

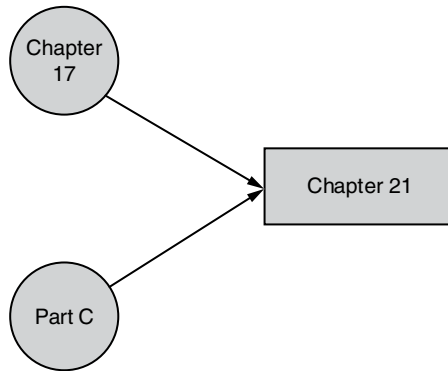
21

Maintenance Economics

Learning Outcomes

After reading this chapter, you should be able to:

- Define capital items;
- Explain the reasons for capital item investment decisions;
- Explain the role of maintenance in capital item investment decisions and the need for a life cycle perspective;
- Identify the cost elements of capital investment and the risks involved;
- Define life cycle cost and identify its elements;
- Define life cycle cost analysis (LCCA);
- Describe the steps of LCCA;
- Describe the procurement process for capital equipment;
- Explain the reasons for capital item replacement decisions;
- Apply different capital item replacement models to determine optimal replacement times;
- Explain the different approaches for making leasing versus buying decisions.



21.1 Introduction

Many objects (products, plants, or infrastructures) used for producing goods and/or services are costly (anything from a few million dollars to tens and hundreds of millions of dollars). These are called *capital items* as the acquisition and the upgrade/replacement (partial or complete) involves a lot of capital. The replacement/upgrade of capital items (for example, a fleet of expensive products such as aircraft, plants, and infrastructures) impacts significantly on the financial expenditure of a business. The expenditure (investment) on these items is termed *capital expenditure* (CAPEX) (investment) and is under the control of senior management. A proper understanding of the different issues involved is critical for proper decision making and effective life cycle management using models. Maintenance economics deals with these issues and is the focus of this chapter.

The outline of the chapter is as follows. We start with some basic concepts and terminology from economics and accounting in Section 21.2. These form the foundation for later sections of the chapter. Section 21.3 deals with capital investment and the framework needed for decision making. Section 21.4 looks at the cost elements of capital investment, and Section 21.5 deals with life cycle costing and its main elements. Section 21.6 deals with capital equipment replacement, and buy versus lease decisions are discussed in Section 21.7. Section 21.8 [Section 21.9] deals with life cycle cost analysis (LCCA) for products and plants [infrastructures]. We conclude with a summary of the chapter in Section 21.10.

21.2 Basic Concepts and Terms

21.2.1 Capital Items

Although the term capital item is widespread in theory and practice, no standard definition is available, as is illustrated by the following two definitions.

Definition 21.1

Capital items are of considerable value and durability and are used to provide a service or to make, market, keep, or transport products. (www.business dictionary.com)

Definition 21.2

Capital equipment present tangible and intangible goods that are procured by organizations and that present the technical prerequisites for the production of goods and services. One characteristic of capital equipment is the permanence of use with the possible inclusion of services of provision, maintenance, and repair; another characteristic is the high value of an individual object compared with the material used. (Hofmann *et al.*, 2012)

Most businesses establish criteria for designating acquired items as either capital or non-capital items. These criteria are based partly on local tax laws, but they also represent accounting policy choices by management. The criteria usually specify that capital items must have a minimum useful life (for example, one year or more), have an acquisition cost above a certain threshold (for example, \$5000 or more), and contribute value to the business.

21.2.2 *Economics and Accounting Terms*

In this section we define various terms from economics and accounting that are needed in building models for capital investment decisions.

21.2.2.1 Time Value of Money

Engineered objects such as infrastructure and plants are items with long lives extending over many years or even decades. Financial analysis related to their acquisition, their operations, and maintenance throughout their useful life and their disposal needs to take account of the time value of money. In this section, 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 (EAC).

21.2.2.2 Interest Rate

Having money now is worth more than having it later. Interest is simply the cost of money. It is either the rent one pays on money borrowed from a bank, bonds issued by a corporation, or the money one receives for investing money in a bank or other financial institution. The interest rate on borrowing is higher than that on lending, the difference being the bank's margin or source of income. Interest rates are normally given on an annual basis but they may be monthly or even daily rates.

21.2.2.3 Future Value

The future value, F_n , of an amount F_0 invested at interest rate i for n years is:

$$F_n = F_0 (1 + i)^n \quad (21.1)$$

21.2.2.4 Present Value

The present value, PV , of an amount F_n received in n years for an interest rate i is:

$$PV = F_n / (1+i)^n \quad (21.2)$$

21.2.2.5 Discount Factor

The multiplier $1/(1+i)$ which occurs in calculating present values arises frequently in discounted cash flow analysis and is known as the *discount factor*.

21.2.2.6 Net Present Value

The *net present value* (NPV) of a series of amounts received or expended over a number of years is the sum of the present values of these amounts.

21.2.2.7 Annuity Factor

The annuity factor is used to convert the NPV into an equivalent annual amount and is given by:

$$A(i,d) = \frac{i(1+i)^d}{(1+i)^d - 1}$$

where d is the number of years considered.

21.2.2.8 Equivalent Annual Cost [Value]

The equivalent annual cost EAC [equivalent annual value (EAV)] is the amount of a regular annual cost [profit] which, over a given period of years, has the same NPV as any given series of costs [profits]. The EAC [EAV] converts the NPV into an equivalent annual amount by multiplying it by the annuity factor. It helps in the comparison of options, particularly where the options are dissimilar in type or duration.

21.2.2.9 Cash Flow Diagram

A cash flow diagram is a schematic representation of cash received and expended over the course of an activity.

Example 21.1 Mining

A mining company would like to buy a new load-haul-dump truck with a useful life of four years. The costs (in \$1000) involved are as follows:

- Acquisition cost = \$600;
- Resale value at the end of year 4 = \$150;
- Maintenance costs over the four years = \$70, \$90, \$130, \$180.

The cash flow diagram is as shown in Figure 21.1. ■

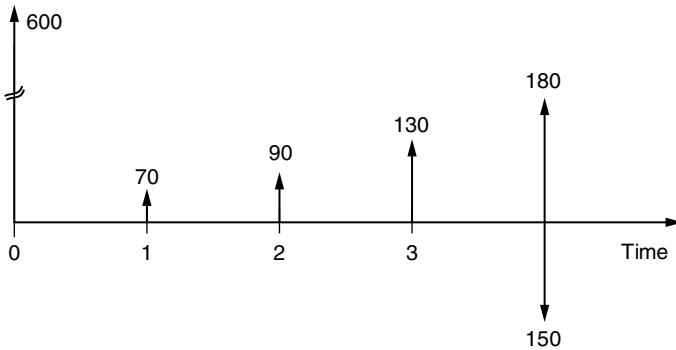


Figure 21.1 Cash flow diagram.

21.2.2.10 Inflation

Inflation means that identical goods cost more money now than they did a year ago.¹ The inflation rate, f , is not the same as the interest rate. However, the two are related, as the interest rate normally exceeds the inflation rate, otherwise there would be no attraction in saving or investing. The inflation rate usually varies from year to year.

The expression *real terms* is used when money quantities are adjusted to allow for inflation. The unadjusted figures are referred to as *nominal* dollars.

21.2.2.11 Real Rate of Interest

The “real” rate of interest, r , is the annual increase in the value of invested money in terms of its purchasing power, allowing for inflation, and is related to the bank interest rate, i , and the inflation rate, f , by the following relation:

$$1 + r = \frac{(1 + i)}{(1 + f)} \quad (21.3)$$

21.2.2.12 Acquisition Cost

The acquisition cost of an item is the full purchase price plus any initial costs for installation or transportation, and so on.

21.2.2.13 Effective Life

The effective or useful life is the age to which an item retains value, as specified in tax legislation as a basis for depreciation allowances. Typical effective lives (ELs) of a sample of items are shown in Table 21.1.

¹ *Deflation* is also possible and corresponds to a decrease in the price of goods with time.

Table 21.1 Sample of effective lives for items (in years).

Item	EL	Item	EL
Aircraft general use	20	Mining compressors	15
Cars	8	Dragline (coal mining)	20
Medical CAT scanner	7	Electricity industry storage batteries	13
Pumps	20	Cranes	20
Conveyor belts	7	Sewage treatment plant	20

21.2.2.14 Depreciation

Depreciation is an amount by which the value of a capital item is decreased to approximately reflect its decreasing value with age, for accounting purposes. Depreciation is deductible from income in determining taxable income. As an item depreciates, its reduced value is referred to as its *book value*, which may not necessarily reflect the actual value of the item.

21.2.2.15 CAPEX and OPEX

- CAPEX (*capital expenditure*) is an expense that a business incurs in acquiring new assets (tangible assets such as products, plants, and infrastructures, and intangible assets such as patent licenses) and/or upgrading its existing assets to create future benefits with a time horizon of several years. CAPEX can be financed either internally or externally. In the latter case, the investors are interested in interest payments and getting their money back in the end and/or a part ownership of the business. This expenditure is usually shown in the financial statement as cash flow or investment in an asset.
- OPEX (*operating expenditure*) is the expenditure required for the day-to-day functioning of the business and includes items such as wages, utilities, and so on, needed to produce the output (goods and/or services). It also includes depreciation of plants and machinery which are used in the production process.² Thus, OPEX is expenses that are necessary to maintain capital assets.

The distinction between CAPEX and OPEX has become very complicated today, especially in businesses where products and services are driven by knowledge workers.³

21.3 Capital Investment

CAPEX for acquisition is typically driven by operating cost control, technical obsolescence, requirements for performance and functionality improvements, and safety. Rational decision making about capital replacement must take account of engineering, economic, and safety aspects.

²Depreciation of the asset takes place every year over the effective life (as determined by the taxation office) after which it becomes zero.

³Business valuation often starts with the measurement of CAPEX and OPEX.

The term “upgrade” is general and many other terms have been used as synonyms. These include the following:

- *Shutdown maintenance* is a term discussed in Chapter 4.
- *Overhaul* is a term that is used in many private and public sectors (Example 21.2 is an illustrative example).
- *Turnaround maintenance* (referred to as TAM) is a term used in manufacturing and processing industries and is discussed further in Section 19.8.1.

Example 21.2 US Navy Fleet Modernization

The *Fleet Modernization Program* provides the management structure by which the characteristics of ships of the active and reserve fleets are improved. Changes to ship characteristics are accomplished by Field Changes and are developed and installed when military, survivability, or technical characteristic considerations dictate ship configuration changes.

Ship overhauls constitute alterations at a naval shipyard or other shore-based depot to update the ship’s capabilities and other large-scale maintenance that cannot be undertaken at other times. ■

21.3.1 Framework for Investment Decisions

A framework for capital investment decisions needs to take into account various factors and we discuss each of these briefly.

21.3.1.1 Cost of Upgrade

The cost of upgrade is comprised of several elements which can be grouped broadly into two categories which are discussed in the next two subsections: (i) direct costs and (ii) indirect costs. Some illustrative cost figures are given below.

Upgrade Costs in Two Industry Sectors

- *Transport sector:* In mass urban transportation, annual expenditure on equipment replacement for the Hong Kong underground is of the order of \$50 million, and further, the Hong Kong underground network is a fraction of the size of that in London, Paris, or New York.
- *Mining sector:* A dragline undergoes shutdown maintenance every five years. The direct cost of maintenance is roughly 50% of the purchase price and the indirect costs due to the loss of revenue are around \$40 million (based on a loss of \$1 million per day for 40 days).

21.3.1.2 Capital

Capital is the money needed to acquire or carry out an upgrade. The alternatives available for the business are any one or a combination of the following:

- Self-financing: This reduces the capital for other projects;
- Borrowing from banks;
- Issuing new float on the stock market.

Each option has advantages as well as disadvantages and they need to be taken into account in deciding on the best option. If the business is not able to raise the capital, it might look at the following two options:

- *Leasing the object as opposed to buying*: The decision between buying and leasing is discussed in Section 21.7.
- *Private–public partnership (PPP)*: Several PPPs are discussed in Chapter 18 and these are used in the context of infrastructures.

21.3.1.3 Technology

The technology for the new/replacement item may be well established or something new and innovative. In the latter case, the performance of the object is uncertain and so there are risk implications. The level of risk depends on the degree of technological innovation in the new object.

21.3.1.4 Risks

There are many different types of risk associated with capital investment, as indicated below.

- *Demand risk*: Risk associated with the demand for goods and/or services falling short of the initial expectations.
- *Financing risk*: Risk associated with variation in the financing costs from initial expectations, which includes the following:
 - *Interest rate risk*: Risk that interest rates and/or their implied volatility will change;
 - *Currency risk*: Risk that foreign exchange rates and/or their implied volatility will change.
- *Legal risk*: Risk that a business may incur losses due to violation of laws and regulations, breach of contract, entering into improper contracts, or other legal factors.
- *Liability risk*: Risk to a business arising from the possibility of liability for damages resulting from the new or upgraded object.
- *Operational risk*: Risk of loss resulting from performance of the new/upgraded object not performing as expected.
- *Regulatory change risk*: Risk that may result in losses due to changes in various regulations or systems, such as those related to law, taxation, and accounting.
- *Technological risk*: Risk associated with technological change that could render the new object obsolete earlier than expected or the object performance falling well below expectations.

21.3.1.5 Time Horizon

The time horizon may be (i) one period or (ii) multi-period. In the one-period case, it is the useful life of the new object – from the time it is put into operation to the time it is discarded. In the multi-period case, the time horizon includes the useful life of the new item and several subsequent replacements.

21.3.2 Objective Function

The objective function may be either a scalar or a vector and it may be based solely on economic factors or on both economic and non-economic factors.

21.4 Cost Elements of Capital Investment

There are many cost elements that need to be taken into account in making capital investment decisions. The process of upgrading/replacing an object may be viewed as a project, and a business might be looking at several projects either concurrently and/or sequentially. The various costs may be divided into two categories: (i) costs associated with the execution of the project and (ii) the *potential costs* that may be incurred once the upgraded/replaced object is put into operation. The first category costs may be further divided into *direct* and *indirect* costs, and the potential costs may be viewed as indirect costs in the context of investment decision making.

21.4.1 Direct Costs

Direct costs are the costs attributable to a specific project and are charged on an item-by-item basis. The items include:

- Labor-related costs;
- Material-related costs;
- Equipment-related costs;
- Other costs, such as insurance premiums, and so on.

21.4.2 Indirect Costs

Indirect costs are costs that are not directly attributable to a specific project and benefit more than one project. Their precise benefits to a specific project are often difficult or impossible to trace. However, they need to be distributed over several projects and over time. These costs may be categorized into two groups:

- *Fixed*: These do not vary substantially and are usually associated with the initial stage of the project (for example, building a temporary road to access a site);
- *Recurring*: These are costs incurred on a regular basis (for example, maintenance of records, payment of salaries, etc.).

Example 21.3 Rail Track Upgrade

Some of the direct and indirect costs associated with the upgrading of rail track are as follows:

- *Direct costs:*
 - *Labor:* Cost of all craftsmen (track laborers, welders, machine operators, and any helpers) and their direct supervision (the crew foremen for most organizations).
 - *Materials:* Cost of components and materials needed, including delivery to the site.
 - *Expendables:* Cost of fuel.
 - *Premiums:* Extra payments for working in tunnels or other constricted areas, at night, and so on.
- *Indirect costs:*
 - *Labor:* Costs of preparing crews, mid-level supervision, and so on.
 - *Materials:* Storage costs (material stock-pile efforts, including purchasing activities, inventory, etc.).
 - *Equipment:* Procurement and associated maintenance costs.
 - *Other:* Travel from a staging area to a site; delays (for example, due to limited track access or material not being available); training; and organization overheads. ■

21.4.3 Potential Costs

There are several different potential costs depending on the object, and a small illustrative list is given below.

- The new object not performing as expected – for example, OPEX being significantly higher than planned.
- Quality of output (goods and/or services) falling short of expected targets and this, in turn, leading to customer dissatisfaction and possibly losing some customers.
- Unforeseen catastrophic damage to property, humans, and environment (for example, water or air contamination).
- Increased insurance costs due to unanticipated risks.

21.5 Life Cycle Cost

There are many different notions of life cycle, as discussed in Chapter 5, and one of them is the useful life, with the object being discarded (and in some cases replaced) at the end of its useful life. *Life cycle cost* (LCC) refers to the total costs associated with an object (product, plant, or infrastructure) over its useful life. It is comprised of several cost elements, shown in Figure 21.2, some of which were discussed in earlier chapters of Part D of the book.

LCC is a concept originally developed by the U.S. Department of Defense (DoD) in the early 1960s, with the main aim of increasing the effectiveness of government procurement. Two related purposes were (i) to encourage a longer planning horizon that would include operating and support costs and (ii) to achieve a reduction in total costs by spending more on design and development.

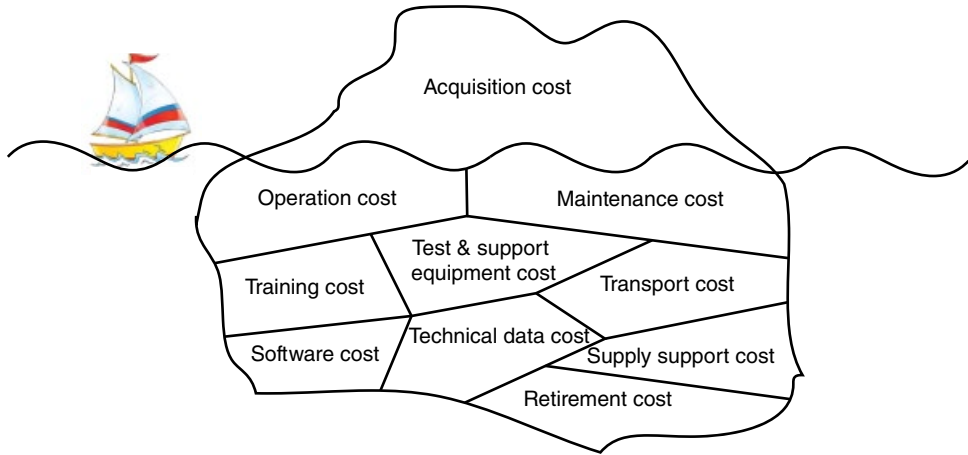


Figure 21.2 Different elements of LCC.

The LCC from the manufacturer's perspective is different from that of the customer. They differ in the cost elements (shown in Figure 21.2) considered in the LCC analysis discussed later in the section.

As can be seen from Figure 21.2, acquisition cost is only the tip of the iceberg if one takes into account all life cost elements. Therefore, making an investment decision based only on initial cost is shortsighted, as the initial investment represents only a small percentage of LCC for many engineered objects. For example, the energy cost of a pump over its useful life is many times more than its acquisition cost.

21.5.1 Elements of Life Cycle Cost

LCCs can be divided into three broad categories and several subcategories, as indicated below.

- *Acquisition costs:*
 - Research and development costs;
 - Non-recurring investment costs;
 - Recurring investment costs.
- *Sustaining costs:*
 - Maintenance (PM and CM) costs;
 - Facility usage costs.
- *Disposal costs.*

Each of these is comprised of several different costs, as indicated in Table 21.2.

It should be noted that not all of the cost categories are relevant to every project. The selection of relevant cost elements to perform a realistic LCC comparison of project alternatives is dependent on the type of the engineered object under consideration and its intended function and intensity of usage. If costs in a particular cost category are the same for all alternatives under consideration, they can be documented as such and removed from consideration in the LCC comparison.

Table 21.2 Acquisition cost categories.

Research and development costs	Non-recurring investment costs	Recurring investment costs
Program management R&D	Spare parts and logistics Manufacturing and operations and maintenance	Upgrade parts Support equipment upgrades
Engineering design	Facilities and construction	System integration and improvement
Equipment development and testing	Initial training	Utility improvement costs
Engineering data	Technical data	Green and clean costs
Maintenance (PM and CM)	Facility usage costs	Disposal costs
Labor, materials and overheads	Energy costs and facility usage costs	Permits and legal costs
Replacement and renewal	Support and supply maintenance costs	Wrecking/disposal
Replacement/renewal and transportation	Operations costs	Remediation costs
System/equipment modification	Ongoing training for maintenance and operations	Write-off/asset recovery costs
Engineering documentation	Technical data management	Green and clean costs

Depending on the type of engineered object, not all cost categories are equally important. Certain costs may have a significant influence, whilst others have only a minor influence on the total cost. For example, for a nuclear power plant, environmental protection aspects and issues of disposal costs are eminently important. In other investments, energy might be a considerable cost driver, such as for pumps or aircraft. The evaluation criteria must be crafted for each engineered object, and Sections 21.6–21.8 deal with this.

21.5.2 Life Cycle Cost Analysis

Definition 21.3

Life cycle cost analysis (LCCA)⁴ is a tool that combines financial, technical, and other information covering the life cycle of an engineered object to facilitate capital investment decision making.

According to IEC60300-3-3, LCCA may be used for the following:

- The evaluation and comparison of alternative designs;
- The assessment of economic viability of projects/products;
- The identification of cost drivers and cost-effective improvements;

⁴The term *life cycle costing* is sometimes used instead of LCCA.

- The evaluation and comparison of alternative strategies for product use, operation, test, inspection, maintenance, and so on;
- The evaluation and comparison of different approaches for replacement, rehabilitation/life extension, or disposal of aging facilities;
- The optimal allocation of available funds to activities in a process for product development/improvement;
- Long-term financial planning.

LCCA may be implemented by following these steps:

Step 1: Determine the item's useful life.

Step 2: Estimate relevant costs (acquisition, operation, maintenance, disposal, etc.).

Step 3: Estimate the terminal (residual) value of the item.

Step 4: Discount all costs to present value.

Step 5: Obtain the LCC by adding all cost categories.

Step 6: Repeat the above steps for all items under consideration.

Usually Step 2, where all relevant costs should be estimated, requires the most time and resources. Furthermore, effective LCCA requires skill in many areas including engineering, finance and accounting, logistics, statistical analysis, maintenance and reliability, contracting, and so on. It should be conducted by a cross-functional team covering all areas relevant to the problem at hand. Furthermore, LCCA should also be combined with risk analysis to assess the degree of financial or safety risk associated with individual alternatives.

21.6 Capital Equipment Replacement

Capital equipment refers to costly machines used in the production of goods (such as a drag-line in an open-cut mine or machinery in manufacturing or processing plants) or services (such as a fleet of locomotives or aircraft). We first discuss the procurement process and then look at some models (based solely on economic considerations) for optimal capital equipment decision making. The models may be categorized into two groups: (i) one-period models and (ii) multi-period models.

21.6.1 Procurement Process

The procurement process involves the following steps.⁵

1. *Identification of capital investment needs:* Managers identify capital investment needs and opportunities from many sources such as changes in sources and quality of materials, production bottlenecks caused by old or obsolete equipment, new production or distribution methods, a requirement for adding new products to the product line or the need to expand capacity in existing product lines to capture market share, or a requirement to reduce cost by automating existing production processes.

⁵Based on Needles *et al.* (2010).

2. *Formal request for capital investment:* Such a request includes a complete description of the investment, justification, and specifications.
3. *Preliminary screening:* This ensures that only proposals that meet both company strategic goals and produce the minimum rate of return set by management are considered.
4. *Establishment of the acceptance–rejection standard:* The organization establishes an acceptance–rejection standard in order to attract and maintain funding for capital investments. For example, the standard may be expressed as a minimum rate of return, and if the number of acceptable requests for capital investments exceeds the funds available for such investments, the proposals must be ranked according to their rates of return.
5. *Evaluation of proposals:* Proposals are evaluated using key decision variables including (i) expected life, (ii) estimated cash flow, and (iii) investment cost. The commonly used method of evaluating proposed capital investments is the NPV method. In addition, management will take into consideration some qualitative factors, such as availability and training of employees, possible future technological improvements, and the investment’s impact on other company operations.
6. *Capital investment decisions:* The acceptable proposals are usually ranked in order of the company acceptance–rejection criteria and the highest-ranking proposals are funded first, taking into account available funds. The final capital investment budget is then prepared by allocating funds to the selected proposals.

21.6.2 One-Period Models

In this section we consider a model for optimal useful life determination for a capital item used for only one period (one-time investment). This would be the case if the products produced with the acquired capital equipment would be discontinued after the end of the capital equipment’s useful life.

21.6.2.1 Assumptions and Notation

It is assumed that the item generates income (in-payments) and incurs costs (out-payments) and therefore the objective function is to maximize NPV. The following notation will be used.

I_0	Acquisition out-payment
SP_t	Payment surplus at time t calculated from the difference between in-payments (revenue) and out-payments (OPEX)
R_k	Residual value after a useful life of k periods
i	Interest rate
r	Discount factor, that is, $r = 1 / (1 + i)$
NPV_k	NPV at a useful life of k years
NPV_k^j	The NPV for period j of duration k years calculated at the beginning of period j
$NPV(k)$	The total NPV for a finite number of periods of duration k years each

Model 21.1 NPV Approach

This is the simplest model for useful life determination. It relies on the calculation of the net present value introduced in Section 21.2. The net present value is calculated as follows:

$$NPV_k = -I_0 + \sum_{t=1}^k r^t SP_t + r^k R_k \tag{21.4}$$

The optimal useful life is the period k which maximizes the net present value of the investment.

The determination of optimal useful life is carried out following the steps given below, and is illustrated in Example 21.4:

1. Payment surpluses SP_t of every year are calculated from revenue minus OPEX (columns 1 and 2 respectively, and placed in column 4).
2. The discount factor for year t is calculated as $r^t = (1+i)^{-t}$ and placed in column 5.
3. Payment surplus and residual value are multiplied by the discount factor to discount them to the present point in time and are placed in columns 6 and 7, respectively.
4. For every useful life k , the cumulated payment surplus is calculated up to that point in time and is placed in column 8.
5. Finally, the net present value of the capital equipment is calculated from the sum of the discounted residual value and the cumulative discounted payment surpluses of the corresponding year, minus the initial acquisition payment I_0 according to Equation (21.4) and is placed in column 9.

Example 21.4 Wind Turbine

Table 21.3 shows useful life calculations for a wind turbine ($I_0 = \$800\,000$). All entries are expressed in \$1000.

Table 21.3 Useful life calculations for a wind turbine.

t	(1) Revenue	(2) OPEX	(3) Resale value	(4) Net surplus	(5) Discount rate	(6) Discount surplus	(7) Discounted resale value	(8) Cumulative discounted surplus	(9) NPV
1	450	207	720	243	0.91	221	655	221	75.455
2	450	215	652	235	0.83	194	539	415	153.405
3	450	224	593	226	0.75	170	445	585	230.268
4	450	233	543	217	0.68	148	371	733	303.662
5	450	242	499	208	0.62	129	310	862	372.075
6	450	252	462	198	0.56	112	261	974	434.619
7	450	262	429	188	0.51	97	220	1071	490.855
8	450	272	401	178	0.47	83	187	1153	540.656

(Continued)

Table 21.3 (Continued)

t	(1) Revenue	(2) OPEX	(3) Resale value	(4) Net surplus	(5) Discount rate	(6) Discount surplus	(7) Discounted resale value	(8) Cumulative discounted surplus	(9) NPV
9	450	283	377	167	0.42	71	160	1224	584.113
10	450	295	357	155	0.39	60	137	1284	621.463
11	450	306	339	144	0.35	50	119	1334	653.041
12	450	319	324	131	0.32	42	103	1376	679.234
13	450	331	311	119	0.29	34	90	1410	700.463
14	450	345	300	105	0.26	28	79	1438	717.157
15	450	358	291	92	0.24	22	70	1460	729.744
16	450	373	283	77	0.22	17	62	1477	738.636
17	450	388	278	62	0.20	12	55	1489	744.230
18	450	403	274	47	0.18	8	49	1498	746.898
19	450	419	271	31	0.16	5	44	1503	746.989
20	450	436	270	14	0.15	2	40	1505	744.824

The optimal useful life is 19 years, as this yields the maximal net present value. ■

21.6.3 Multi-Period Models

Let N be the number of periods (or future replacements) that defines the time horizon for optimal decision making and let's assume that this is specified and finite. One needs to look at two scenarios: (i) no change in technology occurs, so that all replacements are identical and (ii) changes in technology occur, so that an item used for replacement is an improvement over the one being replaced. The time between two replacements is a period. The length of period j is k_j (years) for $1 \leq j \leq N$ and is a decision variable to be selected optimally. We first look at the simple case where all the k_j 's are the same (so that $k_j = k$) if there is no change in technology.

Model 21.2 No Change in Technology

In this case, we consider the replacement with an identical object over N periods. Each period (the useful economic life of the object) is k (years) and is a decision variable to be selected optimally. Figure 21.3 shows the time history of replacements.

It is assumed that the trends in OPEX costs following each replacement will remain identical in every period. This assumption may be relaxed if the OPEX changes from period to period.

Note that $NPV_k^j = NPV_k^1$ $j = 2, 3, \dots, N$, where NPV_k^1 is given by Equation (21.4). Therefore, the total net present value, $NPV(k)$, is calculated by discounting and adding all net present values of the N periods to time 0, namely:

$$NPV(k) = \sum_{i=1}^N NPV_k^1 r^{(i-1)k} = NPV_k^1 \sum_{i=1}^N r^{(i-1)k} = NPV_k^1 \frac{1-r^{kN}}{1-r^k} \tag{21.5}$$

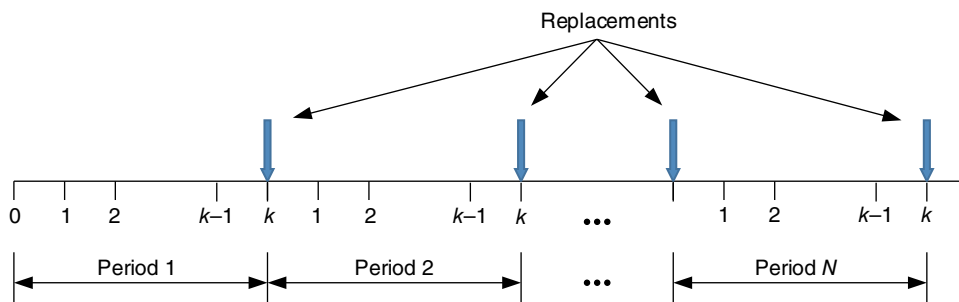


Figure 21.3 Replacement under a finite horizon with an identical item.

The last equality results from the finite geometric progression. Using the expression for NPV_k^1 (from Equation (21.4)) we have:

$$NPV(k) = \left[-I_0 + \sum_{t=1}^k r^t SP_t + r^k R_k \right] \frac{1 - r^{kN}}{1 - r^k} \tag{21.6}$$

The problem is to find k^* (the optimal k) which maximizes $NPV(k)$.

Example 21.5 Wind Turbine

Table 21.4 shows useful life calculations for a wind turbine ($I_0 = \$800\,000$) in the case of recurrent investment cycles over a finite time horizon of 10 periods, so that $N = 10$. We make use of the calculations of net present value for the first period from Example 21.4. All entries are expressed in \$1000.

The optimal useful life (k^*) is nine years, which yields the maximal net present value. Note that in terms of the time horizon, this corresponds to 90 years. ■

Table 21.4 Useful life calculations for a wind turbine in the case of recurrent investment cycles over a finite time horizon of 10 periods, so that $N = 10$.

k	NPV_k^1	$NPV(k)$	k	NPV_k^1	$NPV(k)$
1	75.5	539.1	11	653.0	1005.4
2	153.4	775.3	12	679.2	996.9
3	230.3	886.1	13	700.5	986.1
4	303.7	943.5	14	717.2	973.5
5	372.1	976.3	15	729.7	959.4
6	434.6	996.1	16	738.6	944.1
7	490.9	1007.6	17	744.2	927.8
8	540.7	1013.2	18	746.9	910.7
9	584.1	1014.2	19	747.0	893.0
10	621.5	1011.4	20	744.8	874.9

Model 21.3 Changes in Technology

In this section we consider a two-period model where one can either use an item based on the current technology for replacement or one based on a new technology. The new item can be more expensive, have lower operating and maintenance costs, generate higher revenue and/or have a longer useful life. The decision choices are: (i) remain with the current technology for both periods; (ii) switch to the new technology at the end of the first period; and (iii) switch to the new technology at the beginning of the first period and use it in the second period. This leads to the three scenarios (S_1 - S_3) shown in Figure 21.4. The replacement times of an item used for j periods are denoted k_o^j and k_n^j for current and new technologies, respectively. These are decision variables to be selected optimally to determine the optimal scenario that maximizes the equivalent annual value.

To build the model to obtain the optimal decisions, we need some additional notation, given below.

k_o^j	Optimal replacement of old item if used for j periods
k_n^j	Optimal replacement of technologically improved item if used for j periods
$NPV_o(j)$	Optimal net present value for the current item if used for j periods
$NPV_n(j)$	Optimal net present value for the technologically improved item if used for j periods
$A(i, d)$	Annuity factor corresponding to an interest rate i and d years
$EAV(S_j)$	Equivalent annual value corresponding to scenario $S_j, j = 1, 2, 3$

Note that $NPV_o(j)$ ($NPV_n(j)$) is given by Equation (21.4) for $j = 1$ and by Equation (21.6) for $j = 2$.

The equivalent annual values for these three scenarios are given by:

$$EAV(S_1) = NPV_o(2)A(i, 2k_o^2) \tag{21.7}$$

$$EAV(S_2) = (NPV_o(1) + NPV_n(1))A(i, k_o^1 + k_n^1) \tag{21.8}$$

$$EAV(S_3) = NPV_n(2)A(i, 2k_n^2) \tag{21.9}$$

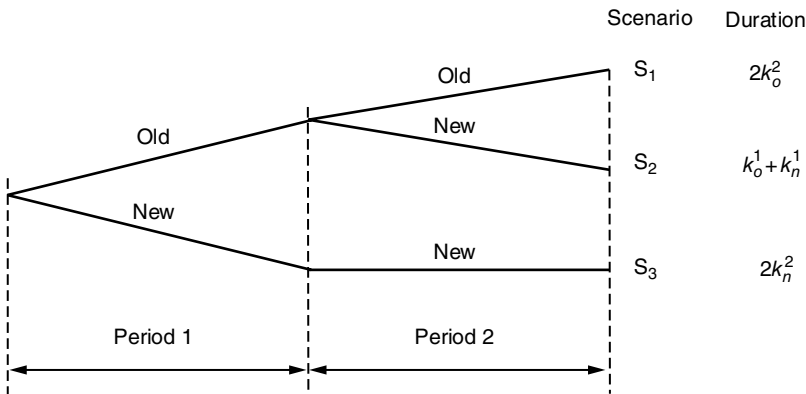


Figure 21.4 Replacement scenarios.

Example 21.6 Wind Turbine

Consider again Example 21.4 and assume that there is a technologically improved turbine that incurs the same costs and has the same acquisition cost but generates higher revenues per year (\$460 000 instead of \$450 000 for the old turbine). Assume that the interest rate is 10% and the useful life is 20 years for both machines.

From Example 21.4, $k_o^1 = 19$ and $NPV_o(1) = 747.0$. Using Model 21.1 for the new turbine yields $k_n^1 = 19$ and $NPV_n(1) = 830.6$. Using Model 21.2 with $N = 2$ yields $k_o^2 = 12$ and $NPV_o(2) = 906.01$ for the old turbine and $k_n^2 = 12$ and $NPV_n(2) = 999.07$ for the new turbine.

Now, using Equations (21.7)–(21.9), we have:

$$EAV(S_1) = NPV_o(2)A(i, 2k_o^2) = 906.01 \times 0.1113 = 100.84$$

$$EAV(S_2) = (NPV_o(1) + NPV_n(1))A(i, k_o^1 + k_n^1) = (747.0 + 830.6) \times 0.1027 = 90.7$$

$$EAV(S_3) = NPV_n(2)A(i, 2k_n^2) = 999.07 \times 0.1113 = 111.20$$

Thus, the optimal solution is to switch to the new turbine at the beginning of the first period and then use it for both periods.

21.7 Buy versus Lease Decisions

In this section we discuss approaches for making leasing versus buying decisions. The models are based on one of two approaches, and we discuss each of these briefly.

21.7.1 Approach 1

This approach is based solely on economic considerations. We consider a simple deterministic model based on the NPV criterion.

Model 21.4 NPV Approach

• *Notation:* We use the following notation:

N	Duration of period 1 (years)
t	Discrete time $t = 0, 1, 2, \dots, N$ (years)
k	Marginal cost of capital for the lessee (this is the required return on new investments that will leave the market value of the lessee's equity unchanged and it depends on the financial status of the lessee to borrow capital)
r	Marginal cost of debt to the lessee (this is the rate of borrowing)
I_t	Interest payment in period t for any loan taken
A_t	Amortization of loans for purchase of asset in time period t
E_t	Maintenance and operating cost in time period t
O_t	Additional expenses that would not exist (such as administration, insurance, etc.) in the case of lease in time period t
L_t	Lease payment in time period t
I_0	Initial value of the asset before purchase or lease
R_N	Residual value of the asset at the end of the lease period

- *Assumptions:* Complete information so that the values of the variables and parameters are known to the decision maker.
- *Decision:* The customer must decide whether to buy or lease the object.
- *Objective function:* The customer makes the decision by comparing the net present value (NPV) of both options.

If the asset is purchased, the NPV of cash flows (expenses) to the customer involves the following four components:

1. *Cash expense:* $C_p^E = \sum_{t=0}^N \frac{O_t}{(1+k)^t} + \sum_{t=0}^N \frac{I_t}{(1+r)^t} + \sum_{t=0}^N \frac{A_t}{(1+r)^t}$
2. *Maintenance and operation:* $C_p^M = \sum_{t=0}^N \frac{E_t}{(1+k)^t}$
3. *Salvage value:* R_N
4. *Initial asset value:* I_0

Thus, the NPV of cash flows to the customer if the asset is purchased is given by:

$$NPV_p = I_0 + C_p^M + C_p^E - R_N \quad (21.10)$$

The NPV of cash flows (expenses) to the customer in the case of leasing is the sum of the following two components:

1. *Cash expense:* $C_L^L = \sum_{t=0}^N \frac{L_t}{(1+r)^t}$
2. *Maintenance and operation:* $C_L^M = \sum_{t=0}^N \frac{E_t}{(1+k)^t}$

Thus, the NPV of cash flows to the customer if the asset is leased is given by:

$$NPV_L = C_L^M + C_L^L \quad (21.11)$$

The optimal decision for the customer is as follows: If $NPV_p < NPV_L$ then buy the asset; if $NPV_p > NPV_L$ then lease and if $NPV_p = NPV_L$ then the customer is indifferent between the two options.

Example 21.7 Photocopier

An office manager is planning to replace a photocopier with a new one. The manager needs to decide whether to buy⁶ or lease the machine using a discount rate of 12% given the information shown in Table 21.5.

Table 21.6 provides a summary of the NPV calculations for both options.

Since $NPV_L < NPV_p$ the better option is to lease the photocopier. Note that there is no operating cost for the lease option. ■

⁶If the customer buys, internal funds are used and the money needed is not borrowed so there are no cash expenses.

Table 21.5 Information on buying/leasing a photocopier.

Buy option	Lease option
Purchase price \$25 000	Annual lease payment \$7500 (including all supplies and maintenance)
Useful life four years	Length of contract four years
Salvage value after four years \$5000	
Annual operating cost \$1100	

Table 21.6 Summary of the NPV calculations for the two options.

Cost item	Present value	Cost item	Present value
Purchase price	25 000	Lease	$= \sum_{t=1}^4 7500 / 1.12^t = 22\ 780$
Salvage value	$= 5000 / 1.12^4 = 3415$		
Operating cost	$= \sum_{t=1}^4 1100 / 1.12^t = 3341$		
NPV_p	$= 25\ 000 - 3415 + 3341 =$ \$24 926	NPV_L	\$22 780

21.7.2 Approach 2

In many cases, especially for products, purchasing decisions are not solely made based on economics. Other intangible factors are taken into consideration, leading to a multi-objective problem. The analytic hierarchy process (AHP) method is an effective method for dealing with such multi-criteria problems, which involve criteria that can be carefully measured or roughly estimated, well-, or poorly understood – anything at all that applies to the decision at hand.⁷ We illustrate by the following example.

Example 21.8 Buying versus Leasing a Fleet of Vehicles

When a firm decides on a fleet of vehicles for use by its staff, then factors such as comfort, safety, company image, and ego are important, and cost and maintenance also play an important role. The benefits accrued by the firm from leasing versus purchasing vary from firm to firm. Some of the benefits are related to:

1. The financial status of the firm (wealth of the firm);
2. The availability of working capital;
3. Centralization or decentralization of the fleet operations;
4. Tax advantages;
5. Company image;
6. Specifications;

⁷ See Appendix B for a brief introduction to the AHP.

7. Greater rate of return and earning power of the firm;
8. Increase in the total resources of the firm;
9. Economic security and others.

The last four items play an important role in the decision if fleet financing requires large amounts of capital. Different answers would be obtained if all benefits were considered separately. The impact of buying and leasing on the centralization of the operation depends on factors such as the size of the fleet, the disposition of the firm to have the leasing company manage the operation of the fleet, availability of experienced personnel, and so on. The firm may be correct in assuming that it can do a better (i.e., cheaper) job than a leasing company. The principle of comparative advantage suggests that the firm may increase its benefits (for example, profits) by hiring a leasing company to free up manpower and time which the firm can then use in some other, more profitable activities. One must also compare the alternatives according to the tax advantages provided, and this depends on the debt rate of the firm and the depreciation rate allowed by the law.

In practice, one needs to make a trade-off amongst the factors and the AHP provides the framework for doing this. The structure that captures the relationships among the overall wealth of the firm, the alternatives at hand, and the four benefits is the *analytic hierarchy* shown in Figure 21.5.

To apply the AHP procedure one must compare all the benefits. Two benefits are compared at a time by answering the question: Given two benefits, which is the more desirable one to pursue and how strongly? We illustrate by looking at the tax advantage benefit. Leasing expenditures are tax deductible, and so are operating expenses, interest payments, and depreciation. By leasing, the firm may obtain some tax advantages due to leasing expenditure. However, leasing has an impact on the debt rate of the firm and possibly leads to the loss of some other tax advantages due to the decreasing borrowing capability of the firm. Thus, it is not clear that either one of the alternatives would provide better tax advantages. We omit the subsequent steps as it requires a deeper understanding of AHP, which is beyond the scope of this book. ■

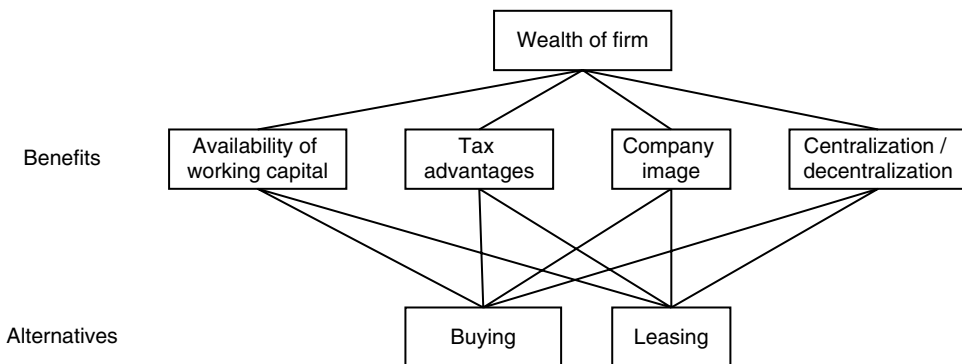


Figure 21.5 Analytic hierarchy.

21.8 LCCA for Products and Plants

21.8.1 Pump

Pumping systems represent about 20% of the world's electrical energy demand. In certain plant operations, they consume from 25 to 50% of the energy usage.⁸ Pumping systems are widespread in many sectors of the economy, ranging from domestic services, commercial and agricultural services, municipal water/wastewater services, to industrial services for chemicals, petrochemicals, pharmaceuticals, and so on.

The components of an LCCA typically include initial costs, installation and commissioning costs, energy costs, operation costs, maintenance and repair costs, downtime costs, environmental costs, and decommissioning and disposal costs. The typical LCC for a medium-sized pump is comprised of roughly 10% initial cost, 30% maintenance costs, 50% energy costs, and 10% other costs. Note that energy costs have the largest share and are many times higher than initial costs and therefore weigh heavily in the decision.

Because of the widespread use of pumps in many sectors, reliable information is available from many sources about all of these cost elements. This is an area where LCCA is able to assist rational decision making based on sound information.

21.8.2 Machine Tools

The cost categories and the LCCA for machine tools⁹ are summarized in Table 21.7.¹⁰ The results indicate, among other things, that CM is one of the major drivers of LCC (23.8% of LCC). These results prompted a systematic improvement process to deal with the high CM costs. The main cause of machine stops was uncontrolled chip removal. Subsequently, several design solutions were proposed to deal with this problem. The implementation of these design solutions lowered the corrective maintenance (CM) task costs by a factor of 2. Although preventive maintenance (PM) cost did not have the impact of CM, PM frequencies were revised and adjusted to real components' behavior. As a consequence, frequencies of spare part replacements were reduced. This allowed an increase in machine availability without causing more breakdowns. Therefore, the LCCA provided the information required for acting on reducing costs on those cost drivers that had greater influence on the total LCC.

Table 21.7 Machine tool LCC categories and their contribution to LCCs.

Acquisition cost 50%	Operation cost 2%	Maintenance cost 28%	Turnover/scrap cost (negligible)
Purchase price	Tooling cost 50%	PM labor 13%	—
Administration cost	Consumables 10%	CM 85%	
Installation	Utilities 35%	Spare parts 2%	
Training	Floor space 3%		
Support equipment	Inventory cost 2%		
Extended warranty			
Shipping cost			

⁸ Hydraulic Institute (2001).

⁹ Machine tools are expensive machines that include lathes, CNC machines, and so on.

¹⁰ Based on Enparantza *et al.* (2006).

21.9 LCCA for Infrastructures

In this section we illustrate LCCA for a road infrastructure. We briefly describe a study used to evaluate alternative pavement designs.¹¹ The LCCA adopted for pavement design is based on the eight-step procedure described briefly below.

Step 1 Establish alternative pavement design strategies for the analysis period: A pavement design strategy is a combination of the initial pavement design and necessary supporting maintenance and rehabilitation activities. As a rule of thumb, the analysis period should be long enough to incorporate at least one rehabilitation activity. The American Federal Highway Authority's September 1996 Final LCCA Policy statement recommends an analysis period of at least 35 years for all pavement projects, including new or total reconstruction projects as well as rehabilitation, restoration, and resurfacing projects.

Typically, each design alternative will have an expected initial design life, periodic maintenance treatments, and possibly a series of rehabilitation activities.

Step 2 Determine performance periods and activity timing: Performance life for the initial pavement design and subsequent rehabilitation activities has a major impact on LCCA results. It directly affects the frequency of agency intervention on the highway facility, which, in turn, affects agency cost as well as user costs during periods of construction and maintenance activities.

Work zone requirements for initial construction, maintenance, and rehabilitation directly affect highway user costs and should be estimated along with pavement strategy development. The frequency, duration, severity, and year of work zone requirement are critical factors in developing user costs for the alternatives being considered.

Step 3 Estimate agency costs: Agency costs include all costs incurred directly by the agency over the life of the project. They typically include initial preliminary engineering, contract administration, construction supervision and construction costs, as well as future routine and preventive maintenance, resurfacing and rehabilitation costs, and the associated administrative cost. Agency costs also include maintenance of traffic cost and may include operating costs such as pump station energy costs, tunnel lighting, and ventilation. At times, the salvage value, the remaining value of the investment at the end of the analysis period, is included as a negative cost.

Step 4 Estimate user costs: In the simplest sense, user costs are costs incurred by the highway user over the life of the project. User costs are an aggregation of three separate cost components: vehicle operating costs (VOCs), user delay costs, and crash costs. In the LCCA of pavement design alternatives, there are user costs associated with both normal operations and work zone operations. During periods of initial construction and future maintenance and rehabilitation activities (i.e., work zone operation), VOC, user delay, and crash costs may be significantly different between alternative pavement design strategies.

User costs are calculated by multiplying the quantity of the various additional user cost components (VOC, delay, and crash) incurred by the unit cost for those cost components.

¹¹ *Pavement design* is defined as "a project-level activity where detailed engineering and economic considerations are given to alternative combinations of sub-base, base, and surface material which will provide adequate load-carrying capacity. Factors that are considered include: materials, traffic, climate, maintenance, drainage, and life cycle costs."

Step 5 Develop expenditure stream diagrams: Expenditure stream diagrams are graphical representations of expenditures over time. They are generally developed for each pavement design strategy to help visualize the extent and timing of expenditures. Figure 21.6 is a cash flow diagram of an expenditure stream for illustrative purposes.

Step 6 Compute net present value: An NPV calculation is illustrated using Example 21.9.

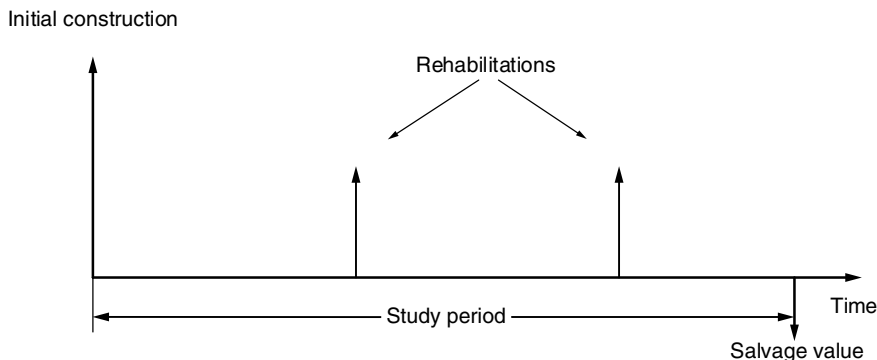


Figure 21.6 Cash flow diagram for pavement study.

Example 21.9 Road Infrastructure

Consider a pavement design alternative for a study period of 35 years that calls for two rehabilitations at years 15 and 30. The different costs and calculations are summarized in Table 21.8 for a discount rate of 4%.

This alternative can be compared to other alternatives that call for different rehabilitation timings or a different number of rehabilitations. ■

Table 21.8 NPV calculations for a pavement design alternative.

Cost component	Years (<i>t</i>)	Costs (\$1000)	Discount cost = cost/(1.04) ^{<i>t</i>}
Initial construction	0	1000.00	1000
Initial work zone user cost ¹²	0	300.00	300
Rehabilitation 1	15	325.00	180
Rehabilitation 1 work zone user cost	15	269.00	149
Rehabilitation 2	30	325.00	100
Rehabilitation 2 work zone user cost	30	361.00	111
Salvage value	35	-216.60	-55
Total NPV			1785

Step 7 Analyze results: Once completed, LCCA should, at a minimum, be subjected to a sensitivity analysis. The sensitivity analysis allows the analyst to subjectively get a feel for the impact of the variability of individual inputs on the overall LCCA results.

¹²User cost, such as delays due to the zone of the road under maintenance.

Example 21.10 Road Infrastructure

Consider Example 21.9 and let us conduct a sensitivity analysis with respect to the discount rate. The results are shown in Table 21.9.

Sensitivity analysis with respect to other parameters deemed uncertain may also be conducted. ■

Table 21.9 Sensitivity analysis – effect of discount rate.

Cost component (%)	Year	Cost	NPV				
			2	3	4	5	6
Initial construction	0	1000	1000	1000	1000	1000	1000
Initial work zone user cost	0	300	300	300	300	300	300
Rehabilitation 1	15	325	241	209	180	156	136
Rehabilitation 1 work zone user cost	15	269	200	173	149	129	112
Rehabilitation 2	30	325	179	134	100	75	57
Rehabilitation 2 work zone user cost	30	361	199	149	111	84	63
Salvage value	35	-217	-108	-77	-55	-39	-28
Total NPV			2011	1888	1785	1705	1640

Step 8 Reevaluate design strategies: Once the net present values have been completed for each alternative, the analyst needs to reevaluate the competing design strategies. The overall benefit of conducting a life cycle cost analysis is not necessarily the LCCA results themselves, but rather how the designer can use the information resulting from the analysis to modify the proposed alternatives and develop more cost-effective strategies.

21.10 Summary

Many objects (products, plants, or infrastructures) used for producing goods and/or services are costly (running from a few million dollars to tens and hundreds of millions of dollars). These are called *capital items*, as acquisition and upgrade/replacement (partial or complete) involves a lot of capital. Maintenance economics deals with several related issues.

There are many cost elements that need to be taken into account in making capital investment decisions. The process of upgrading/replacing an object may be viewed as a project, and there can be several projects either occurring concurrently and/or sequentially. The various associated costs that are relevant may be divided into two categories: (i) costs associated with the execution of the project (*direct* and *indirect* costs) and (ii) the *potential costs* that may be incurred once the upgraded/replaced object is put into operation.

This chapter dealt with three main issues related to capital investment decisions: (i) the LCC perspective of capital investment decisions; (ii) capital item replacement decisions; and (iii) lease or buy decisions.

LCC refers to the total costs associated with an object (product, plant, or infrastructure) over its useful life. It is comprised of several cost elements. Making investment decisions based only on initial cost is shortsighted, as the initial investment represents only a small percentage of the LCC for many engineered objects. LCCA is a tool that combines financial, technical, and other information covering the life cycle of an engineered object to facilitate capital investment decision making.

The main reason for replacement is economic – the item being no longer profitable due to increased maintenance and operation costs. In some cases, the replacement is driven by new technology – the new item being far superior to the existing one in terms of economic and operational performance. Several models for optimal replacement decision making have been presented under various conditions.

Some engineered objects may be leased instead of owned for several reasons. Different approaches for making leasing versus buying decisions have been presented.

Finally, capital investment issues for products, plants, and infrastructures have been presented in the last three sections of this chapter.

Review Questions

- 21.1 What is a capital item?
- 21.2 Why are capital investment decisions important for a business?
- 21.3 What are the cost elements of capital investment?
- 21.4 What are the risks involved in capital investment decisions?
- 21.5 What are the elements of life cycle cost (LCC)?
- 21.6 Why should capital investment decisions be based on a life cycle perspective?
- 21.7 What is LCCA?
- 21.8 What are the main steps of LCCA?
- 21.9 What are the reasons for capital item replacement?
- 21.10 What are the main elements of a capital item replacement model?
- 21.11 What are the reasons for leasing capital items instead of buying them?
- 21.12 What are the main issues involved in lease versus buy decisions?

Exercises

- 21.1 Switches and crossings (S&Cs) are important elements of rail track. Their renewal requires track possession and therefore minimizing the replacement time is important for avoiding train delays. The conventional renewal methods assemble S&Cs on site. However, some new technologies provide modular designs and

pre-assembled units that have several advantages: shorter possession time, better quality leading to fewer failures, and lower renewal costs in terms of manpower and renewal time.

What are the factors that need to be taken into account in order to conduct an LCCA to estimate the expected savings due to the adoption of the new technologies?

- 21.2 The selection of relevant cost elements to perform a realistic LCC comparison of project alternatives is dependent on the type of the engineered object under consideration and its intended function.

What are the most relevant cost elements of an LCCA for hybrid cars?

- 21.3 Repeat Exercise 21.2 for wind turbines.
- 21.4 Repeat Exercise 21.2 for rail maintenance projects.
- 21.5 A capital item is currently in use. The estimated O&M costs and resale values for this item for the next six years are given in the following table:

Year	0	1	2	3	4	5	6
$C_{o,i}$	—	3000	4000	5000	6000	7500	8000
$R_{o,i}$	7000	6500	6000	5000	4500	4000	4000

A technologically superior capital item has appeared with the following data:

Year	0	1	2	3	4	5	6
$C_{n,i}$	—	500	600	800	1 000	1 500	2 500
$R_{n,i}$	10 000	8 000	7 000	7 500	7 000	6 000	5 000

- (a) What is the optimal replacement time for the current item if it is used for only one period?
- (b) Repeat (a) for the technologically superior item.
- (c) For a two-period planning horizon, when should we switch from the current item to the new one?
- 21.6 Consider Example 21.6.
- (a) Extend Model 21.3 to the case of three periods.
- (b) Determine the switching period to the new equipment based on a three-period planning horizon.
- 21.7 A farmer is about to make a lease or buy decision about a tractor. The tractor is financed at an interest rate of 8% for seven years, with an annual payment of \$10 564. The cash flows of both options for seven years and the factors taken into consideration are summarized in the table below. Also, it is assumed that there are no repair costs associated with leasing the equipment.

Year	1	2	3	4	5	6	7
Buy option							
Down payment	5 000	—	—	—	—	—	—
Repairs	1 000	1 500	2 500	3 000	3 500	4 000	4 500
Loan payment	10 564	10 564	10 564	10 564	10 564	10 564	10 564
Tax reduction	3 912	3 914	4 045	4 024	3 990	3 942	3 879
Salvage value	—	—	—	—	—	—	31 000
Lease option							
Up-front charges	3 000	—	—	3 000	—	—	3 000
Lease cost	7 500	7 500	7 500	7 500	7 500	7 500	7 500
Tax reduction	2 940	2 100	2 380	2 940	2 100	2 380	2 940
Lease penalty	—	—	1 000	—	—	1 000	—

- (a) Using net present value of cost, determine the best approach for the farmer.
 (b) Explain why fuel cost is not included in the comparison.
- 21.8 Rolls-Royce provides airlines with what is called “Power By The Hour,” selling its engines along with the services to maintain, repair, and overhaul them over many years.
 (a) Discuss how this business model fits in the lease or buy framework discussed in this chapter.
 (b) Highlight the LCC implications of this business model.
- 21.9 Identify other engineered objects where the business model mentioned in Exercise 21.8 may be applied. Discuss the advantages of such an arrangement.
- 21.10 Develop a model for optimal decision making for the arrangement described in Exercise 21.8.
- 21.11 Interest rates fluctuate in an uncertain manner. How should a business model this fluctuation in order to build models for capital acquisition decisions?

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