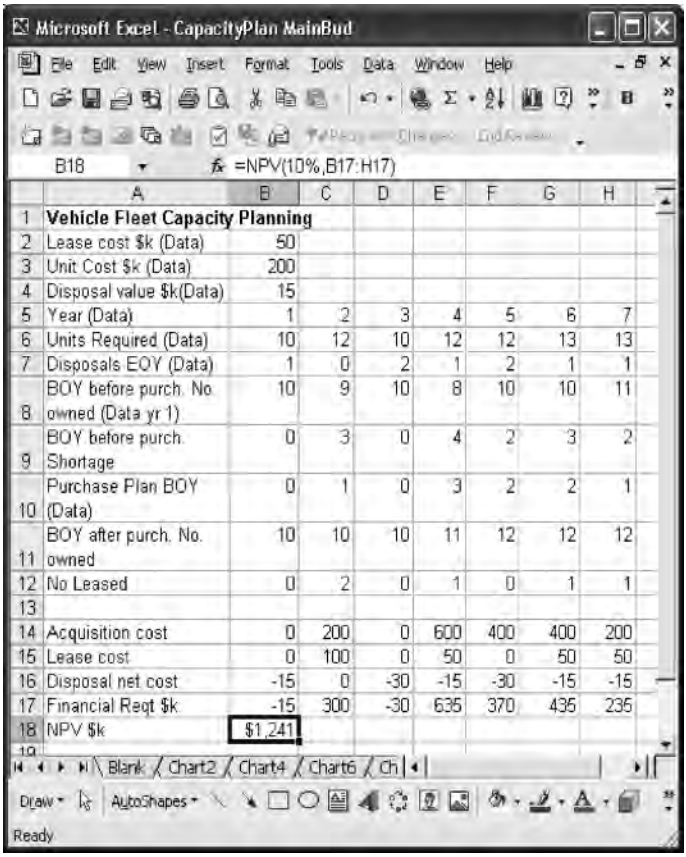
Notes:

a. A rolling plan will be reviewed annually.
b. Capital costs are smoother if approximately the same number of vehicles bought each year, but this is not necessarily a critical factor.

1. Year, i	1	2	3	4	5	6
2. Vehicles Reqd BOY	10	12	10	12	12	13
3. Disposals EOY	1	0	2	1	2	1
4. Number Owned BOY before purchase = Row 7(i-1) – Row 3(i-1)	10	9	10	8	10	10
5. BOY Shortage(+) or Surplus (-) Row 2 – Row 4	0	3	0	4	2	3
6. Purchase Plan BOY	0	1	0	3	2	2
7. Number Owned BOY after purchase = Row 4 + Row 6	10	10	10	11	12	12
8. Lease Reqt BOY =Row 2 – Row 7	0	2	0	1	0	1
9. Lease cost = Row 8 x $50k	0	100	0	50	0	50
10. Capital cost = Row6 x $200k -Row3 x $15k	-15	200	-30	585	370	385
11. Total cost $k	-15	300	-30	635	370	435

Fig. B.4 Vehicle fleet planning solution

c. Leasing is usually more expensive than owning in terms of costs per vehicle leased, but…
d. Leasing costs are an expense which is tax deductible in the current year
e. Leasing gives more flexibility in responding to changes in demand, particularly downturns; there is more downside liquidity.
f. If demand is up, revenue will be up and the extra cost of leasing will be affordable.



	A	B	C	D	E	F	G	H
1	**Vehicle Fleet Capacity Planning**							
2	Lease cost $k (Data)	50						
3	Unit Cost $k (Data)	200						
4	Disposal value $k(Data)	15						
5	Year (Data)	1	2	3	4	5	6	7
6	Units Required (Data)	10	12	10	12	12	13	13
7	Disposals EOY (Data)	1	0	2	1	2	1	1
8	BOY before purch. No owned (Data yr 1)	10	9	10	8	10	10	11
9	BOY before purch. Shortage	0	3	0	4	2	3	2
10	Purchase Plan BOY (Data)	0	1	0	3	2	2	1
11	BOY after purch. No. owned	10	10	10	11	12	12	12
12	No Leased	0	2	0	1	0	1	1
13								
14	Acquisition cost	0	200	0	600	400	400	200
15	Lease cost	0	100	0	50	0	50	50
16	Disposal net cost	-15	0	-30	-15	-30	-15	-15
17	Financial Reqt $k	-15	300	-30	635	370	435	235
18	NPV $k	$1,241						

Fig. B.5 Vehicle fleet planning – Excel® solution

B.8 Long River Ferry Company Exercise 8.11

The capital expenditure as proposed is as follows:

Year	1	2	3	4
Small boats	14	8	1	11
Large Boats	3	8	8	5
Shore Facilities	6	0	1	0
Total	23	16	10	16

Suggestions: Propose cutting back expenditure on small boats in years 1 and 2 in case demand is taken by large boats from year 3.
Is it possible to lease boats to cover the short term?
Better demand information may emerge over years 1 and 2. Market may switch to large boats, or may grow in total.

B.9 Standby Generator Exercise 9.11

Use is made of the Table A Discount factors and Table B Annuity Factors from Appendix A

1. Convert the initial capital cost of $75,000 to an EAC by dividing by the Annuity Factor for 5 years at 9%.

   $75,000 / 3.8897 = $19,282 per year.

2. Convert the terminal value to a NPV by multiplying it by the 5 year discount factor:

   $40,000 × 0.6499 = $25,996

3. Convert the terminal value NPV from step 2 to an EAC by dividing it by the annuity factor:

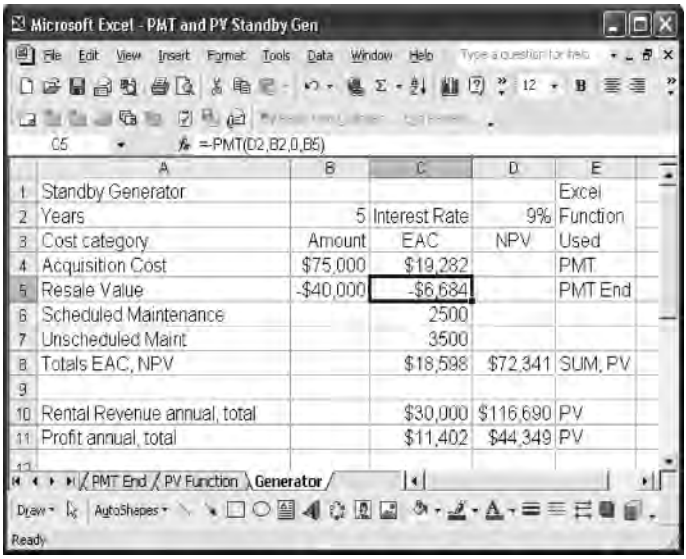
   $25,996 / 3.8897 = $6,683 per year

4. The maintenance costs are already annual costs, and their total is:

   $2,500 + $3,500 = $6,000 per year.

Add the amounts from steps 1, 3 and 4 to get the total cost (the terminal value is negative):

Initial capital EAC	=	19,282 $/year
Terminal value EAC	=	– 6,683 $/year
Maintenance EAC	=	6,000 $/year
Total EAC	=	18,599 $/year



	A	B	C	D	E
1	Standby Generator				Excel
2	Years	5	Interest Rate	9%	Function
3	Cost category	Amount	EAC	NPV	Used
4	Acquisition Cost	$75,000	$19,282		PMT
5	Resale Value	-$40,000	-$6,684		PMT End
6	Scheduled Maintenance		2500		
7	Unscheduled Maint		3500		
8	Totals EAC, NPV		$18,598	$72,341	SUM, PV
9					
10	Rental Revenue annual, total		$30,000	$116,690	PV
11	Profit annual, total		$11,402	$44,349	PV

Fig. B.6 Standby generator Excel solution

Total NPV = EAC × Annuity factor = 18,599 × 3.8897 = $72,341.

If rent is $30,000 p.a. the net revenue is 30,000 – 18,599 = 11,401 p.a.
The total NPV of net revenue is 11,401 × 3.8897 = $44,346.
The solution of this ex
The solution of this excise using an Excel spreadsheet is shown in Fig. B.6.

B.10 Solar or Diesel Power Exercise 9.12

Option 1: Solar Power

(a) Acquisition $90,000,	15 years EAC = 90,000/9.1079	=	9,882
(b) Batteries $60,000,	7 years EAC = 60,000/5.3893	=	11,133
(c) O & M Cost		=	3,000
	Total $/Year	=	*24,015*

Option 2 – Diesel Power

(a) Calculate NPV over 20 year life cycle:

NPV = Acquisition + 10 year discount factor × overhaul cost
= 50,000 + .5,083 × 20,000 = $60,166

EAC = NPV / AN for 20 years
= 60,166 / 10.5940 = $5,679 per year

(d) O & M Cost = 12,000

Total $/Year *17,679*

Solar NPV to infinity at 7% = EAC/r = 24,015/0.07 = $343,071
Diesel NPV to infinity at 7% = EAC/r = 17,679/0.07 = $252,557

Increasing the interest rate would favour diesel because it has fewer up front costs. Lowering the interest rate would favour solar power, but diesel is still cheaper at zero interest.

Solution at Zero Interest

Option 1 – Solar Power

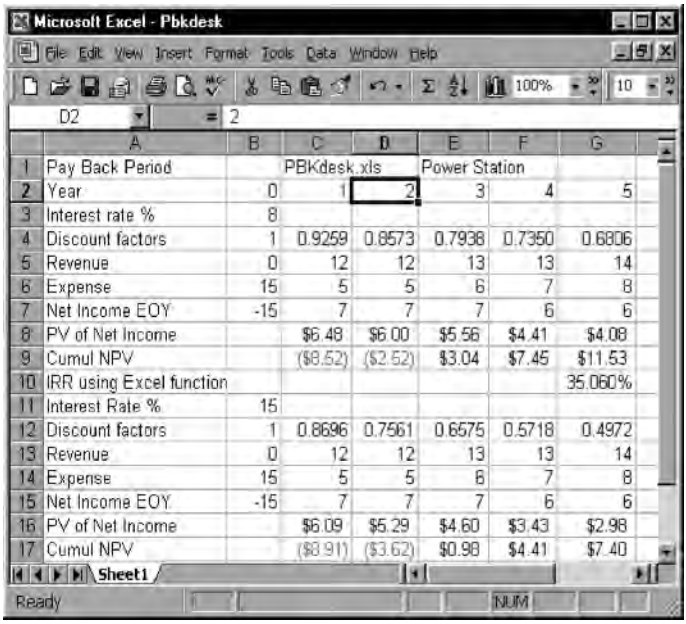
(a) Acquisition $90,000,	15 years EAC = 90,000/15	=	6,000
(b) Batteries $60,000,	7 years EAC = 60,000/7	=	8,571
(c) O & M Cost		=	3,000
	Total $/Year	=	*17,751*

Option 2 – Diesel Power

(a) EAC = NPV/20			
= 70,000/20		=	3,500
(d) O & M Cost		=	12,000
	Total $/Year		*15,500*

In this case diesel power is cheaper at all interest values. In some applications the optimum policy may vary with the interest rate.

B.11 Financial Analysis of Turbo-Generator Exercise 11.9



	A	B	C	D	E	F	G
1	Pay Back Period		PBKdesk.xls		Power Station		
2	Year	0	1	2	3	4	5
3	Interest rate %	8					
4	Discount factors	1	0.9259	0.8573	0.7938	0.7350	0.6806
5	Revenue	0	12	12	13	13	14
6	Expense	15	5	5	6	7	8
7	Net Income EOY	-15	7	7	7	6	6
8	PV of Net Income		$6.48	$6.00	$5.56	$4.41	$4.08
9	Cumul NPV		($8.52)	($2.52)	$3.04	$7.45	$11.53
10	IRR using Excel function						35.060%
11	Interest Rate %	15					
12	Discount factors	1	0.8696	0.7561	0.6575	0.5718	0.4972
13	Revenue	0	12	12	13	13	14
14	Expense	15	5	5	6	7	8
15	Net Income EOY	-15	7	7	7	6	6
16	PV of Net Income		$6.09	$5.29	$4.60	$3.43	$2.98
17	Cumul NPV		($8.91)	($3.62)	$0.98	$4.41	$7.40

B.12 Regional Health Clinics Exercise 12.8

Objectives

- Increase service capacity
- Improve range of services
- Maintain access

Basic Information

- Numbers of existing treatments and trends
- Demographics
- New treatment options projected

Evaluation Criteria

- Cost
- Capacity provided
- Range of services provided
- Accessibility

Scenarios

1. One big central clinic and close small ones
2. Enlarge all existing clinics
3. Combinations of big and small

Costs/Savings – For Each Scenario

- Capital costs: Land purchase, construction, relocation, refurbishment (existing locations)
- Sale of property if clinics closed.
- Operating costs: Staff, building maintenance
- Travel costs: For members of the public to each location

Qualitative

- Improved range of services at major clinic
- Improved staff working conditions at major clinic
- Travel time and inconvenience for public if clinics closed.

Ranking

- The cost analysis favoured the creation of a single central clinic
- Dis-benefit of closure of local clinics was considered to be a significant factor.
- Option 3 was selected, with intermediate development at central location and minor refurbishment of existing clinics.

B.13 Logistic Support Analysis Exercise – Tooth Brush 14.13.1

The Antarctic Corporation (AC) is sending a party of 100 persons to a remote Antarctic site for one year (Fleet size = 100; Mission duration = 1 year; Climatic factor). Carry out a Logistic Support Analysis for two toothbrush options:

- Manual
- Electric

Manual. Brush life 3 months estimated. Estimated consumption 400 including initial issue. Contingency allowance 10%. Asset management policy: Replace on request, notify users if consumption excessive.
ILS Plan: Purchase 440 brushes, plastic container for storage.
Electric. Components: Batteries × 2 per brush, battery life 2 months (climate factor); brush body life 12 months; brush head life 3 months; battery case end cap life 12 months. Asset management policy: replace components on request; hold some complete brushes to cover possible losses.
ILS Plan. Purchase 120 complete brushes; 1,100 batteries; insulated, waterproof container for batteries; allocate battery storage space in protected area; 10 brush bodies; 330 brush heads; 10 end caps; plastic container for storage. Rechargeable battery model dismissed as impractical for this location. Might also consider, toothpaste, disposal of items.

B.14 Cycle Team Logistic Support Exercise 14.13.2

Routine maintenance checks for lubrication, brakes, gears, alignment, geometry, balance

- Tools
- Spare parts
- Spare bicycles
- Transport
- Communication system
- Health and medical support
- Skilled mechanics with strong expertise and sense of commitment

B.15 Level of Repair Analysis Exercise 14.13.3

Operators were trained in basic maintenance such as battery changing and cleaning and handling. The organization decided to provide first line technician support to cover simply breakages and fixes. Electronic faults were dealt with by replacing the radios from a repair pool and retuning the failed sets to the equipment supplier.

B.16 Water Pump Exercise 16.8.1

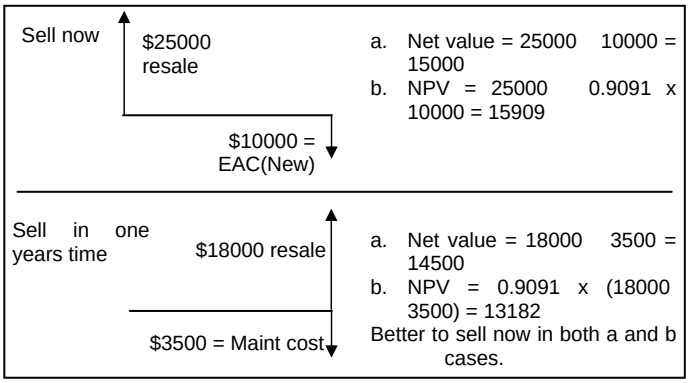


Fig. B.7 Water pump replacement options

B.17 Transformer Replacement Exercise 16.8.2

Calculate new transformer EAC

Capital cost	300,000
Life in years	40
Annuity factor	11.9246
Capital Cost EAC	25,158
Maintenance cost EAC	2,700
Total EAC	27,858

Calculate new transformer cumulative NPV

1	Year	1	2	3	4
2	New Trans EAC (EOY)	27,858	27,858	27,858	27,858
3	Discount factor	.9259	.8573	.7938	.7350
4	New Trans NPV	25,794	23,882	22,114	20,476
5	New Trans Cumul NPV	25,754	49,678	71,793	92,269

Calculate old transformer cumulative maintenance cost NPV. Calculate savings from keeping old transformer (row 9)

6	Old Trans Maint EOY	14,250	14,200	24,000	45,450
7	Old Trans Maint NPV	13,194	12,174	19,052	33,407
8	Old trans Cumul Maint NPV	13,194	25,368	44,420	77,827
9	Savings row 5 – row 8	12,600	24,310	27,373	14,442

Ans: (a) Replace at age 43 (savings are maximum). (b) Do not repair as savings < 30,000

B.18 Spend Limit Exercise 16.8.3

The spend-limit is given by:
Spend-limit = EAC(new) × 3 – Annual maintenance cost of old × 3
= \$10,000 × 3 – \$3,000 × 3 = \$7,000 × 3 = \$21,000.
The maximum that we should be willing to spend on repair is \$21,000.
To repair the old machine will cost \$25,000.
Hence it is cheaper to replace the old machine.
Alternative method with same result:
Cost of old = 3 × 3,000 + 25,000 = \$34,000
Cost of new = 3 × 10,000 = \$30,000 = cheaper.

B.19 Plant Criticality Exercise 18.6

The furnace and blower are critical. Increasing their availability through better maintenance planning, resource provision and execution are recommended. In practice this solution enabled increased production targets to be met without installing a new product line.

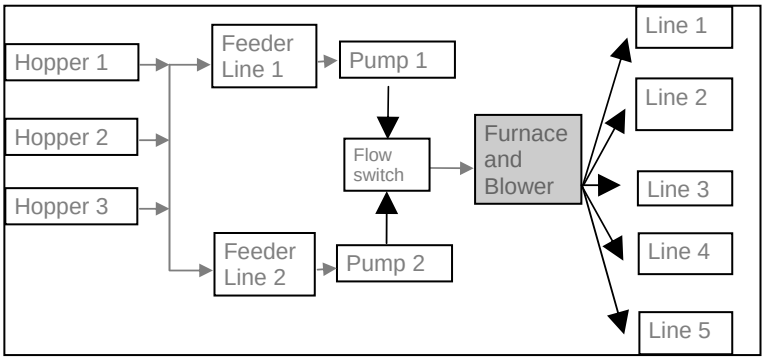


Fig. B.8 Plant criticality block diagram

B.20 Asset Data Setup Exercise 19.6.1

Chlorination Blower Reformer A	RA-CB-00-00-00-00
Mechanical System	RA-CB-MS-00-00-00
Housing	RA-CB-MS-HS-00-00
Casing	RA-CB-MS-CA-00-00
Fan Shaft	RA-CB-MS-FS-00-00
Seals	RA-CB-MS-FS-SE-00
Guards	RA-CB-MS-FS-GD-00
Coupling	RA-CB-MS-CO-00-00
Guard	RA-CB-MS-CO-GD-00
Impeller	RA-CB-MS-IM-00-00
Bearings	RA-CB-MS-IM-BE-00
Seals	RA-CB-MS-IM-BE-SE

By part number:
Plugs
Fasteners
Numerous other ‘nickel and dime’ parts.

Trade: Mechanical	M
Activity Types:	
Inspect	I
Lubrication	L
Replace	X
Repair	R
Adjust	A
Vibration Monitor	V
Fabricate/Manufacture	F

Work Request. Loose casing and fluid leak. Location = RA-CB-MS-CA-00-00
Inspection Reference: INS1234
Work Order 1. Location = RA-CB-MS-CA-00-00
Replace broken casing bolt; Trade M, Activity X
Location = RA-CB-MS-00-00-00
Vibration monitor blower; Trade M, Activity V
Work Order 2. Location = RA-CB-MS-IM-BE-00
Replace impeller bearing; Trade M, Activity X

B.21 Pacific Earth Moving Part 4 CMMS 19.6.2

a. Functions are listed in Sect. 19.1
b. Resource support requirements are required for the computer system itself and the related hardware and software support, plus data administration and training

for all users. Trades personnel should be fully familiar with the system and make extensive use of it. See sections 18.3.1 and 19.3.2

c. An information system is essential to maintain a record of maintainable assets. This is a separate requirement from the financial asset viewpoint, although some systems may offer both features. Key functions include, work management, scheduling maintenance, records of equipment maintenance, inventory control and spares purchasing, maintenance budget planning and control, work procedures including safety and permit systems.

B.22 Maintenance Budgeting Exercise 20.14.1

Cost = Direct-labour hours × Cost rate × Multiplier × Annual increase
Example: Routine for Trucks = 30,000 × 30 × 2.75 × 1.24= $3,069,000

Equipment Type	Routine $	Non-routine $	Spares and consumables	Total $
Trucks	3,069,000	1,023,000	$241,800	4,333,800
Loaders	2,557,500	1,227,600	$229,400	4,014,500
Excavators	2,864,400	1,534,500	$254,200	4,653,100
Total				13,001,400
Contingency				1,950,210
Total Budget				14,951,610

B.23 Pacific Earth Moving Part 5. Maintenance. 20.14.2

a. See Fig. 20.3 Maintenance organization, Fig. 20.4 Maintenance services and Fig. 20.5 Maintenance layout.
b. See Fig. 20.6 Maintenance activity and information flows, Fig. 20.7 Work management activities and typical roles, Fig. 20.8 Job scoping, planning, scheduling, controlling and Fig. 19.6 Data flows in a CMMS
c. See Fig. 20.11 Basic logic of the maintenance budget, Fig. 20.12 Labour estimates for routine work, Fig. 20.13 Labour estimates for non-routine work, Fig. 20.15 Monitoring budget expenditure and supporting points from Sect. 20.7.

B.24 Pacific Earth Moving Part 6. RAM. 21.11.1

- System of review and response to operator reports of losses or faults
- Incident reporting and management

- Failure reporting and corrective action system
- Failure mode and effects analysis
- Reliability Centered Maintenance or related review of maintenance regime
- Root cause analysis
- Condition monitoring, oil, vibration, thermal, etc.
- Maintainability analysis
- Spare parts optimization
- Repair pools and rotables provision and planning
- Component replacement policy analysis
- Forward repair teams
- Workshop facilities provision
- Equipment replacement planning

B.25 Cost of Downtime 21.11.2

Hours per year = 48 weeks × 48 hours × 87% availability = 2,004 hours
Cost of downtime per hour = $30,000,000 / 2,004 = $15,000.

B.25.1 Availability Related to Total Time 21.11.3

A(TT)	= 90.8%
A(WRmaint)	= 89.6%
ME	= 80.6%
A(WRall)	= 85.7%
Lost time other	= 2.8 hours
Relative Maintenance Losses	= 72.8%

Bibliography

Bentley, John P, "An Introduction to Reliability & Quality Engineering", Longman Scientific and Technical

Bierman, Harold Jr & Smidt, Seymour, "The Capital Budgeting Decision", Maxwell Macmillan International Editions

Blanchard, Benjamin S, "Logistics Engineering and Management", 4th ed, Prentice-Hall International

Blanchard, Benjamin S and Lowery, E.Edward. "Maintainability", Mcgraw-Hill 1969

Blank L.T. and Tarquin A.J., "Engineering Economy", 4th Edition, ISBN 0-07-063110-7 McGraw-Hill 1998.

Blischke W.R. and Murthy D.N.P. Case studies in Reliability and Maintenance, Wiley, 2003.

Bloch, Heinz P & Geitner, Fred K, "Machinery Failure Analysis and Troubleshooting", 2nd ed, Gulf Publishing Co, Texas

Campbell, John Dixon, "Uptime – Strategies for Excellence in Maintenance Management", Productivity Press

Campbell, John D. and Jardine, Andrew K.S, "Maintenance Excellence", Marcel Dekker, Inc, 2001.

Canada, John R & White, John A Jr, "Capital Investment Decision Analysis for Management and Engineering", Prentice-Hall

Chemical Process Safety, Center for. "Guidelines for Chemical Process Quantitative Risk Analysis." And "Guidelines for Process Equipment Reliability Data" with data tables.

Collacott R.A., "Mechanical Fault Diagnosis", Chapman and Hall, London, 1977. ISBN 0 412 12930 2

Competency Requirements for the management of physical assets and infrastructure. Institute for Asset Management, 221 St Johns Street, London EC1V 4JY, UK. www.iam-uk.org.

Damodaran, A, "Investment Valuation", 2nd ed. Wiley, New York, 2002. ISBN 0-471-41488-3.

Defence Capability Development Manual. Australian Defence Publishing Service, Department of defence, Canberra, ACT, Australia 2600.

DMO Acquisition and Sustainment Manual, Defence Materiel Organization, Russell Offices, Canberra, ACT, Australia 2600.

Gano, Dean L., Apollo Root Cause Analysis. Apollonian Publications, Yakima, Washington, Second Edition 2003. ISBN 1-883677-01-7

Hartmann, E.H., Successfully Installing TPM in a Non-Japanese Plant. TPM Press Inc., 1992.

Hastings, N.A.J., Asset Management and Maintenance – The CD. www.albanyint.com.au, email: naj.hastings@bigpond.com.

Hastings, N.A.J., Component Reliability, Replacement and Cost Analysis with Incomplete Failure Data. Chapter 16 in "Case Studies in Reliability and Maintenance", Wallace R. Blischke and D.N. Prabhakar Murthy, Wiley, New Jersey, 2003.

Higgins, Lindley R, "Maintenance Engineering Handbook", 5th ed, McGraw-Hill Inc, New York

Hodges, N W, "The Economic Management of Physical Assets", Mechanical Engineering Publications Ltd, London, 1996

International Infrastructure Management Manual. Association of Local Government Engineering NZ Inc. P.O. Box 118, Thames, New Zealand. www.ingenium.org nz

Ishikawa, Kaoru, "Guide to Quality Control", Asian Productivity Organization

Jardine, Andrew K.S. and Tsang, Albert H.C., "Maintenance, Replacement and Reliability", Taylor and Francis, 2006.

Juran, J M & Gryna, Frank M, "Juran's Quality Control Handbook", 4th ed, McGraw-Hill Inc, New York

Kelly, Anthony, "Plant Maintenance Management", 3 volumes: "Strategic Maintenance Management", "Managing Maintenance Resources", "Maintenance Systems and Documentation". Butterworths-Heinemann 2006.

Knights P., Jullian F. and Jofre L., "Building Business Cases for Maintenance Improvement Projects.", International Mine Management Conference, Melbourne, October 2006.

Lawless, J F, "Statistical Models and Methods for Lifetime Data", John Wiley & Sons

Levitt J. "Managing Maintenance Shutdowns and Outages". Industrial Press Inc, New York. ISBN 0-8311-3173-X

Mann, Lawrence, "Maintenance Management", Lexington Books, New York 1983. ISBN 0-669-04715-5.

Mannan, Sam, ed, "Lees' Loss Prevention in the Process Industries – Hazard Identification Assessment and Control", 3rd edition. Elsevier, Butterworth, Heinemann, 2005 (3 vols).

Moubray, John, "Reliability-centered Maintenance", Industrial Press, New York

Neale, M J, ed, "Component Failures Maintenance and Repair", Butterworth Heinemann, Oxford, 1995

Nyman D. and Levitt J. "Maintenance Planning, Scheduling and Coordination". Industrial Press Inc. New York. ISBN 0-8311-3143-8

O'Connor, Patrick D T, "Practical Reliability Engineering", 4th ed, John Wiley & Sons, 2002.

PAS 55-1 and PAS 55-2 Asset Management, British Standards Institution, www.bsi-global.com

Peterson R, and Silver E., "Decision Systems for Inventory and Production Planning", Wiley 1998.

PMBOK guide. A guide to the project management body of knowledge. Project Management Institute Inc, Newton Square PA, USA. ISBN 1-930699-45-X.

RCMCost. ARMS Reliability Engineers, www reliability.com.au,

Reason, J and Hobbs A. "Managing Maintenance Error", 2003.

RELCODE, Weibull Reliability and Replacement Analysis Software. Albany Interactive Pty Ltd., www.albanyint.com.au, email: Albany.interactive@bigpond.com.

Sherwin, D J & Bossche, A, "The Reliability, Availability and Productiveness of Systems", Chapman & Hall

Smith, Anthony M, Hinchcliffe Glen R., "RCM – Gateway to World Class Maintenance". Elsevier, 2004. ISBN 0-7506-7461-X.

Smith, David J, "Reliability Maintainability and Risk" 4th ed, Butterworth-Heinemann, Oxford, 1993

SuperSMITH Weibull software, Barringer and Associates, PO Box 3985, Humble TX 77347-3985, USA. www.barringer1.com

Suzuki, Tolutaro, "Total Productive Maintenance in Process Industry", Productivity Press, Portland, USA, 1994

Web References

www.albanyint.com.au (RelCode – Weibull analysis and preventive replacement)
www.barringer1.com (SuperSmith Weibull analysis)
www relexsoftware.com (Relex Reliability)
www.omdec.com (Exakt – Condition monitoring statistical analysis)
www.banak-inc.com (Agecon, Perdec) Economic Life
www.api-u.org (American Petroleum University) Oil and Gas Industry
www maintenancejournal.com.au (Asset Management and Maintenance Journal)
www.assist.daps.dla mil (Military Standards)
www.bsi-global.com (British standards)
www.apptechgroups.com Training Asia
www.iqpctraining.com Training
www.cieam.com research, training.
RIAC U.S. Department of Defense Reliability Information Analysis Center

Standards

API 510 – Pressure Vessel Inspection Code
API 570 – Piping Inspection Code
API 580 and API 581 – Risk Based Inspection
AS 1200:2000 Pressure Equipment
AS 3788:2001 Pressure Equipment In-service Inspection
AS 4343:1999 Pressure Equipment – Hazard Levels
AS 4360 – Risk Analysis and Management
AS 4536 – Life Cycle Costing
AS 4801 – Occupational Health and Safety
ATA MSG-3 – Air Transport Association Maintenance Steering Group
BS 5760 – Failure Mode and Effects Analysis
BS 18001 – Occupational Health and Safety
CSA Z662 – Oil and Gas Pipeline Systems
IEC 60300 – Dependability Series
-3-3 Life Cycle Costing
-3-10 Maintainability
-3-11 Reliability Centered Maintenance
-3-12 Integrated Logistic Support
IEC 60812 Failure Mode and Effects Analysis
IEEE C57.12.00 General Requirements for… Transformers
IEEE C57.12.90 Test Code for…Transformers
ISO 10007 Quality Management Systems, Configuration management
ISO 15288 Systems Engineering – Systems Life Cycle Processes
ISO 17776 Oil and Gas Offshore Production Installations
JAE1011. Reliability Centered Maintenance. Society of Automotive Engineers.
MIL-STD-1388-2B. Integrated Logistic Support
PAS 55 – Asset Management, British Standards Institute
SAE J 817-2 Maintainability Index;
SAE JA1010 Maintainability Program;

Organizational abbreviations:
API = American Petroleum Institute
AS = Australian Standard
ATA = Air Transport Association
BS = British Standard
IEC = International Electrotechnical Commission
IEEE = Inst. Of Electrical and Electronic Engineers
ISO = International Standards Organization
JAE = Journal of the Society of Automotive Engineers
PAS = Publicly Available Specification

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