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Venkatesh Govindarajan

Life-Cycle Costing

A Primer

VENKATESH GOVINDARAJAN

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Life-cycle costing: A Primer
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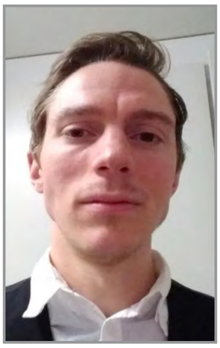
Peer review by Kenny Pettersson, Lecturer, Department of Engineering and Chemical Sciences, Karlstad University, Karlstad, Sweden

CONTENTS

Dedicated to my mother
Mrs Chandra Govindarajan

FOREWORD



The honour in writing this foreword is double, since the author of this book is a person whom I admire for both his professional achievements and for his attitude to the world around us. In *LCC – A primer,* he lets the content reflect his constructive mindset. Venkatesh has planted a variety of thought-provoking questions and meaningful quotes amongst the raw information. He nudges you towards a state of reflection and the welcome fact that you´ve actually processed what you read. This is an unusual experience, because, any of you who has ever engaged in non-fiction literature knows that the common way to read it is by simply letting the words stream past, before your eyes. This may be compared to the impression one gets by watching a multi-carriage cargo-train passing by, at a railway crossing. This book which 'puts your mind into process', so to say, is simply a more inspiring and more rewarding reading experience.

Reading this foreword, most of you will wonder - "What does this book promise more or different from others of its ilk?" I have had the privilege of meeting the author daily at Karlstad University, and therefore I find the answer apparent. This book is written with just one overarching goal in mind - to give the fundamentals of LCC to the reader. It is not written to attract a high-ranked publisher, not with the idea of amassing citations, and not for any personal accolades. It is just meant to serve the reader and introduce you to LCC. I reckon that is why it is filled with hands-on examples and relevant exercises instead of 'old article residues'.

The thought that a world developing sustainably is conceivable, is something I always harbour in my mind. I and Venkatesh, after numerous 'over-lunch' discussions, came to the conclusion that sustainable development is meaningful and possible only when everyone is willing to support it. LCC is an important tool in the pursuit of sustainable development, and that is where this e-book is a purposeful and practical offering to students. It will nullify any excuse you may come up with for not implementing LCC-supported decision making in your personal and professional lives.

I work in the field of civil engineering and LCC is indispensable to this field – both in the academic and industrial spheres. Being convinced that every industry, every organization and every worker has to contribute, in order to stem the rot that has set in, is the first step. Without unjustly glorifying, or naively neglecting profit, LCC-calculations enable us to incorporate profitability into decision-making. *In other words, if you know your numbers, sustainable business is good business.*

– Kenny Pettersson, Lecturer, Department of Engineering and Chemical Sciences, Karlstad University, Karlstad, Sweden

PREFACE

This primer can serve as a handy guide to help you get a solid hold on the concepts of Life-Cycle Costing Analysis (LCCA or simply LCC). Students of engineering will at once recognise the importance of this weapon in their armoury, when you will, almost certainly, be handling 'sustainability-related' issues in your career. LCC, for that matter, is a universal tool in the sustainability toolkit and is used by practitioners from different backgrounds. It can be applied to systems and projects, big and small, as well as to single pieces of equipment and machinery.

Some numerical problems appear at the end of some of the chapters. You can 'recreate an examination atmosphere' and try to solve the sample examination paper appended at the end of this booklet. There is also a collection of numerical exercises at the end, for the sake of revision, after you have read through the book and understood the concepts. A glossary of terms is also presented at the end. In addition to the theory and the numerical exercises, it is always important to read published journal papers to understand how researchers apply this tool in practice. As the author is based in Sweden, the Swedish currency – SEK – is used more commonly in this book.

Thanks to my friend and colleague, Kenny Petterson, for the brilliant 'review and preview', and to prospective readers for finding good use for this book!

Purposeful reading and good luck.

G Venkatesh **Karlstad (Sweden), 2019**

LIST OF FIGURES

LIST OF TABLES

1 CONCEPTS OF LCC

In this chapter, you get an introduction into the concept – the nuts and bolts - of LCC, and having read it, you will be equipped with the necessary grounding to venture forth and get a strong grasp of the elements of LCC – the framework in other words. The indispensability of a good foundation to the durability of an edifice cannot be forgotten!

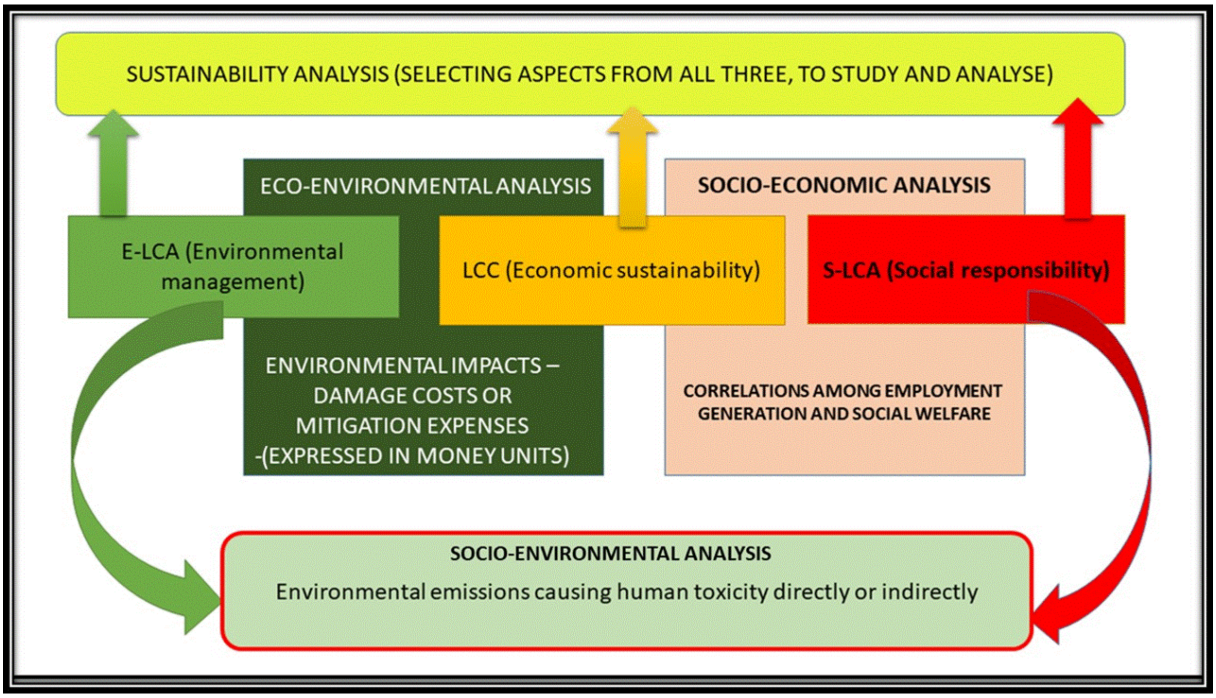


Figure 1-1: LCC in sustainability analysis – standalone, double-bottom-line and triple-bottom-line[1]

Let us first try to position LCC in the maze of sustainability to understand how it can be used.

In the figure above, the three tools which will be useful to you as 'sustainability-engineers' in the future have been shown – Environmental Life-Cycle Analysis (E-LCA), Life-Cycle Costing Analysis (LCCA) and Social Life-Cycle Analysis (S-LCA). The rudiments of E-LCA can be learnt from another BookBoon publication by this author[2] . These three tools, when used as standalone tools, are used to analyse and make decisions about environmental sustainability, economic sustainability/feasibility and the preservation of social welfare, respectively. These three are more often than not, in conflict with each other, if one blindly pursues one at the expense of the other two. A good improvement would be to move up to the second level, where we talk of a double bottom-line analysis. Eco-environmental analysis, is one where you try to optimise economic feasibility and environmental impacts. Note the use of the word 'optimise' here! When you optimise, you do not increase or decrease. You compromise and look for the best situation possible. Likewise, you have socio-economic analysis and socio-environmental analysis, where the aspects of sustainability[3] you seek to optimise are different. In these double-bottom line analyses, you conveniently ignore the third aspect on the grounds of irrelevance to the case or country or region, or or being beyond the scope of the decision-making at that given instant of time. Then, you can also jump further up to the highest level of analysis – the triple bottom line analysis or the triple-P analysis (Planet, standing for the Environment, People for the Society and Profit for the Economy). Once you understand the rudiments of each of these three tools (and remember that they are evolving continuously), you will be well-equipped to analyse the alternatives you have at hand, from a double bottom-line or a triple bottom-line perspective.

1.1 THE HEART AND SOUL OF LCC

LCC is much older than E-LCA, and had its roots in the USA, quite like E-LCA. As mentioned in the previous paragraph, it enables one to understand if decisions made, guarantee economic sustainability. Note however, that economic sustainability is a fast-moving target and pursuit of it is challenging for the simple fact that the global economy is highly volatile. Thanks to unpredictable geopolitical climes, the making and breaking of economic alliances, irresponsible banking systems and partisan politics; what seems to be sustainable today may not be so, next year. The question then arises – is it at all worthwhile to learn and apply LCC when everything is uncertain? Well, uncertainties can also be measured with some certainty (if that statement makes sense), and LCC enables one to chalk out different scenarios and have a long list of plans – A,B,C,D,E... A solid What-If analysis, akin to a strong defence in soccer. Things change, your team gains ball possession midfield, and you would instantly know what course corrections to make…you advance towards the opponents' goal to score. For that matter, some things are certain though. People may deny climate change and global warming - let them do so. Resource depletion cannot be doubted and questioned…and the impact of scarcity on the cost of resources is very much real and something to be worried about. As we shall see later, when you consider a long business life-cycle, depending on the kind of business and its degree of reliance on material and energy resources, resource economics plays a key role in LCC – as a source of data.

Well, simply put, LCC advocates a long-term perspective. Not a case of 'Eat, drink and make merry, for tomorrow we die', but more of a *'Be patient, no pains in the present means no gains in the future'.* Another proverb comes to mind – *Penny-wise and pound foolish.* There is a contrary one which needs to be interpreted correctly which we will also discuss a little while later – *'Take care of your pennies and your pounds will take care of themselves'.* Of course, you replace pennies and pounds with the monetary units in your country and feel closer home. The first one, 'Penny-wise, Pound-foolish' indicates 'living very much in the present' while investing and making purchases of goods/assets/equipment/machineries; and opting for the cheapest option on the shelf. Needless to say, this cheapest option may have a shorter lifetime necessitating a fresh investment and a new purchase again very soon. It may also mean that you end up spending more on maintaining whatever you purchased, as it may tend to break down very often. Now what about the contradictory adage - *'Take care of your pennies and your pounds will take care of themselves'.* This needs to be interpreted carefully. It must not be taken in the literal sense. It simply means 'use your pennies well, to help you make money out of money'. In other words, it means that the smallest details matter – the nuts and bolts, if we may say so.

Here we can define an acronym which one would come across often in LCC – the total cost of ownership (TCO) of an asset. When there is 'ownership', there is the necessity (and the responsibility) to spend on operation and maintenance.

TCO = Initial cost + Operation & maintenance expenses + Disposal cost

TCO-thinking or life-cycle cost thinking can be applied to anything in fact, which has an initial purchase price and a life-cycle (this could for that matter range from a few minutes to several years) You can thus categorise products (assets) on a high-to-low scale in terms of the initial cost, and a high-to-low scale in terms of the O&M expenses, by defining ranges in terms of percentages of the respective TCOs. Having defined the ranges for ‘low’, ‘high’ and ‘medium’, if you are comparing a set of different products or projects, you can visually depict them on a graph like Figure 1-2, when you present your results.

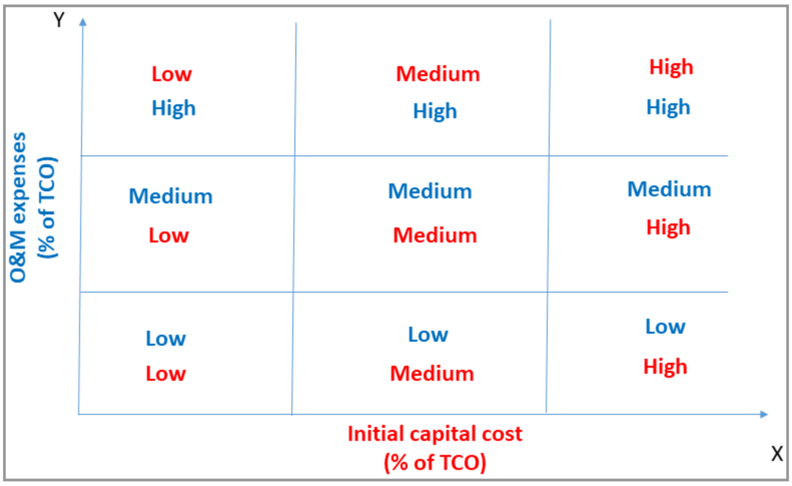


Figure 1-2: Placing products/assets/projects in a matrix to compare TCOs

1.2 DRIVERS AND BENEFITS

A common flaw observed in decision-making in some big projects – in the construction sector for instance – is the proclivity towards opting for bids based on the lowest initial cost alone. By ‘construction sector’, the reference here is to highways, roads, buildings, bridges, shopping complexes, sports stadiums etc. These have long lifetimes, and though the initial investment may be conspicuously high, the expenses that would be incurred to maintain the infrastructures during their long lifetimes – materials, energy, labour etc. – will also be quite high. The operation costs of a hospital building for instance during the first 3-5 years of its functioning is much more than its initial cost[4] – and this can be explained by the expenses incurred regularly on heating, ventilation, refrigeration and electricity, efficient waste management, water treatment and wastewater handling, among other items of expenditure. A hospital building would exist and function for a few decades and thereby an energy-efficient structure would enable a possible truncation in the TCO. One must also consider the possibility of a rise in energy prices over time – owing to scarcity of resources, the introduction of costlier renewable energy options into the mix, and/or carbon taxes. However, to make it energy-efficient (or resource-efficient in general), greater initial costs would be incurred – energy-efficient devices, water-saving appliances, captive solar power units, captive biogas generation and utilisation units, material resource recovery units for reuse within the facility or for sale in the marketplace, etc. Here is where a detailed LCC will often come in handy when different options must be assessed.

This flaw, wherever it exists – be in the private sector or the public sector - needs to be corrected. Entrenching LCC in decision-making will go a long way in promoting the conservation of natural resources, when inflation resulting from the impending scarcity of the non-renewable resources is factored into an LCC, revealing a rise in operation expenses later in the life-cycle. This may mean that decisions will tend to be made in favour of resource-lighter alternatives. Being fully aware that scarcity of some of the resources you need, correlates directly to cost, is a 'good weapon' to have in your armoury. Knowledge is power in this case, as it helps you to be forewarned. If a decision is likely to save a lot of money (this would vary depending on the range of alternatives, the type of project/asset, and the sector in focus), then all the time and effort invested in performing an LCC is fully worth it!

The factors which make the adoption of LCC unquestionable would be:

1. High energy-intensiveness of the projects during their respective lifetimes, when it is a known fact that energy prices will increase
2. High project lifetimes, and thereby near certainty that the operation and maintenance expenses that must be managed, cannot be ignored
3. High initial capital cost which needs to be justified by an optimisation of operation and maintenance expenses

Likewise, there are cases when one makes purchases based on lowest initial cost, and that is perfectly rational. Take safety pins, or pencils, for instance, which have zero operation and maintenance expenses. If you consider light bulbs for instance, the initial investment is not very high, and the lifetimes are not high either. Yes, light bulbs consume electricity during their short lifetimes and that is 100% of the operational expenditure. So, would an LCC be necessary here? Well, a light bulb is one of the many components within larger structures. The hours of use of light bulbs can be minimised effectively if in the design phase of the buildings, a 'design-for-sustainability' or a 'design-for-energy-efficiency' approach is adopted. Hence, if the overall energy consumption of the residents of buildings needs to be reduced (or optimised) in the longer run, an LCC to compare different lighting alternatives is certainly of great interest!

1.3 THINK 'SYSTEMS' WHENEVER POSSIBLE

It is the function that matters, not so much the form, unless of course the form is necessary for the function. Engineers focus on function, artists and designers focus on form. While yours sincerely will not be partisan in this debate, it will suffice to say, that if form is very much necessary for the function (the practical function that is), then a collaboration among the two groups is necessary. We however know that 'sustainability' includes the socio-psychological dimension, and if people like colour for instance, you cannot force them to use 'black-and-white' just because it is cheaper and eco-friendly, without trying to determine the willingness to give up the former for the latter! We need to think like Leonardo da Vinci here and not like Galileo Galilei[5].

Take the 'life-cycle' of a detergent for instance. There are different detergents on the marketplace, with their individual Unique Selling Propositions (what you often hear being referred to as USPs). The function you need from the detergent is, *inter alia*, soil removal, whiteness retention and inhibition of bacterial activity. Detergents have their own claims, and often small differences in performance, are unnoticeable. So, by and large, one makes a choice based on the lowest initial cost. However, if something is priced a little higher, one often is curious to find out why. Perhaps, the costlier ones are eco-friendlier, or claim that reduction in use per wash will fulfil the aforenamed functions. It is possible that clothes can be washed at a lower temperature setting with so-called 'more effective detergents', thereby contributing to lower energy use in the operation phase. However, as readers may have gathered by now, the other components of the 'washing system', play a much bigger role – washing machine, the degree of water and wastewater treatment in the city/town of use and thereby the costs, the electricity mix and thereby the costs, and most importantly, the end-user behaviour.

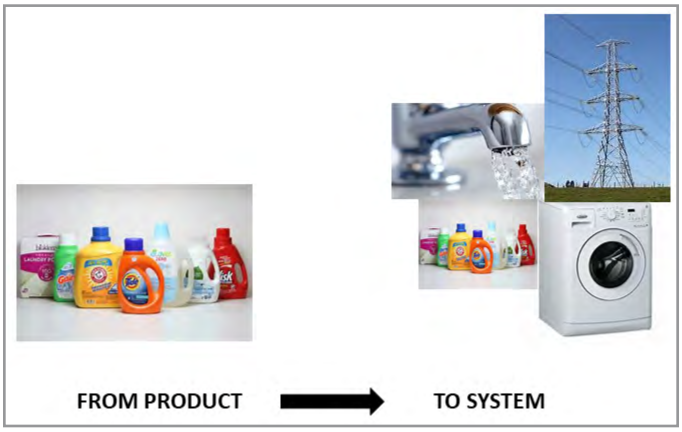


Figure 1-3: Systems thinking in an LCC

The detergent on the shelf in its packaging is idle. It is not performing its function. Only when it is added to the 'washing machine system', and electricity and water are fed to the equipment, does it 'actualise' itself. Hence, when one considers the life-cycle of a detergent, one may wish to think in terms of the total kilograms of clothes washed using all the detergent in a single container. Alongwith the detergent used, these 'N' kilograms of clothes would also have incurred electricity costs, water treatment and wastewater treatment costs (all these being paid by the user). Now, the detergent requires water for its functioning and the water leaves the cleaned clothes wet. The clothes would have to be dried subsequently. If a drier is used, the associated electricity consumption can also be accounted for, by expanding the system boundaries of the LCC. Of course, by doing so, you would motivate the choice of energy-efficient driers (in addition to energy-efficient washing machines), or recommend natural drying by hanging the clothes out in a room heated by sunlight, for example, or by space-heating provided by a ground-source/air-source heat pump. Similar to hospitals, as mentioned earlier, the energy expenses for equipment like driers and washing machines over their lifetimes are often much greater than the initial capital cost incurred to purchase them.

1.4 EXERCISE

a) Solve this individually and then compare your results with your classmates. Discuss for better understanding[6] (The author has used Swedish Kroner as the currency here for the simple fact that he is based in Sweden).

Variable (or constant)	Car A	Car B	Car C
Purchase price (SEK)	82280	95000	100000
Sales tax (% of purchase price)	5	5	5
Salvage (SEK)	9000	13500	18000
License fees per year (SEK)	500	500	500
Miles/gallon	18	24	28
Miles between tune-ups	8000	11800	15000
Insurance per year (SEK)	2700	3700	6000

- Tune-ups cost 800 SEK each
- User drives 22000 miles per year
- Use the current gasoline cost for starting year (this year) and assume that it increases by 2% per year
- Owner uses car for 5 years (in all three cases)

  Which car will you purchase based on LCC-thinking?

b) If Car B can be used for 5.5 years and car C for 6 years, what indicator will be used to compare the cars based on the basis of an LCC?
In that case, will your decision change?

In both (a) and (b), you have considered the salvage value. This will be discussed in detail, in Chapter 4.

2 TIME VALUE OF MONEY

In this chapter, you get to know everything about the time value of money, and terminologies like Single Compound Amount, Single Present Worth, Uniform Capital Recovery, Uniform Present Worth, Uniform Compounded Amount, Uniform Sinking Fund, frequency of compounding and continuous cash flows

"Making money is art, and working is art and good business is the best art"

– Andy Warhol, American artist

2.1 THE PURPOSE OF INVESTMENTS

When you commit investments into a project, be that in the private sector or the public sector, you are focused on fulfilling a set of functions. These may be mandated by socio-political objectives or motivated by the possibility of private gain. Thus, there are always expectations – for greater value for money (for the beneficiaries of the functions provided), or more money for that matter (for the investors), or both (obvious, when the investors are also the beneficiaries of the functions fulfilled by the project).

Life-cycle costing (used commonly in the public sector) and capital budgeting (a synonymous term used in the private sector), have as their leitmotif, the maximisation of social benefit (for the taxpayers) and private benefit (for the shareholders), respectively. A citizen is a taxpayer and can also be a shareholder and thus may seek benefits in both his/her capacities. As taxpayers, we have the right to demand that our tax payments are utilised optimally. We thus talk of optimal productivity of capital investment – maximise benefit to some extent, while trying to minimise capital investment and/or operational/maintenance expenses. Here the term 'economic effectiveness' can be introduced – providing products and services of desirable quality at an optimal life-cycle cost. Focusing on minimising initial costs may result in a rise in operation and maintenance expenses, and vice versa. Hence, optimising here would mean being willing to raise one to lower the other, so that the TCO can be controlled at a feasible level.

Just for the sake of reinforcing the meaning, when one says, 'Education is a wise investment for the future', it means that the money you spend on educating yourself, will return in much greater amounts over time.

2.2 TIME IS MONEY

The two variables one deals with in an LCC are time and money. The project or the life-cycle follows the so-called 'arrow of time', and the streams of expenses and incomes keep changing, in general. Likewise, what is saved in a bank account for instance, grows with time. In other words, an SEK (Swedish Krone) today is more valuable than an SEK next year. This is because if you invest it in your savings bank account, it will yield some 'interest'. This is what we call the 'time value of money'. Money which 'waits' without being spent, grows in value. Can money buy you time? I am not sure, though some may say that spending on healthcare will prolong your life, and thus buy you more time. However, certainly, time can always buy you more money!

Understanding the time value of money is very much the backbone of an LCC. It helps one find answers to many questions which arise in the minds of project planners, decision-makers in government, engineers and business managers. Some of those could be:

c) Will the project pay for itself over time? If so, in how many years?
This is the urge to recover what you have put into the project and thereafter commence making profits
d) Which alternative saves the most or costs the least, over time?
This could be for a person who wishes to invest (as a shareholder) a sum of money into one of many projects he can choose from.
e) Should a piece of equipment be purchased and owned or simply hired?
This is catching up these days, as a popular option in manufacturing/production/services
f) Which process or technology alternative must be chosen?
This is about the resource efficiency and the initial cost premium one pays for advanced technologies
g) Should an existing piece of equipment which is owned by the company be replaced or retained with regular maintenance?
Good idea to minimise resource usage by not placing a demand for a new equipment (and thereby use of more materials and energy on the upstream) and make the most of the existing equipment by stretching its functional lifetime. Patchwork, some may say, but often, making wise maintenance interventions and replacing components at the right time, can yield overall benefits

2.3 COST OF CAPITAL

The capital investment or the initial cost of a project is what needs to be committed to it in the initial design, planning and construction phase, in the so-called zero-year before operation starts, before maintenance schedules are drawn up, and before benefits start accruing from the sale of services and/or products. "This capital has a cost. In other words, it does not come free. If you invest X SEK in year-zero, over the lifetime of the project, you would have to pay back more than X SEK to the sources you have gotten the investment amount from."

If the investment takes the form of loans, then the additional payable (the cost of the loans) is the interest rate (or interest rates, if they are from different sources, which demand different interest rates) on them. If the investments are in the form of shares or bonds, the additional payable (cost of the shares or bonds) is what would be termed as a dividend. The shareholders or bondholders who receive dividends and the lenders (banks usually) are treated differently by the executors of the project. When a company issues bonds, it is generally able to lock in a long-term interest rate that is lower than the rate a bank would charge. The lower the interest rate for the borrowing company, the less the loan ends up costing. Additionally, when a company issues bonds instead of pursuing a long-term loan, it generally has more flexibility to operate as it sees fit. Bank loans tend to come with certain operating restrictions that could limit a company's ability to grow physically and financially. For example, some banks prohibit their borrowers from making further acquisitions until their loans are repaid in full. Bonds, by contrast, do not come with operating limitations.

Nature of project	Common sources of capital investments
Public sector	Sale of bonds
	Tax revenues re-invested
Private sector	Sale of shares
	Bank or other financial institution loans
	Retained profits

Table 2-1: Common sources of capital investment

Now, what is the 'time value' of the investments committed through bonds, shares, loans, tax revenues and retained profits? When individuals commit money to a project, they are foregoing the chance of securing interest on those sums of money, which would have accrued if they had put those sums in their savings accounts in banks or investing them elsewhere. They thus must be compensated for that. When banks lend money to a business, they are using money from savings accounts which need to grow! After all, the person putting money in a savings account expects it to grow! What about tax revenues then? The government collects tax from the public – taxes of various types. If there had been no taxes, and the taxpayers had had the option to use that money to make more money, they would have resorted to a plethora of existing options in the financial marketplace. The average 'rate of growth' of money that would have resulted in that case, is what must be looked upon as the cost of investing tax revenues in projects. This applies to retained profits as well. The business could well have chosen alternate means of 'generating' the 'time value' of the retained profits. This makes it clear why lenders expect interests and shareholders and bondholders expect dividends on the investments they commit to get the project up and running. So, if a business wishes to earn profits and does so by a combination of 'reducing expenses and increasing income', it is to make sure that it honours its promise of interests and dividends payable to the entities who have invested in it. Profit thereby is not evil. To a certain extent, it is a necessity for economic sustainability.

2.4 INTEREST RATE AND DISCOUNT RATE

These two terms sound like contradictions. They are and are not, at the same time. In fact, they mean one and the same thing. As we discussed in the previous section, money grows with time. It does so, at a rate called the 'interest rate'. When one follows the 'arrow of time', this rate is called the interest rate. It adds to money. However, if you wish to find out how much you must save in the bank today to get a known amount of money after 'n' years, you would think in terms of the 'discount rate'. Numerically, it is the same as the interest rate, but you would use it to 'discount' (or shrink or truncate) a bigger sum of money to a lower sum of money in the present. In other words, you multiply by the interest rate factor (1+0.01*i), where 'i' is the interest rate expressed as a percentage, when you move forward by one year to calculate the time value of money. You divide by the same factor (this time, we can call it the discount rate factor), when you wish to find the present value of a known future sum of money after 12 months. (PV is a common acronym used for present value, in LCC literature. In this book, at some junctures, just the letter P has been used to denote the present value). In general, if you wish to find the 'time value of money' after 'n' years from year-zero, you would multiply its present value (that is, its value in year-zero), by $(1+0.01*i)^n$. If you wish to discount a known future sum of money 'n' years from year-zero, back to year-zero, you will divide the value of that known sum by $(1+0.01*i)^n$. It must be mentioned here, that for your LCC, all along you assume an average constant rate of interest (or discount rate). It must be borne in mind that there may be drastic fluctuations in the behaviour of the global financial market, which may throw businesses out of kilter. This is where one may find it useful to test the sensitivity of the final picture provided by the LCC about the project, to different 'possible' discount rates.

For the sake of understanding, we can term discounting to be the reciprocal of interest compounding. The word 'compounding' implies that interest is 'compounded' not just on the principal amount in question, but also for the interest which accrues. (This, as readers would know is different from simple interest.) It must be noted that in this discussion we are in general, talking about annual compounding, where the compound interest is calculated once a year. The frequencies of compounding however can be much shorter.

2.4.1 FREQUENCIES OF COMPOUNDING

Let us begin this section with the hypothesis that as the frequency of compounding increases – half-yearly, quarterly, monthly, daily or continuous – the effective interest rate at the end of year, also increases, with respect to the nominal annual interest rate.

Let us demonstrate this with an example.

Let the nominal annual interest be 5%. For annual compounding (once in 365 days), 5% is used.

Semi-annual to daily

Interest is compounded once in 6 months, and thereby twice a year. In other words, **half-yearly, twice** a year. The words 'half-yearly' and 'twice' are keywords there to help you to remember the equation below.

$$\text{Effective interest rate (semi-annual)} = \{(1+0.05/\mathbf{2})^2 - 1\}*100\% = \mathbf{5.062\%} \qquad \mathbf{(1)}$$

Now, 'half-yearly' and 'twice' will be replaced respectively by

a) 'quarterly' and 'four times',
b) 'once in a month' and '12 times';
c) 'once a day' and '365 times'

Effective interest rate (quarterly) = $\{(1+0.05/\mathbf{4})^{4} - 1\} * 100\%$ = **5.094%** **(2)**

Effective interest rate (monthly) = $\{(1+0.05/\mathbf{12})^{12} - 1\} * 100\%$ = **5.107%** **(3)**

Effective interest rate (daily) = $\{(1+0.05/\mathbf{365})^{365} - 1\} * 100\%$ = **5.126%** **(4)**

(Note that for a leap year, 366 can be used instead of 365, but that would not affect the effective interest rate.)

Continuous compounding

For effective interest rate when continuous compounding is adopted, 'half-yearly' and 'twice' will be replaced respectively by 'infinitely' and 'infinite number of times'. 'n' in the equation below tends to infinity.

Effective interest rate (continuous) = $\{(1+0.05/\mathbf{n})^{\mathbf{n}} - 1\} * 100\%$

$$= 100 * [\{1 + 1/(n/0.05)\}^{(n/0.05)*0.05} - 1]$$

The underlined term in the equation above, tends to the Napierian logarithmic constant 'e' (2.71828)[7].

That reduces it to $100*(e^{0.05} - 1)$ = 100 (1.05127-1) = **5.127%** **(5)**

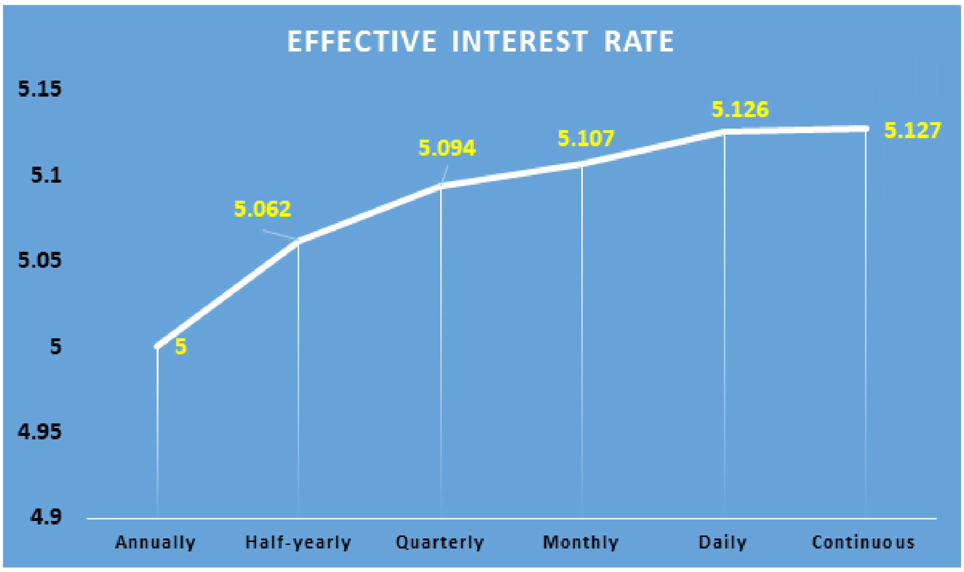


Figure 2-1: Effective interest rates when nominal rate is 5%

Figure 2-2 plots the six points and shows the span of the effective interest rate, which is 0.127%, when the nominal interest rate is 5%.

2.4.2 CHOICE OF DISCOUNT RATE

It will be of interest to know how a business goes about choosing the discount rate it would use for its planning.

The discount rate, as you know by now, represents the cost of capital put into the business/project. It is the rate at which investors and lenders want their money to grow. Capital comes in many forms (Table 2-1) – debt without interest payment, debt with interest payment, shareholder equity which is also called as common stock and retained earnings (from profits made in the business after tax and interest payments have been made). The last two attract dividends for the investors, which is analogous to the interest on debt.

Post-tax debt rate: Let us say your income is I and you pay income tax of 40% on it (0.4I in other words). If the debt is D and the pre-tax interest on D is say 10%, the pre-tax interest payment would amount to 0.1D. One usually gets a tax rebate on the interest payments one makes on one's debts. The rebate in this case, will equal 0.4*0.1D = 0.04D. It follows that you pay an interest of 0.1D to the lenders and get back 0.04D from the tax authorities. This means, that effectively, you have paid interest equal to 0.06D, which is the same as saying that the post-tax debt rate is 6% of the debt. We thus calculated the post-tax debt rate by knowing the income tax rate and the pre-tax debt rate.

Equity rate or dividend: Let us say that the market price of common stock is trending at 700 SEK. The recent earnings per share (also abbreviated usually as EPS) were 82 SEK, giving an equity rate or expected divided of 82*100/700 = 11.7%.

Weighted average cost of capital (WACC): For example, if you have a debt with interest (post-tax debt rate) of 300 million SEK, equity of 400 million SEK and retained earnings of 300 million SEK, the weighted average discount rate can be calculated as follows:

Discount rate in percent = {300 * 6 + (400+300)* 11.7}/(300+400+300) = 9.99% (approximately 10%)

Adjusting the weighted average discount rate: The project planner may use the mathematically-determined weighted average discount rate as a base for adjusting the rate he/she would choose for the project-planning, based on its risk. A low risk project (assuming that investors and lenders know that for a fact) may perhaps have a marginally-lower cost of capital. In other words, if you know for sure that you will get a steady and guaranteed return on your investment or loan, you would be willing to charge less. On the other hand, investing in a high-risk project makes one act conservatively – rather being safe than sorry, in other words. Thus, the 10% may be adjusted for instance to 9% for a low-risk project, 11% for a medium-risk project and 13% for a high-risk project, tuning it to the influence risk would have on the demands from investors.

Tax deductibles : In the section on post-tax debt rate, we introduced interest payment on debt as a tax-deductible expense. Likewise, there may be other categories, which may be considered as tax-deductible expenditures. Property tax, insurance payments, investments made in environmental-friendly technologies, and contributions made to social welfare, are examples. The last two can be looked upon as soft tools (inducements) to impel businesses towards internalising their social and environmental externalities (a link to S-LCA and E-LCA).

2.5 FUTURE AND PRESENT VALUES

Having discussed about the discount rate, we can move on to study how it is used to determine:

a) Single compound amount (SCA)
b) Single present worth (SPW)
c) Uniform capital recovery (UCR)
d) Uniform present worth (UPW)
e) Uniform compound amount (UCA)
f) Uniform Sinking Fund (USF)

In the sub-sections that follow, **F** denotes future worth, **P** denotes present value, **A** denotes an annuity, **r** denotes the discount rate (interest rate) as a percentage, and **n** stands for the number of years. Annual compounding has been used in all the cases.

2.5.1 SINGLE COMPOUND AMOUNT (SCA)

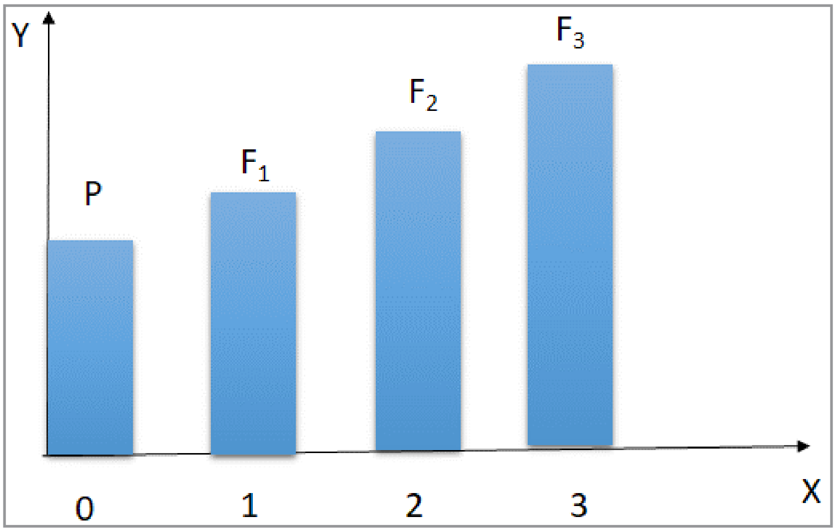


Figure 2-2: SCA and SPW

If the value of a sum of money is P SEK in year 0 (present); and the interest rate is r%;

Value F_1, one year from now, would be:

- $\mathbf{F_1 = P\ (1 + 0.01^*r)}$ **(6)**

Value F_2, two years from now, would be:

- $\mathbf{F_2 = F_1\ (1 + 0.01^*r) = P\ (1 + 0.01^*r)^2}$ **(7)**

Value F_3, two years from now, would be:

- $\mathbf{F_3 = F_2\ (1 + 0.01*r) = F1\ (1 + 0.01*r)^2 = P\ (1 + 0.01*r)^3}$ **(8)**

In general, the **SCA factor** for an interest rate of r% and for 'n' years from the present (year-zero in other words), will be equal to: $\mathbf{(1 + 0.01*r)^n}$ **(9)**

2.5.2 SINGLE PRESENT WORTH (SPW)

Refer to Figure 2-3.

You know the value F_3 at the end of year-3 in the future, and want to determine the values at the end of year-2 and year-1 in the future, and the present worth as well.

Value F_2, at the end of two years from now, would be:

- $\mathbf{F_2 = F_3\ /\ (1 + 0.01*r)}$ **(10)**

Value F_1, at the end of one year from now, would be:

- $\mathbf{F_1 = F_2 / (1 + 0.01*r) = F_3 / (1 + 0.01*r)^2}$ **(11)**

Value P, the present worth, would be:

- $\mathbf{P = F_1 / (1 + 0.01*r) = F_2 / (1 + 0.01*r)^2 = F_3 / (1 + 0.01*r)^3}$ **(12)**

In general, the **SPW factor** for an interest rate of r% and for an amount of money at the end of 'n' years from the present (year-zero in other words), will be equal to: $\mathbf{1 / (1 + 0.01*r)^n}$ **(13)**

2.5.3 UNIFORM CAPITAL RECOVERY (UCR)

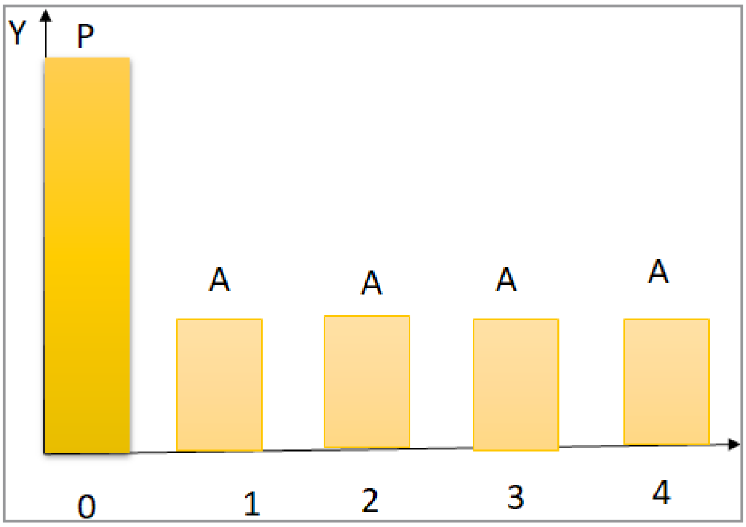


Figure 2-3: UCR and UPW

If a sum of money in the present equal to P SEK has to be recovered as equal sums over a period of 4 years, as shown in the figure, the equal sums – A SEK – are termed as **annuities.** Now, if the interest rate is r%, we would have the following relation between P and A:

$$\mathbf{P = [A/(1 + 0.01*r)] + [A/ (1 + 0.01*r)^2] + [A / (1 + 0.01*r)^3] + [A / (1 + 0.01*r)^4]} \quad \mathbf{(14)}$$

The sum on the right can be considered as a geometric progression[8],

With first term equal to [A/ (1 + 0.01*r)] and the multiplier equal to [1/(1 + 0.01*r)]. The sum then can be expressed as below:

$$= [A/ (1 + 0.01*r)]* [1- \{1/ (1 + 0.01*r)\}^4] / [1- \{1/ (1 + 0.01*r\}].$$

$$= A * \{(1 + 0.01*r)^4 - 1\} / \{0.01*r*(1 + 0.01*r)^4\}$$

Therefore,

$$\mathbf{A = [P * 0.01*r*(1 + 0.01*r)^4]/ [(1 + 0.01*r)^4 - 1]} \qquad \mathbf{(15)}$$

In general, then, the UCR factor of a sum of money equal to P, when the recovery is spread over 'n' years, is equal to

- $\mathbf{0.01*r*(1 + 0.01*r)^n \}/\{(1 + 0.01*r)^n - 1\}}$ **(16)**

2.5.4 UNIFORM PRESENT WORTH (UPW)

Refer to Figure 2-4 above.

If equal amounts of money are expected to flow in or be spent over a period of 4 years, and this amount is equal to A SEK, then at a discount rate of r%, we would have the following relation between P and A:

- $\mathbf{P = [A/(1 + 0.01*r)] +[A/ (1 + 0.01*r)^2]+[A/ (1 + 0.01*r)^3]+ [A / (1 + 0.01*r)^4]}$ **(17)**

The sum on the right can be considered as a geometric progression[8],

With first term equal to [A/ (1 + 0.01*r)] and the multiplier equal to [1/ (1 + 0.01*r)]. The sum then can be expressed as below:

$$= [A/ (1 + 0.01*r)]* [1- \{1/ (1 + 0.01*r)\}^4] / [1- \{1/ (1 + 0.01*r\}].$$

- $\mathbf{A * \{(1 + 0.01*r)^4 - 1\} / \{0.01*r*(1 + 0.01*r)^4\}}$ **(18)**

This makes the UPW factor equal to:

- $\mathbf{\{(1 + 0.01*r)^4 - 1\} / \{0.01*r*(1 + 0.01*r)^4\}}$ **(19)**

2.5.5 UNIFORM COMPOUND AMOUNT (UCA)

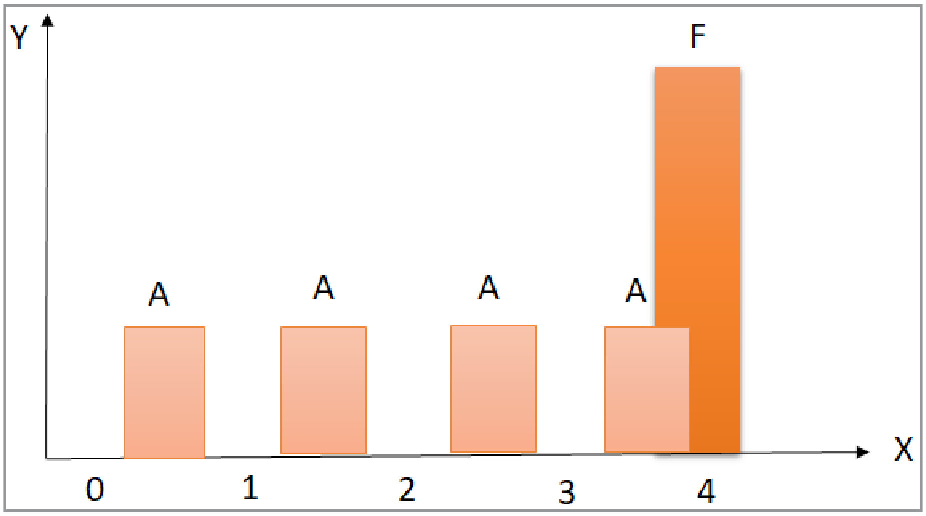


Figure 2-4: UCA and USF

If equal amounts of money A are invested **at the end of years 0, 1, 2 and 3**, the future value of these investments at the beginning of year 4, can be written as:

- $\mathbf{F = A + A*(1 + 0.01*r) + A*(1 + 0.01*r)^2 + A*(1 + 0.01*r)^3}$ **(20)**

The sum on the right can be considered as a geometric progression[8],

With first term equal to A and the multiplier equal to (1 + 0.01*r). The sum then can be expressed as below:

$=A^* \{(1 + 0.01^*r)^4 – 1\} / \{(1 + 0.01^*r)-1\}$

- **$A * \{(1 + 0.01^*r)^4 - 1\} / 0.01^*r$ (21)**

2.5.6 UNIFORM SINKING FUND (USF)

Refer Figure 2-5 above.

If equal amounts of money A have to be invested **at the end of years 0, 1, 2 and 3**, so that the future value of these investments at the beginning of year 4 is F, when the discount rate is r%; the relation between F and A is as under:

- **$F = A + A^*(1 + 0.01^*r) +A^*(1 + 0.01^*r)^2+A^*(1 + 0.01^*r)^3$ (22)**

The sum on the right can be considered as a geometric progression,

With first term equal to A and the multiplier equal to (1 + 0.01*r). The sum then can be expressed as below:

$=A^* \{(1 + 0.01^*r)^4 – 1\} / \{(1 + 0.01^*r)-1\}$.

$= A * \{(1 + 0.01^*r)^4 - 1\} / 0.01^*r$

Therefore,

- **$A = F * 0.01^*r/ \{(1 + 0.01^*r)^4 - 1\}$ (23)**

The USF factor, in general, for a period 'n' years, is thereby:

- **$0.01^*r/ \{(1 + 0.01^*r)^n - 1\}$ (24)**

2.5.7 SUMMARISING THE SIX FACTORS

If you know	...and wish to calculate		
	P	A	F
Present worth (P)		Multiply P by UCR	Multiply P by SCA
Annual payment (A)	Multiply A by UPW		Multiply A by UCA
Future worth (F)	Multiply F by SPW	Multiply F by USF	

Table 2-2: Relations among present and future worth, annual payment and the six factors

2.6 CONTINUOUS CASH FLOWS

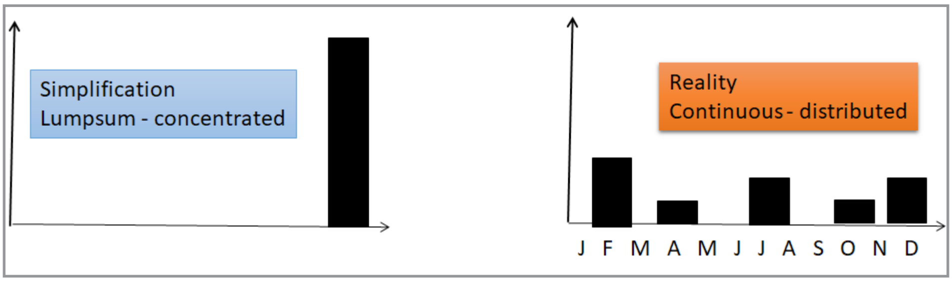


Figure 2-5: Lumpsum cash flow versus continuously distributed cash flows

In Figure 2-6 above, on the left, a lumpsum of money has been concentrated at the end of the year. If, for instance, this is the annual expenditure, it is not necessary that all of it is spent in December. If it is an income, it is not necessary that all of it is earned in December. While the depiction on the left is a simplification at best, the real distribution of expenses or cash inflows may be closer to the depiction on the right. In an LCC, if continuous cash flows are considered (which would be much closer to reality), the factors used will be as shown in Table 2-3. The derivations are complex and beyond the scope of this primer.

UCR	$ie^{in}/\{e^{in} - 1\}$
UPW	$\{e^{in} - 1\}/ ie^{in}$
USF	$\{e^{in} - 1\}/i$
UCA	$i/\{e^{in} - 1\}$

Table 2-3: Factors for continuous compounding of continuous flows as shown on the right of Figure 2-6

2.7 EXERCISE

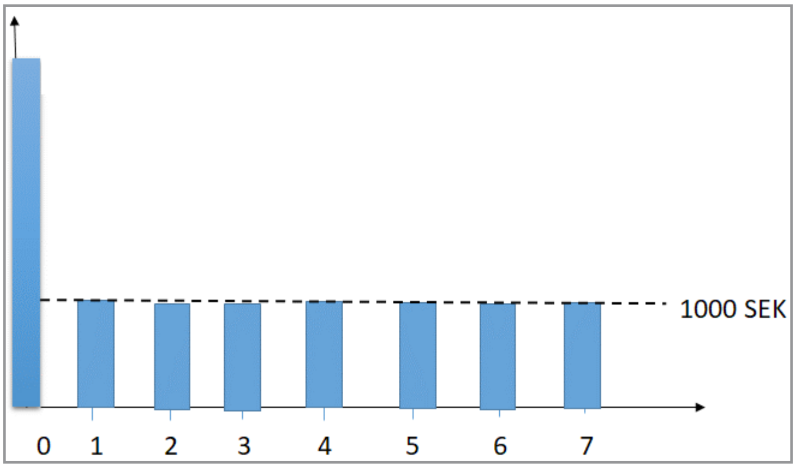
1. Prove that the factors for continuous compounding of discrete cash flows are as under:

UCR	$\{e^{i(n+1)} - e^{in}\}/\{e^{in}-1\}$
UPW	$\{e^{in} - 1\}/\{e^{i(n+1)} - e^{in}\}$
USF	$\{e^{i} - 1\}/\{e^{in}-1\}$
UCA	$\{e^{in} - 1\}/\{e^{i}-1\}$

where i = r/100, where r is the discount rate in %.

Hint: Refer to the section on Continuous Compounding in this chapter.

2. Consider the annuities of 1000 SEK as shown below over a period of 7 years. Consider discrete annuities (lump-sums concentrated at the end of the year) and compute the uniform present worth (UPW) of the annuities in year-zero. Then move a bit closer to reality, and using Table 2-3, compute the UPW for continuous flows. What is the difference between the two computed values for discount rates of 5%, 6% and 7%?



3. Consider Exercise 1.4. Apply a discount rate of 7%. Consider that the owner uses the car for 5 years. Compare the alternatives based on the net present value of life-cycle costs, and also on the basis of net annual average costs. Now try changing the discount rate to 4%, 5%, 6% and 8%. Plot curves to show how the choice of discount rate alters the results. Show all the steps clearly.

3 COST CATEGORIES AND DATA ACQUISITION

In this chapter, you get to know about the different cost categories and sub-categories in an LCC, depreciation methods, data acquisition and extrapolation from historical records, sensitivity and uncertainty analysis. This ground-work is an extremely important step in an LCC. The contents of this chapter should motivate you to read more from other sources and consolidate your knowledge further.

> *"It is a capital mistake to theorise before one has data"*
>
> – Arthur Conan Doyle, creator of Sherlock Holmes

3.1 COST CATEGORIES

The quote above sums up the indispensability of reliable and relevant data for meaningful decision-making. Let us consider the planning for a proposed plant to fulfil the demand in the marketplace for a particular product (group of products) or service/s. The objective of the plant is to sell the product/s and/or service/s in the market; and that will be the sole source of its income. Thus, the income streams are defined. The expenditure streams however are a bit more complex and varied, as depicted in Table 3-1. Most of the categories are self-explanatory but some will be explained in a little more detail, later in this chapter.

<table>
<tr><th>Cost category</th><th colspan="3">Sub-categories</th></tr>
<tr><td>Sunk costs</td><td colspan="3">Made prior to the LCC study and thereby not included in the analysis</td></tr>
<tr><td>Initial investment</td><td>- Conceptual studies
- Design
- Planning
- Acquisition (of land, for instance)</td><td colspan="2">- Installation and testing
- Training
- Financing of the operation phase</td></tr>
<tr><td rowspan="2">Use-phase costs</td><td>Operating costs</td><td>Maintenance costs</td><td>Replacement costs</td></tr>
<tr><td>- Staffing
- Energy and materials
- Insurance payments
- Interest on loans and taxes of different kinds (including environmental)
- Security
- Personnel training
- Increases in working capital when needed
- Depreciation (solely for tax deduction purposes)</td><td>- Repair
- Cleaning
- Painting
- Corrective and preventive maintenance</td><td>- Components, sub-systems, entire machinery and equipment</td></tr>
<tr><td>Disposal costs</td><td colspan="3">- Removal, restoration
- Salvage value (This is a negative cost – a benefit in other words)
- Remediation of contaminated soils
- Release of any unused working capital</td></tr>
</table>

Table 3-1: The cost categories and sub-categories in an LCC

If income streams and expense streams have to be depicted together in an LCC, the former are shown above the X-axis, and the latter below the X-axis. The differential every year amounts to the saving (gain) or the deficit (loss) for that particular year.

3.1.1 INITIAL INVESTMENT – LOANS OR ONE'S OWN MONEY?

If you do not take a loan or sell shares or bonds, but use your own money as initial investment (from retained earnings from an earlier project, for instance), it may appear that there is no interest or dividend payment involved. Of course, there isn't. But yet, there is a 'cost of capital'; even if you are using your own money for the purpose (refer to the previous chapter). You are foregoing the opportunity to earn interest on the money you invest, by not saving it in a bank! This means that you need to think in terms of paying interest to yourself. Hence, the same discount rate which you consider for the project applies to your retained earnings which you decide to invest in the business. You can think of this as a kind of system expansion, where forfeited benefits from another 'system' are interpreted as payments to be made (to yourself, in this case), from within this 'system'.

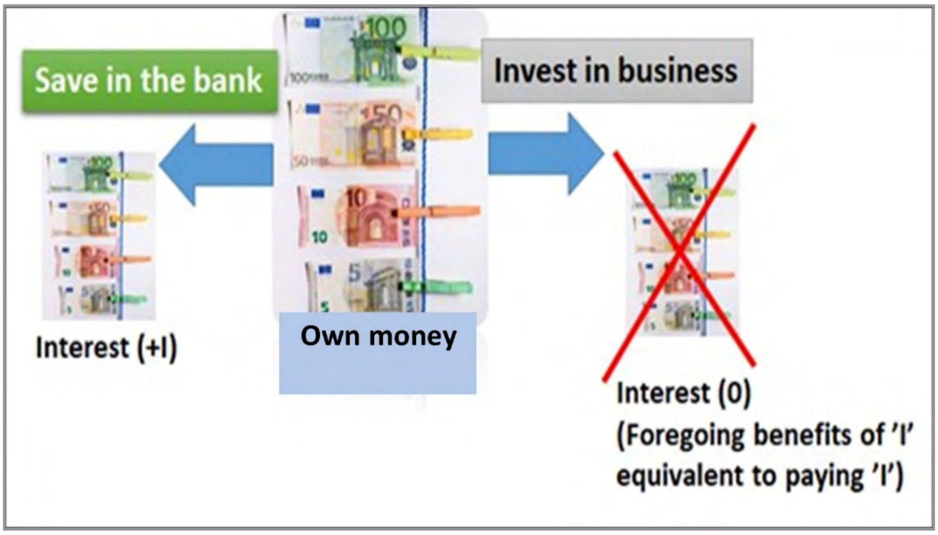


Figure 3-1: Own money or loans, interest rate applies

3.2 DEPRECIATION – WHAT AND HOW

Assets like machinery and equipment have an economic value at the start of their lifetimes (economic and physical). The starting points of these two different types of lifetimes coincide, but the same cannot be said about their respective ends. Usually, the economic lifetime (also called its "service life at the facility in which it is being used") is shorter than the physical. The economic value decreases as the asset gets older and drops down ideally to the salvage value, at the end of the asset's economic lifetime in the facility it is being used in. The functionality of the asset may still be intact, though it may require more frequent and costlier maintenance. Here is where one is faced with the alternatives – replace or retain (discussed in a later chapter).

As and when a decision for replacement is taken, the salvage value come into the picture. This is, as mentioned in Table 3-1, a negative disposal cost. It may be associated with the service the asset could provide when sold forward (second-sale), or with the resale of component parts or the recovery of scrap. The physical lifetime is longer than the service lifetime, and this implies that there is still some residual 'physical material value' which can be utilised. How does the economic value decrease till the salvage value at the end of the asset's service life? Well, interestingly, there are many different depreciation methods. We shall look at four such in the sub-sections that follow. Readers may wish to obtain knowledge about the other methods from suitable literature sources – Wikipedia for instance may provide useful links to relevant sources on the Internet.

While the initial economic value of an asset is a part of the initial capital investment which is made (or the replacement costs incurred during the use phase), depreciation is solely for claiming tax deductions on the capital investments made, distributed throughout the service lifetime of the asset. Thus, this must not be considered as a cost category in the LCC, when the initial economic value has already been considered as a cost incurred in year-zero. That, needless to say, would be double counting!

However, if one wishes to represent the capital cost only as annual depreciation amounts, it must be noted that the values calculated using the methods described below are the present values of these annual depreciation amounts. They would be suitably compounded up using the appropriate SCA factors to get the respective future values. Summing up all the discounted values of these compounded annual depreciation amounts will give us the initial economic value of the asset – in year-zero. But even here, it is only the present values of the annual depreciation amounts which will qualify for tax deduction. The tax deduction can be represented as a benefit in an LCC (in other words, a negative cost). (Figure 3-2 provides an illustration of this using the straight-line method of depreciation.)

3.2.1 STRAIGHT-LINE METHOD

As the name suggests, this is the simplest of them all. The economic value decreases linearly from the starting value to the salvage value, over the known economic lifetime (service life). Mathematically, it would be:

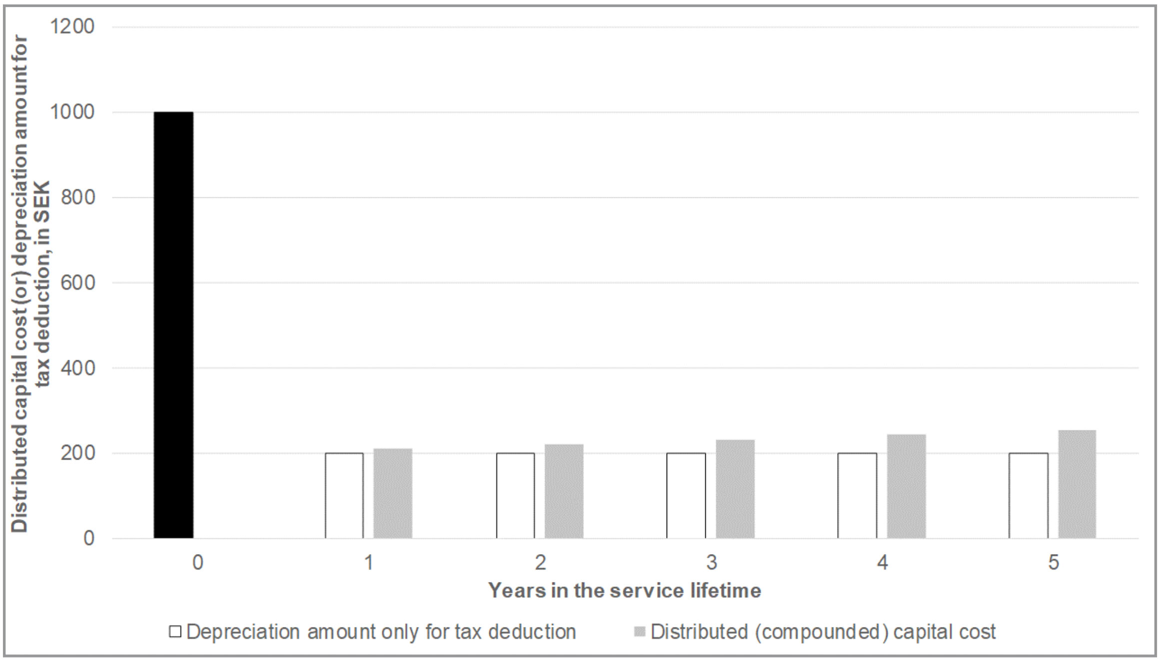
$$\mathbf{D = (C_0 - C_N) / N} \qquad \mathbf{(25)}$$

D = annual depreciation expense (remember that this is an expense)

C_0 = Initial economic value of asset

C_N = Salvage or residual value of asset at end of service lifetime

N = Service lifetime in years



- Discount rate is 5%.
- Service lifetime is 5 years.
- Residual value at end of 5 years is zero.
- Initial economic value is 1000 SEK. Straight-line depreciation method used.
- When the 1000 SEK in year zero is included in the LCC as an initial cost, the grey bars are not considered.
- If the grey bars are considered, the black bar in year-zero is not considered.
- The white bars are considered in both cases, but solely for tax deduction purposes, and not as additive costs in the LCC

Figure 3-2: Depreciation for tax deduction and accounting for the capital cost in two different ways

3.2.2 DOUBLE-DECLINING BALANCE METHOD

In this method, we speak in terms of a depreciation rate (or percentage). This is calculated as under, the notations remaining the same as in sub-section 3.2.1 above.

$$\mathbf{DR = 1 - (C_N/C_0)^{(1/N)}} \qquad \textbf{(26)}$$

DR stands for the depreciation rate. Here, one must note that the salvage value cannot be zero. In other words, it is not applicable for cases where the asset has no residual value.

The application of this method can be illustrated with an example. Consider the initial economic value to be 1000 SEK. Let the service lifetime be 8 years, and the residual value of the asset 100 SEK. The depreciation rate then will be equal to 0.25 or 25%. The tax-deductible depreciation amounts then would be, starting from the first year of the service lifetime, as shown in Table 3-2 below. The drop in economic value from the initial value to the salvage value (solely for tax deduction purposes) can be depicted by a logarithmic relationship (as shown in Figure 3-3). The purpose behind adopting this method is to avail of most of the tax deductions early in the life-cycle of the asset. This approach is advisable when a business is trying to establish itself in the marketplace, amidst stiff competition and uncertainty of survival, and can benefit by maximising its savings in the first few years.

Year	Economic value at start (SEK) C_n	Economic value at the end (SEK) $C_{n+1} = C_n*(1 - DR)$	Depreciation rate DR
0	----	1000	
1	1000	750	0.25
2	750	563	0.25
3	563	422	0.25
4	422	316	0.25
5	316	237	0.25
6	237	178	0.25
7	178	133	0.25
8	133	100	0.25

Table 3-2: Depreciation amounts using double-declining balance method

3.2.3 SUM-OF-YEARS-DIGITS METHOD

In this method, the depreciation in year 'n', for an asset with a service lifetime 'N' (N>=n), is given as under:

$$D_n = (C_0 – C_N)^* [(N-n+1) / \{N (N+1)/2\}] \quad (27)$$

Let us consider the same example as in 3.2.2. Table 3-3 shows the annual depreciation every year during the 8-year service lifetime, while Figure 3-3 compares the drop in economic value from 1000 SEK to 100 SEK for the three methods – linear, double-declining balance and sum-of-years-digits. It is clearly seen that the rate of decrease in the economic value is greater for the double-declining balance method till the 5th year of the service lifetime. Thereafter, the slide down to the salvage value of 100 SEK happens at a slightly faster rate for the sum-of-years-digits method vis-à-vis the double-declining balance method. Both these however, garner over 50% of the savings from tax deductions on the investment made in the asset, within the first three years. Linear depreciation distributes the savings equally over the service lifetime, and thereby it takes four years to reach the 50% mark.

Year	Economic value at start (SEK) C_n	Economic value at the end (SEK) C_n-D_n	Depreciation D_n
0	-----	1000	
1	1000	800	200
2	800	625	175
3	625	475	150
4	475	350	125
5	350	250	100
6	250	175	75
7	175	125	50
8	125	**100**	25

Table 3-3: Depreciation amounts using sum-of-years-digits method

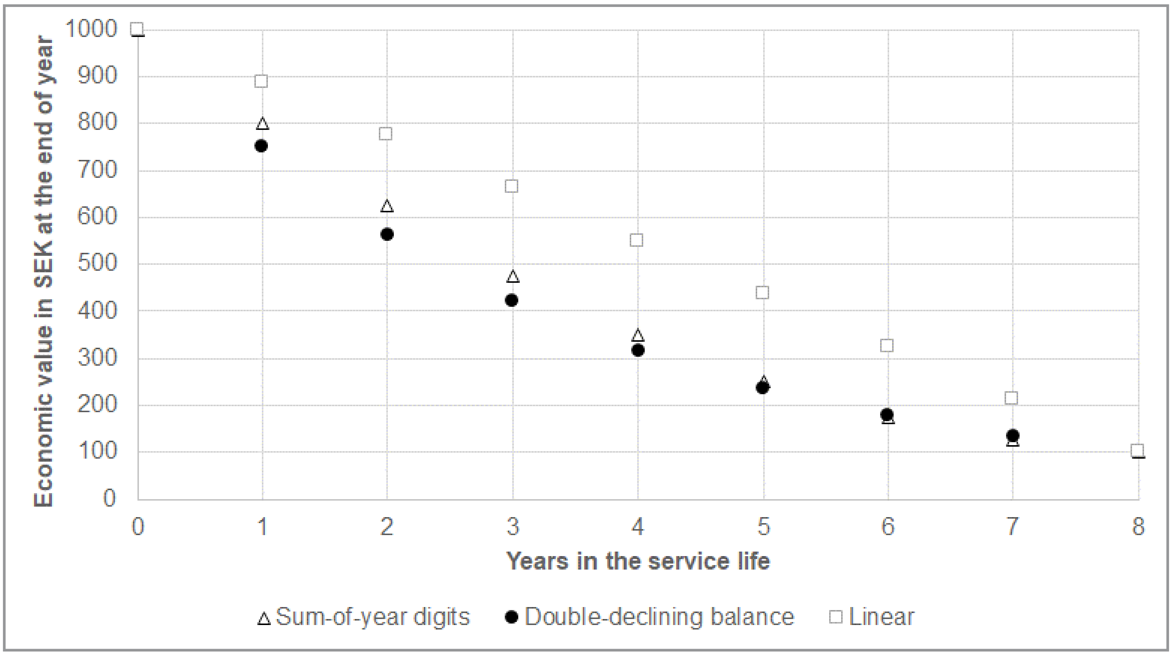


Figure 3-3: The drop in economic value of the asset from the initial value to the salvage value for sum-of-year-digits, double-declining-balance and linear depreciation methods

3.2.4 UNITS OF PRODUCTION METHOD

If the asset is a piece of equipment in a manufactory, and it is estimated to produce X units of a given product during its service lifetime of N years, and if x_n is the actual measured production in year 'n', then the depreciation in year 'n' is calculated as:

$$\mathbf{D_n = (C_o - C_N) * x_n / X} \qquad \mathbf{(28)}$$

You are right if you are wondering what if the estimates are wrong. Well, that is possible, if there are breakdowns or other reasons why the production in a given year, may decrease. If the sum of the annual production quantities does not equal the estimated total amount at the end of the service lifetime (which is very much likely and perhaps almost always the case), the depreciation amount in the last year is adjusted (increased or decreased accordingly). Let us take the same case as above. The equipment costs 1000 SEK at the start, and its salvage value at the end of its service lifetime of 8 years is 100 SEK. In eight years, the estimated total production is 8000 units of some product. The actual measured production quantities at the end of every year of operation, the annual depreciation amounts and the residual economic values at the end of every year are tabulated in Table 3-4.

End of year	Production quantities (nos.)	Depreciation amount (SEK)	Residual economic value (SEK)
1	1000	112.5	887.5
2	1100	123.7	763.7
3	980	110.2	653.5
4	975	109.6	543.8
5	990	111.3	432.4
6	1005	113	319.3
7	975	119.6	209.6
8	900	101.25	**108.45**
Total	**7925**	**891.55**	

Table 3-4 Example of a units-of-production method of depreciation

Now the accountants have estimated the total production to be 8000 units and gone ahead depreciating and availing of tax benefits. At the end of the 8^{th} year, they find that the estimate was off the mark by 75 units. At the end of its service lifetime, the asset had produced 75 units less than what was expected of it. Now, the salvage value of the asset is 100 SEK, and it was on this basis that they had calculated their annual depreciation amounts. But now, they end up with a salvage value of 108.4 SEK. To adjust that down to 100 SEK, the annual depreciation in the last year would need to be adjusted – in this case, increased by 8.45 SEK to 109.7 SEK. That would bring the total depreciated economic value up from 891.55 SEK to 900 SEK. If the asset had produced more than 8000 units, the depreciation amount in the last year would have had to be decreased accordingly.

3.3 ESTIMATING COSTS

Refer Table 3.1. You would identify data sources for each of the cost categories you see listed in the Table. Now, if you are planning for a project in the future, you would need to estimate future costs, and that certainly is not easy. Estimation of costs would involve working with some primary variables (which may be available from published documents or through talks you may have with experts) and some constants. In this chapter, we will not be able to focus on all the cost categories listed in Table 3.1, but we shall see some examples.

3.3.1 SECONDARY COST DATA FROM PRIMARY VARIABLES AND CONSTANTS

Let's say we wish to calculate the labour cost per year (this is an operating expense in the use-phase, listed as **'Staffing'** in Table 3.1). For this, the hourly wage rates of non-managerial employees of different categories (W_n, the wage rate for the n^{th} employee), the annual salary of the managerial employees (F_n, the salary of the nth managerial employee), the number of non-managerial employees (E) and the number of managerial employees (M) must be known. All these are variables and over the lifetime of the project (this could be a manufacturing unit for instance), these are likely to vary for a host of reasons. If historical data for similar manufacturing units are available for W_n and F_n , and if the trend seen in the past can be assumed to continue into the future, the hourly wage rates and monthly salaries for the different categories of non-managerial and managerial employees can be obtained, for each year of the lifetime of the project, by extrapolation (this will be discussed in the next sub-section). The planner will decide how many employees of different categories to hire to begin with, and how they will decrease (if the plan is to downsize) or increase (if the plan is to expand and grow), over time. In other words, the trend in E and M will be determined by the chief planner of the project. The maximum number of hours each non-managerial employee can be expected to work, annually, will be determined by labour regulations enforced in the region by the authorities concerned. This is in fact a tedious task, and needs to be done assiduously. Anyhow, mathematically, the labour (or staffing) cost in year 'Y' can be expressed as:

$$C_L = \sum_{n=1}^{E} W_n * H_n + \sum_{n=1}^{M} F_n \tag{29}$$

In general, all the variables on the right-hand side of the equation are likely to change over time, and thereby, the annual cost of labour will also change. Intuitively, the hourly wage rate will most likely increase, due to inflation. Managerial employees may get promotions and thereby pay rises – pre-planned or otherwise. Some may resign or retire and the vacancies may or may not be plugged instantly. Retirements can of course be accurately predicted, but not resignations. In other words, there will still be uncertainties in the C_L values calculated in advance for each year based on assumptions and extrapolations from historical data.

Repair is another cost category in the maintenance sub-phase of the use-phase of the asset (Table 3-1). In order to get an estimate of the repair costs per year, one needs to consider three primary data categories first:

a) The expected number of repairs per year
b) The mean time to repair
c) Wages to be paid per hour spent on repairing (these could be overtime, or payable to serviceman not employed by the firm). However, these days, this is usually part of a 'life-cycle management' contract signed with the supplier of the machinery/asset, and is included in the initial lump-sum amount paid at the time of purchase, or a periodic fixed monthly or yearly or quarterly payment irrespective of the number of repairs.

To calculate (a) and (b), estimation needs to be done based on available historical data from the same factory or from other factories using the same equipment, or from documents provided by the supplier with technical and performance specifications. We need to go a step further to consult engineers who will factor in technical improvements which may have happened over time. Then the historical data will have to be adjusted. Let us take a look at Tables 3.5 and 3.6 below. While Table 3.5 calculates the expected numbers of repairs per year based purely on historical data available, Table 3.6 factors in expert opinion to modify the result suitably.

Repairs per year	Probability based on historical data	Repairs x Probability
5	0.3	1.5
4	0.48	1.92
3	0.1	0.3
2	0.08	0.16
1	0.04	0.04
	Estimated repairs per year	**3.92**

Table 3-5 : Repairs likely per year estimated on the basis of historical data

Repairs per year	Probability based on historical data	Repairs x Probability
5	0.1	0.5
4	0.2	0.8
3	0.5	1.5
2	0.1	0.2
1	0.1	0.1
Estimated repairs per year, according to experts		**3.1**

Table 3-6 : Repairs likely per year estimated on the basis of historical data modified with expert opinion

The estimated repairs per year, have decreased by 0.82 after factoring in the expert opinions of engineers acquainted with the improvement in the design of the asset. While historically, there was a greater probability of 4 repairs per year (Table 3-5), Table 3-6 assigns the highest probability (50%) to 3 repairs per year. Over time, one may expect this to drop drown further to 2 or 1, if technological improvement goes on indefinitely.

Now that was about the estimated number of repairs. We need to also estimate the mean time to repair (MTTR, in production engineering lingo), as the annual repair cost would be a product of the estimated number of repairs, the mean time to repair and the wages to be paid per unit time spent on repair. Refer to Table 3-7 and Table 3-8.

	Hours		
Probability	Intervals	Midpoint	Hours x Probability
2/25	0-2	1	0.08
6/25	3-5	4	0.96
12/25	6-8	7	3.36
3/25	9-11	10	1.2
2/25	12-14	13	1.04
		Average hours per repair	**6.64**

Table 3-7 : MTTR based on historical data

	Hours		
Probability based on expert judgement	Intervals	Midpoint	Hours x Probability
6/25	0-2	1	0.24
8/25	3-5	4	1.28
11/25	6-8	7	3.08
		Average hours per repair	**4.6**

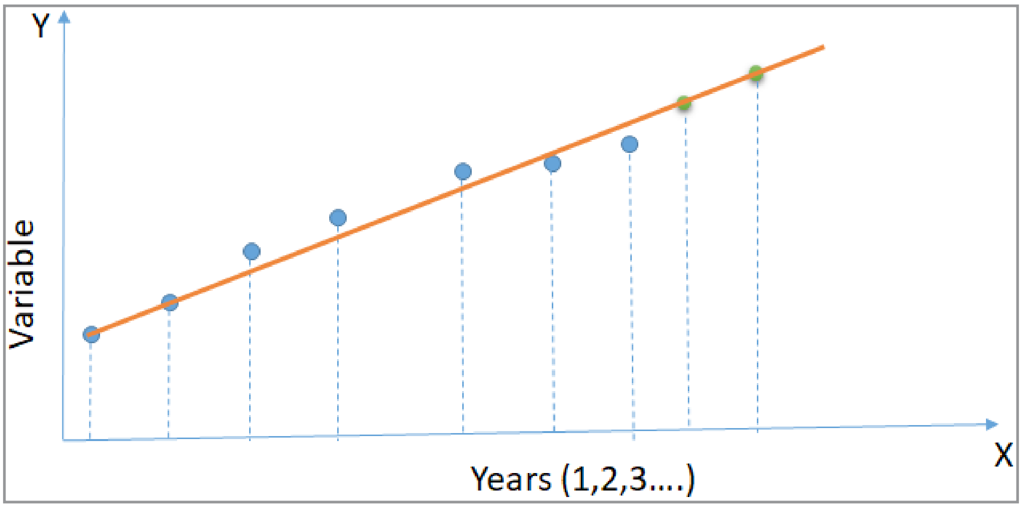
Table 3-8 : MTTR based on historical data modified with expert opinion

From Table 3-7, it is seen that 17 of the 25 repairs (for which data were available), took over 6 hours to be completed. In Table 3-8 on the other hand, this number dropped down to 11. While 5 repairs took over 9 hours each according to the historical data records, experts reckon that repair-time will not exceed 8 hours, thanks on the one hand to the criterion 'design for ease of repair' being adopted widely these days, and on the other hand, to the availability of highly-skilled servicemen.

Just as the hourly wage paid to non-managerial employees (Equation 29) changes with time – increases usually – the hourly wages for repair work will also increase. Extrapolating from historical data will enable one to estimate the rate of increase which needs to be reckoned with, when calculating the repair costs per year.

3.3.2 EXTRAPOLATION FROM HISTORICAL DATA RECORDS

There were references to extrapolating from historical data, in the previous sub-section. This can be illustrated with the aid of Figure 3-4.



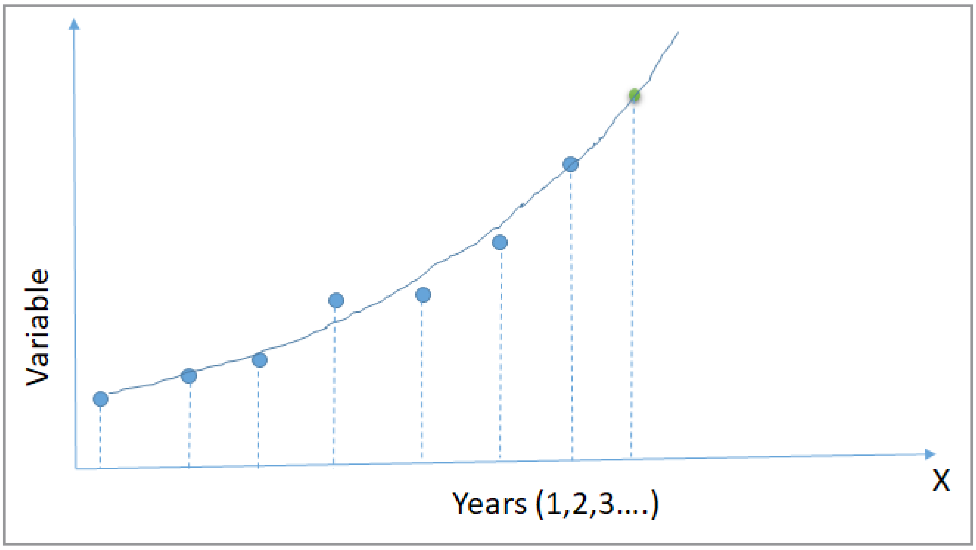
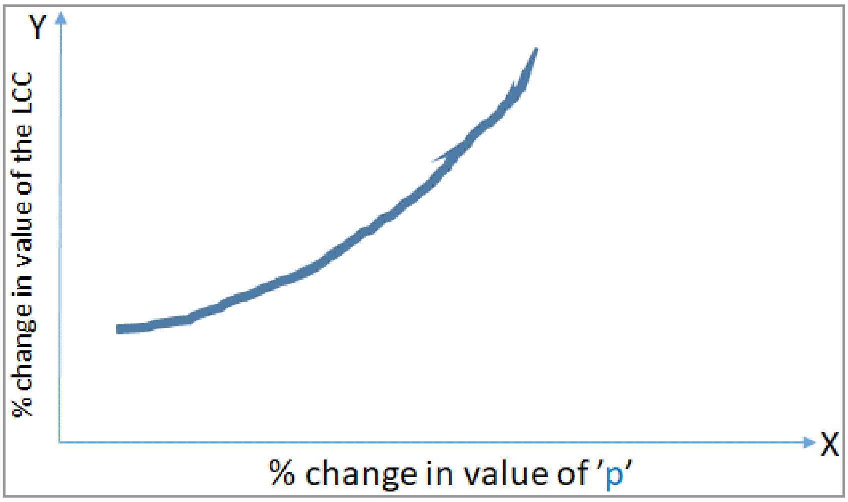


Figure 3-4 :Best-fit line or curve for extrapolation

When historical annual data are available for any variable, a trendline or a so-called best-fit line can be obtained, and the values of the variable for the years in the future can be located on the trendline. On the X-axis, the start-year can be designated a value of zero, and successive years will thereby be 1,2,3 and so on. The best-fit line or curve will have an equation, expressing an approximate relationship between the x and y coordinates. For any given year 'n' in the future, the corresponding value of the variable can be estimated. As shown in Figure 3-4, the blue dots are known values from historical records, while the green dot is the one estimated by extrapolation. More 'green dots' can similarly be located for the other years in the future. It must be mentioned here that one assumes that the trend seen is likely to continue at least during the lifetime of the project being planned. In reality, there may be incidents which may disrupt the trend – natural disasters for instance, or the onset of an economic crisis. Uncertainty does plague LCC; that is one thing which cannot be wished away.

3.4 SENSITIVITY ANALYSIS (OF LIFE-CYCLE COSTS TO DATA ELEMENTS)

When you calculate the present value of all the costs in a project, to get the life-cycle costs, and then calculate the present value of all the benefits, to get the life-cycle benefits, subtracting the former from the latter, will give you what is called the Net Present Value (NPV) of the project. Now, evidently, if this single number can be imagined to be the apex of the cone, the base of the cone represents all the different variables which have been estimated first (most likely by extrapolating as discussed in 3.3.2, or derived from historical data as discussed in 3.3.1. The degree of sensitivity of the NPV to changes in the variables, differs from one variable to another. This can be studied by what is called sensitivity analysis. Refer Figure 3-5 below.



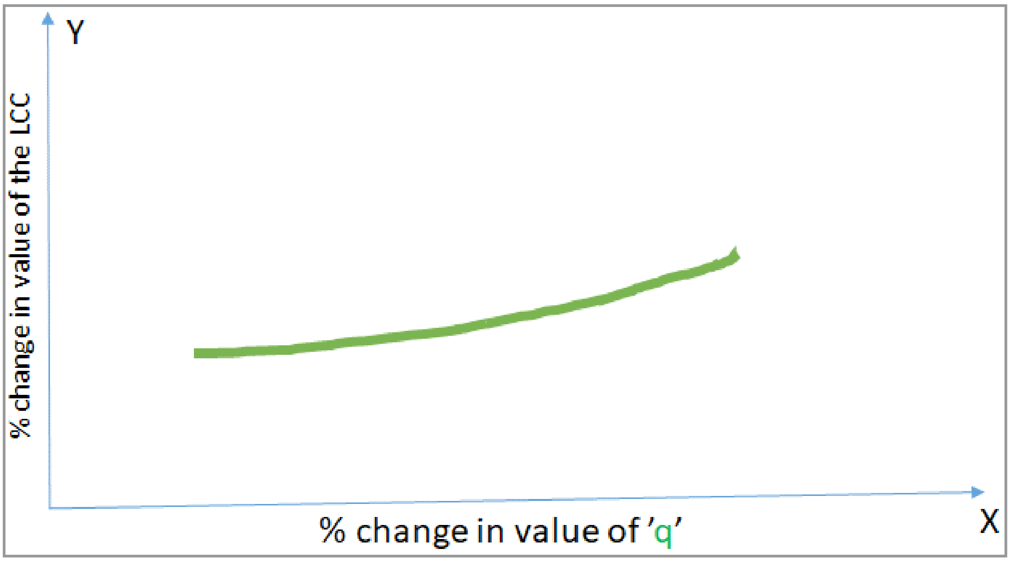


Figure 3-5: Sensitivity analysis

Consider a hypothetical formula for life-cycle cost, like the one below:

$$\textbf{Life-cycle cost} = \mathbf{p^2 * m + p * k * l + q * l} \qquad \textbf{30)}$$

p and **q** are variables; and **k, l** and **m** may either be constants or variables. In the graph on the left, **k, l, q** and **m** are held constant to check the effect of **p** on the LCC. In the graph on the right, **k,l,p** and **m** are held constant to check the effect of **q** on the LCC. It can be easily inferred that the LCC is more sensitive to the variable **p** than it is to **q**. That would mean that if there is even a small uncertainty in the value of **p**, that would cast a darker shadow, so to say, on the reliability of the LCC!

3.5 UNCERTAINTY ANALYSIS – AN EXAMPLE

We referred to 'uncertainty' a few times earlier. Let us now understand uncertainty and try accounting for it, with an example. Consider two energy-saving alternatives with the same lifetimes, with different initial investment costs and different annual expenditure profiles. For each alternative, a fixed amount of energy is saved annually. This amount though is not the same for both the alternatives. Now, energy use reduction implies a concomitant reduction in operation expenses. If the price of energy (or in other words the specific energy cost to the consumer) remains the same, you save exactly the same amount of money every year. Also assume that these are the only benefits which accrue to you every year. Now think of a situation where it is likely that the price of energy will keep increasing at a constant rate (note however that a constant rate of increase in price is a highly-idealised situation) every year. However, it turns out that you do not know what exactly this rate will be. You discuss with an energy economist who gives you 'ball-park probability estimates' of a range of rates. This is the best you could get, to make some headway. For each rate of increase in the price of energy, you determine the NPV for both the alternatives, and plot a graph which may hypothetically look like the one in Figure 3-6. Then, refer to Table 3.9. This records the ballpark estimates of the probabilities of the different rates of increase which the energy economist gave you. From Table 3-9, you can determine a weighted average rate of increase, by summing up the products of each rate of increase and its respective probability.

This turns out to be 6.74%. This weighted average rate of increase and the associated NPVs for the two alternatives are termed as 'expected values' and this analysis is sometimes also referred to as expected value analysis.

Rate of increase (%)	4	5	6	7	8	9	10	11	12
Probability (%)	11	11	27	25	12	5	4	3	2

Table 3-9 : Probabilities of constant rates of increase in energy price

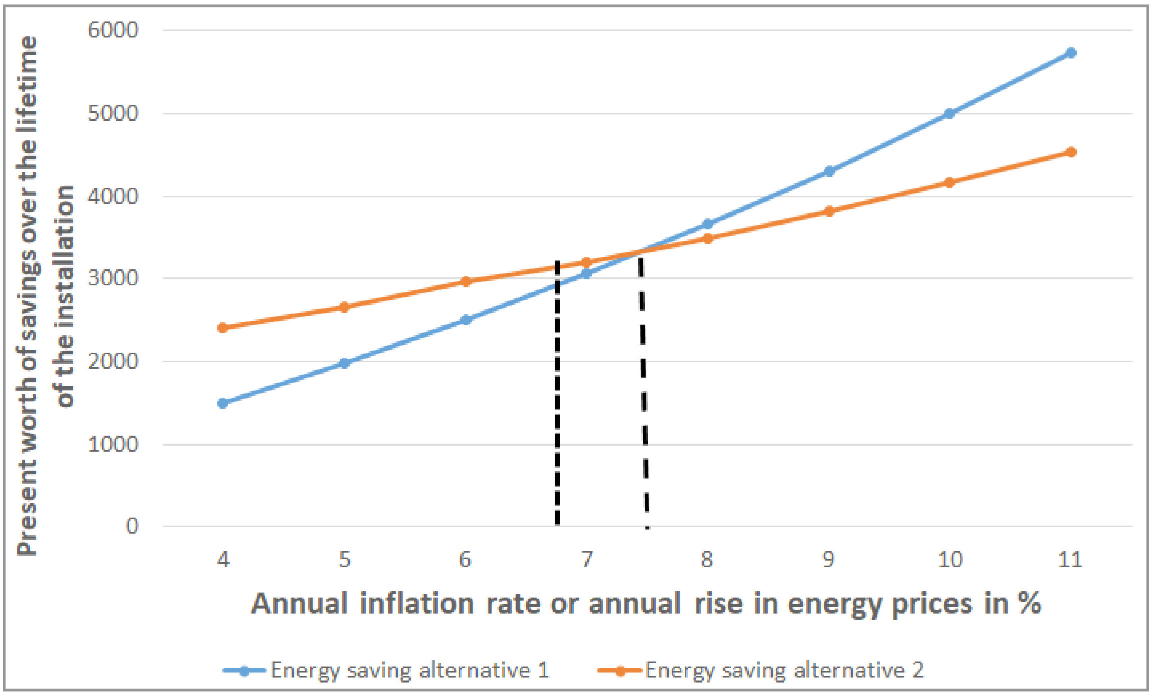


Figure 3-6: Working with uncertainty in rates of increase in energy price

In Figure 3-6, it is seen that at 6.74%, the energy saving alternative '2' has a greater NPV. As the rate rises to around 7.5%, both have the same NPV. At rates above 7.5%, alternative '1' will be preferred over alternative '2'. However, this conclusion has been arrived at by trusting the ballpark estimates given by the energy economist. In the absence of any other source of information about the rate of increase in energy price, this can be taken on board, albeit with a pinch of salt.

3.6 EXERCISE

1. Given below are the probabilities of rates of increase in the price of energy, and the NPVs of two energy-saving alternatives A and B. Which of the two alternatives would you opt for? Plot the lines and find the rate at which you would be indifferent.

Rate of increase in price (%)	Probability (%)	NPV from alternative A	NPV from alternative B
4	1	1491	2410
5	12	1984	2656
6	30	2510	2963
7	30	3072	3200
8	10	3673	3500
9	9	4314	3821
10	4	5000	4164
11	4	5736	4532

2. The initial economic value of an equipment is 20,000 SEK and the salvage value at the end of its service lifetime of 10 years is 1500 SEK. The capital value can be depreciated in three different ways:
   a. Straight-line
   b. Double-declining balance
   c. Sum-of-years-digits

   Plot the curves of the cumulative depreciated amount for the three different cases. Also plot the respective curves for the residual economic value down to the salvage value at the end of 10 years. Identify the points of intersection on the graph of the two curves for each of the three cases.

3. Discuss the inclusion of social and environmental externalities (impacts and effects which are not accounted for monetarily), as cost categories in a life-cycle costing analysis. Do you think that expressing the social and environmental aspects of a project/business in monetary units so that they could be integrated with the economic analysis, is a good solution to analyse projects holistically – from social, economic and environmental perspectives? If yes, why? If no, why?

4 SERVICE LIFE

We referred to 'service lifetime' in one or two of the earlier chapters. In this one, we delve deeper into understanding what an optimum service lifetime is, in terms of streams of expenses incurred. We also discuss decision-making regarding replacing an old asset with a new one vis-à-vis retaining it by choosing to spend more on maintenance instead.

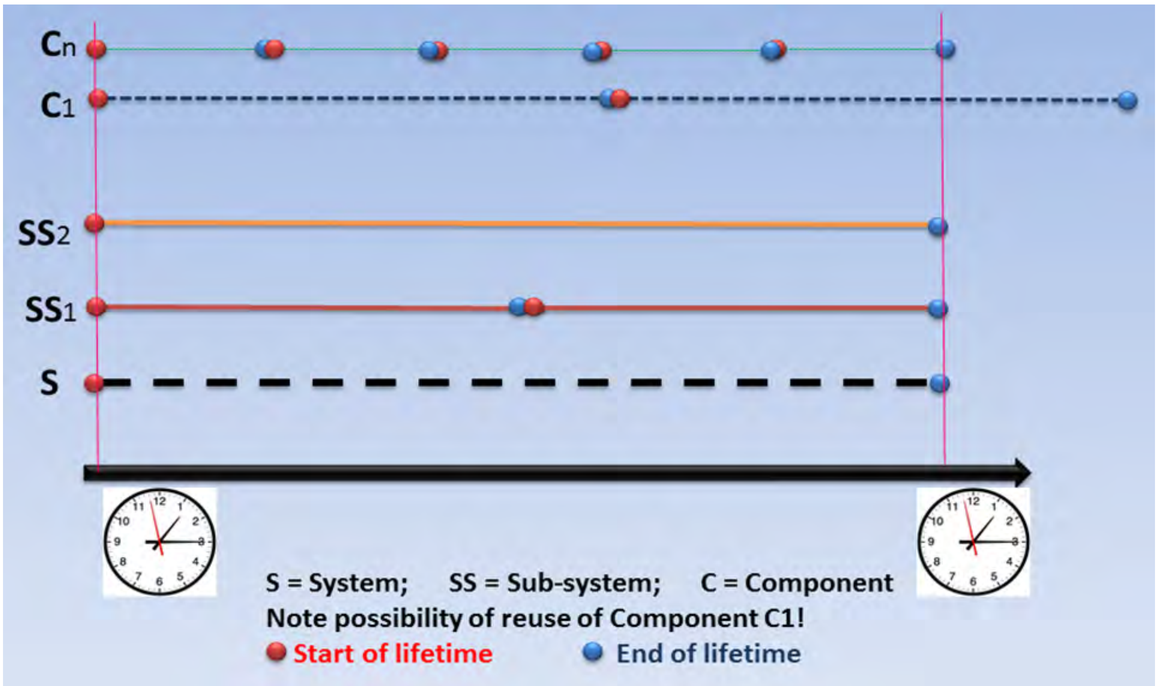


Figure 4-1: Webs of service lifetimes in a project[9]

The figure above shows a system, two sub-systems within it and 'n' components within those sub-systems. The physical system here could be a factory, while its sub-systems could be two different processing units. The processing units will have a range of equipment and machinery, which in turn will be composed of a plethora of component parts. Lifetimes (service lifetimes, in other words), can be defined for the system, right down to all the components of the equipment and machineries. As seen in Figure 4-1, the system may have a predefined service lifetime, after which it may be disbanded or reconstructed. The sub-systems within this system may need to be overhauled once or more, over the lifetime of the factory-system. Different equipment and different components will have different lifetimes.

At the end of the service lifetime of a sub-system/equipment/component at a given firm/factory, it may have salvage (residual) value either for its function or for its material content. In the first instance, we would talk of reusing something for its function by selling it forward (second-sale), while in the latter case, we talk of selling it to a recycler for its material value or recovering energy from it (if it has energetic value). In other words, though the service lifetime at one firm, say A, may have ended (in year-9, as shown in Figure 4-2), a component may still have some residual economic value (10000 SEK) – its economic lifetime has not ended. The economic lifetime at A ends when the residual economic value is realised by the firm. Now, if firm A recovers the residual economic value by selling the asset for its functional value to firm B (for which the initial investment in the asset is now 10000 SEK), a new economic lifetime begins for the asset, at firm B. The salvage value at the end of the service lifetime at firm B is 1000 SEK, as seen in Figure 4-2, and the 'value' here is not for its function anymore, but for its material content. While the economic lifetime at firm B ends once the salvage value is recovered by this firm, the physical lifetime continues till the asset is dismantled, and can be thought of more as 'cradle-to-grave'. The 'cradle-to-cradle' implies the commencement of several new cycles (many economic lifetimes, as parts of several different products), courtesy what we know as open recycling of the materials or reuse of the component parts.

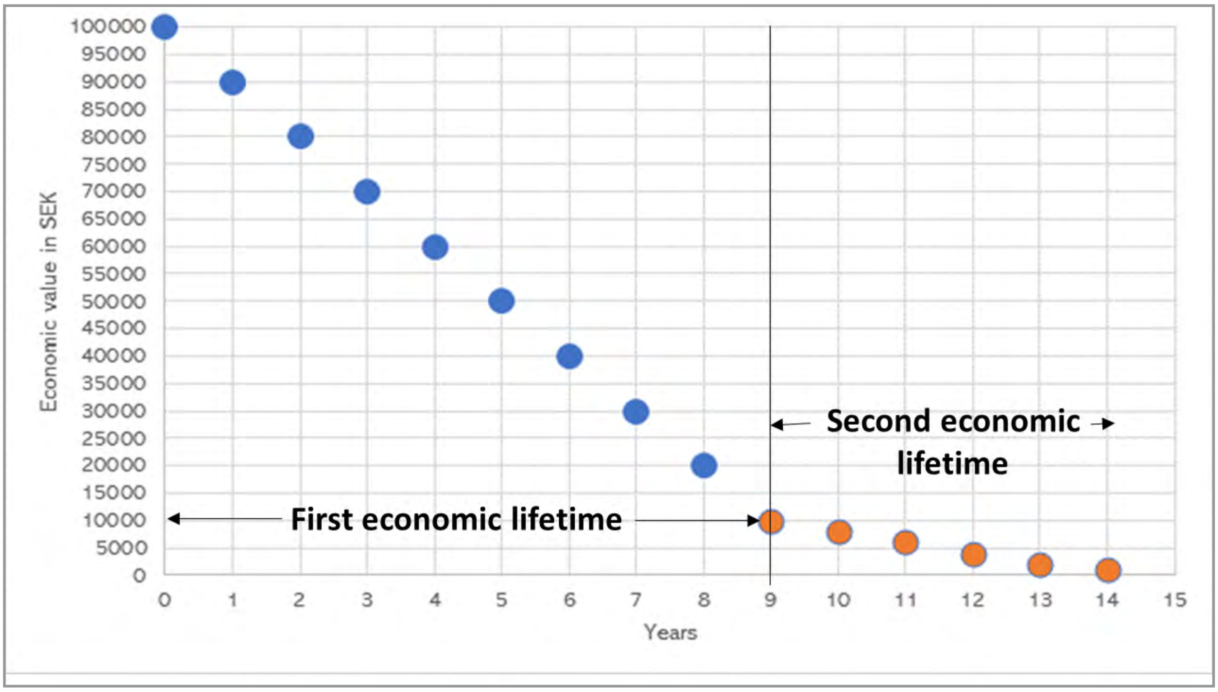


Figure 4-2: Illustration of decreasing economic value and multiple economic lifetimes

That brings us to the concept of the 'optimum' service time? How can it be defined? Is it common to use a piece of equipment if it can be still made to function, by oiling and greasing it more often and replacing component parts more frequently, right till the end of its predefined economic lifetime? If you are told that the 'optimum' service lifetime is defined as 'the duration of time at the end of which the total annualised average costs (capital + maintenance) is the minimum,' you would instantly know why. The adjective 'optimum' is important here. The equipment of course can continue functioning after the optimum service time has been reached.

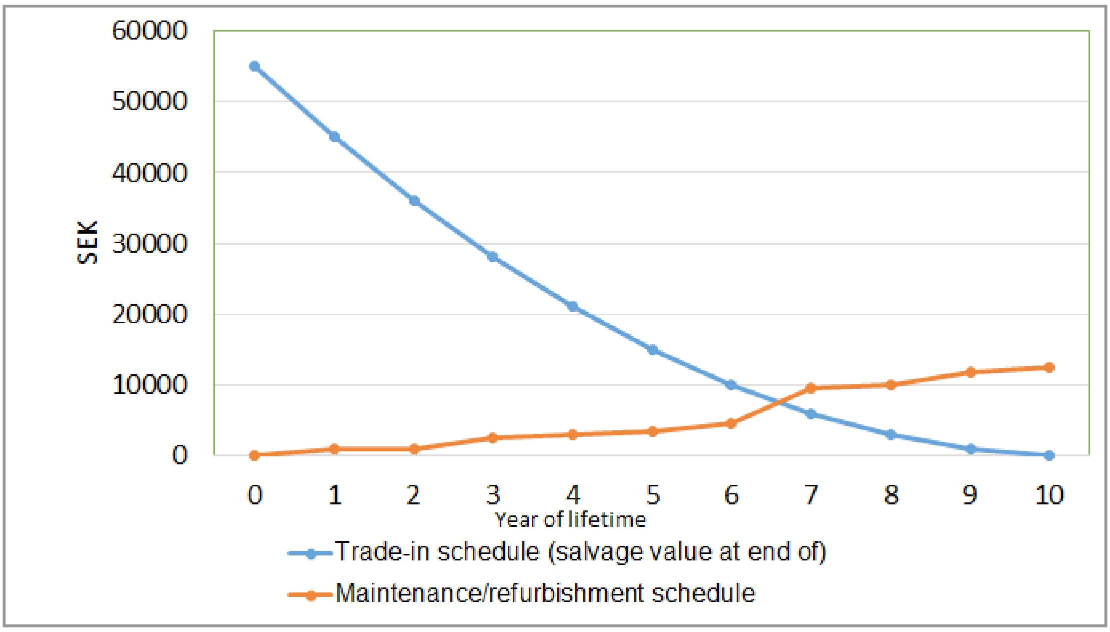


Figure 4-3: Drop in economic value and the rise in maintenance expenses over time

4.1 CALCULATING ANNUALISED CAPITAL COST

Capital cost is the loss in economic value suffered by the asset over its lifetime. As seen in Figure 4-3 (graphical representation of Table 4-1), the economic value decreases over time, implying that the capital cost gets accumulated as the asset gets older. What is meant by annualised capital cost in this case? It is simply the determination of the annuity (A), associated with the Single Present Worth (SPW) of the cumulative capital cost (total reduction in economic value of the asset with respect to the initial value in year-zero). Here, you get an opportunity to go back to Chapter 2, and use the SPW and UCR formulae in that order. Let us understand this more clearly with the aid of Table 4-1 and Figure 4-3.

Year of economic lifetime	0	1	2	3	4	5	6	7	8	9	10
Residual economic value at end of year ('000 SEK)	55	45	36	28	21	15	10	6	3	1	0
Annual maintenance expenses ('000 SEK)	0	1	1	2.5	3	3.5	4.5	9.5	10	11.8	12.5

Table 4-1 : The residual economic value and annual maintenance expenses (refer Figure 4-2 also)

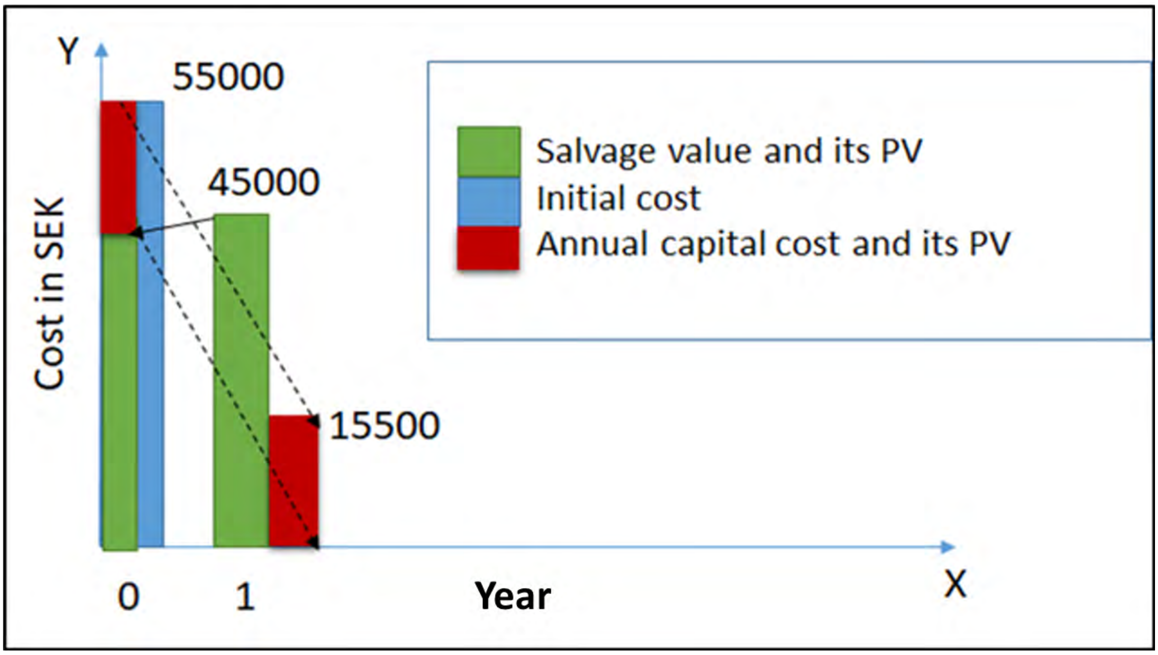


Figure 4-4: Determining the annualized capital cost (costs have been indicated on the positive Y-axis for convenience)

Consider only the second row from Table 4-1 while referring to Figure 4-4. The initial economic value (capital cost) in year-zero is 55000 SEK as indicated by the blue bar. The residual economic value in year-1 is 45000 SEK.

The present value of this amount would be less (by the discount rate considered, which is 10% in this example), and equal to 40909 SEK.

That would give us the present value of the capital cost in year-1 (simply the difference between the initial economic value and the present value of the residual economic value in year-1), and that would be equal to 14091 SEK. This is indicated in red.

Its compounded value in year-1 (also shown in red) – turns out to be 15500 SEK, at a 10% interest rate. Now, when the asset is at the end of its first year of operation, the annualised capital cost would be 15500 SEK. What we have done here is:

a) Use SPW on the residual economic value in year-1.
b) Then use UCR (in this case, it was a simple SCA, as we were considering just one year)

Now, let us skip and jump to year-3. The economic value (Table 4-1) is 28000 SEK. The SPW of this, in year-0 would be 21036 SEK. This would give us the present value of the capital costs (cumulative lost value in year-3) and that would equal 33963 SEK. Applying the UCR equation (refer chapter 2), for a 3-year period, yields an annuity of 13657 SEK. Table 4-2 lists the annuities of the capital costs for every year of the economic lifetime of the asset. We now move over to try to understand the 'annualising' of the maintenance expenses incurred – in other words, determine the annuities.

4.2 CALCULATING ANNUALISED MAINTENANCE EXPENSES

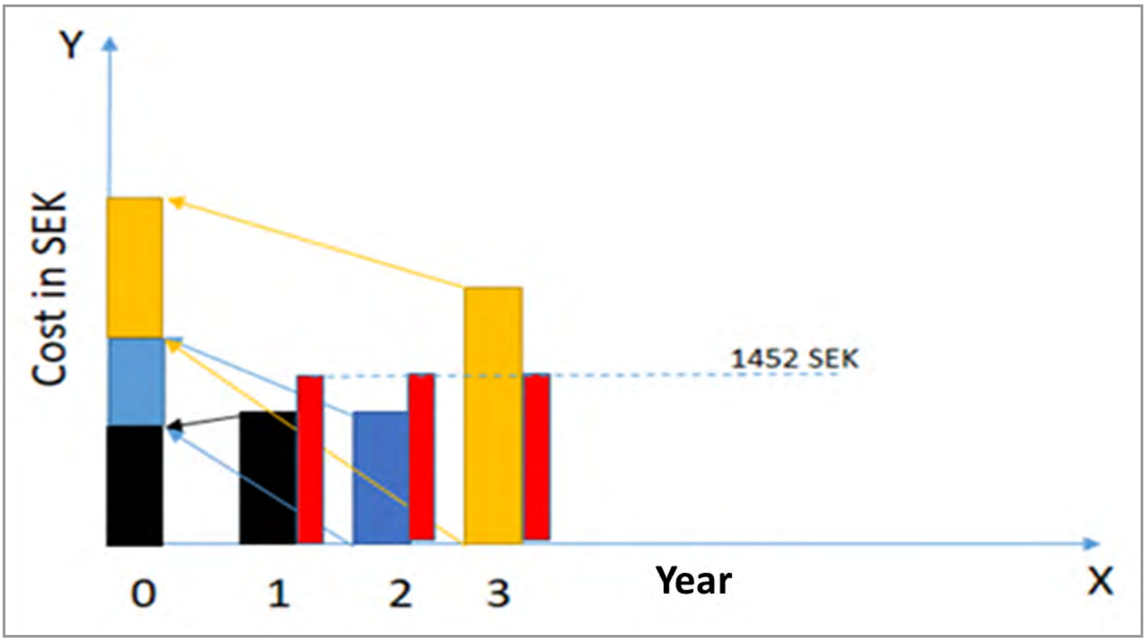


Figure 4-5: Determining the annualized maintenance expense (costs have been indicated on the positive Y-axis for convenience)

Refer to Table 4-1 and consider only the third row. In Figure 4-5, the black, blue and yellow bars represent the given maintenance expenses, for years 1,2 and 3. The data labels have not been provided in order to avoid clustering. The maintenance expenses can be discounted back to get their respective single present values. So, at year-3, if the annuity of the maintenance expenses (incurred thus far), has to be calculated, you would use the UCR equation on the sum of the single present values of the three individual maintenance expenses for years 1,2 and 3. A sum of 1000 SEK in year-1 has an SPW in year-0, of 909 SEK. A similar sum in year-2 has an SPW of 826 SEK. A sum of 2500 SEK in year-3 has an SPW of 1878 SEK. The sum of these three SPWs is 3613 SEK. If this has to be converted to annuities for 3 years, applying the UCR equation gives you a value equal to 1452 SEK.

4.3 DETERMINING SERVICE LIFE FROM THE CURVES OF THE ANNUALISED COSTS

Table 4-2 lists the annuities for both the capital costs and the maintenance expenses, calculated as explained in sections 4.1 and 4.2. The conditional formatting has been used intentionally to give an impression of the relative amounts of these annuities. Figure 4-6 plots the annuity curves over time. As seen, the Y-coordinates of the points on the total annualised cost curve have a minimum value, before the curve slopes up very gradually again. In this example – also verified from Table 4-2, it occurs around 6 years. This means, that even though the economic lifetime is 10 years, the optimum service lifetime is less. However, it must be noted that the asset may continue to be used beyond its optimum service lifetime. This relation is useful to remember.

Service lifetime <= Economic lifetime <= Physical lifetime

Year	Average annual capital costs	Average annual manitenance/ refurbishment	Total annual average costs
1	15500	1000	16500
2	14548	1000	15548
3	13657	1453	15110
4	12826	1786	14612
5	12052	2067	14119
6	11332	2382	13714
7	10665	3133	13798
8	10047	3733	13780
9	9477	4327	13804
10	8951	4840	13791

Table 4-2 : The annuities and the total annualised costs for every year of the economic lifetime

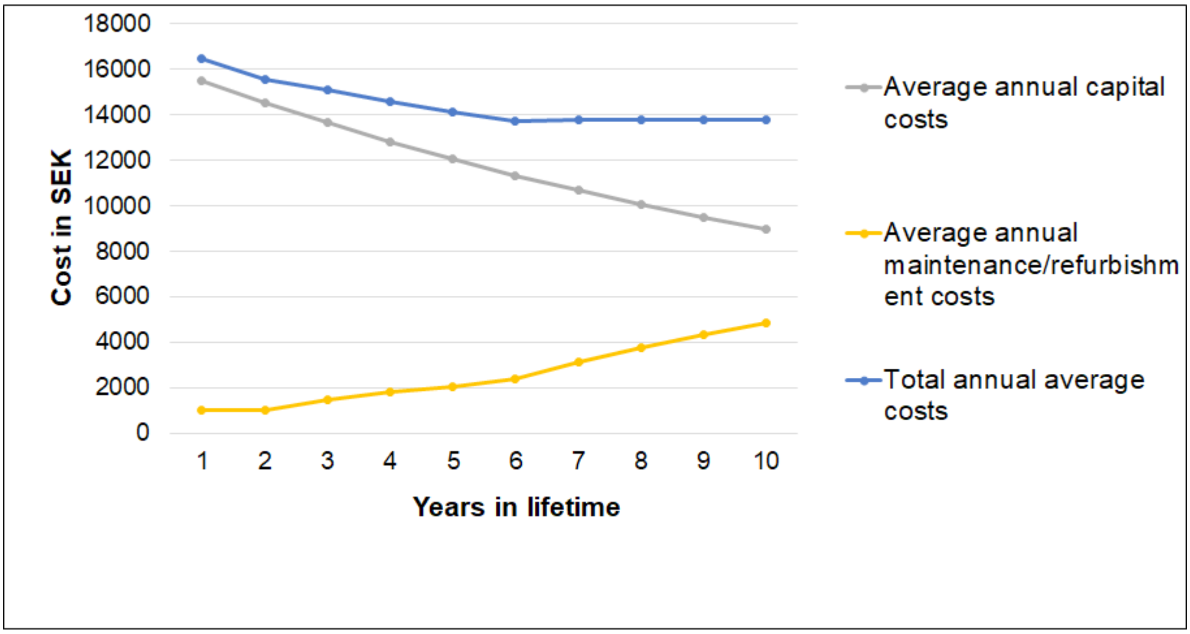


Figure 4-6: Determining the optimum service lifetime

The average annual capital costs (the annuities over time) decrease, while the annualised maintenance expenses increase over time. Adding up the two, gives the total annualised costs curve, seen on the top in Figure 4-6. This, as noted before, slopes down to a point and then creeps up very gradually. The minima, indicated by the 'dark green' cell in Table 4-2, occurs when the asset has completed 6 years of operation. Thereafter, it still has economic value, but the maintenance expenses increase rapidly…resulting in the annuities also rising at a brisker clip after year-6. However, there is not much difference between the total annualised cost in year-6 and year-10 (a slight increase of just 0.56%). Thus, a decision will certainly be made in favour of using the asset till the very end of its economic lifetime – beyond its optimum service lifetime - before a decision can be made about replacement or retention (post refurbishment).

4.4 REPLACEMENT OR RETENTION

When an asset reaches the end of its economic lifetime, what remains of it is just its salvage value, and you know that its efficiency of operation has dwindled with age. This would necessitate frequent maintenance (and thereby an increase in the associated expenses, along with a drop in the quality and/or quantity of the output it provides). You may ponder about selling it to recover its salvage value and invest in a brand new asset to replace it. You may also realise that you can retain the existing asset by overhauling it (major refurbishment) and thereby prolong its useful (functional) lifetime. The refurbishment may entail, for instance, changing some component parts to tide over technological obsolescence.

When we talk of replacement, it could mean:

a) Replacing the asset with a totally different one
b) Replacing the asset with a similar new one
c) Replacing the asset with manual operation
d) Abandoning the need of the asset altogether

4.4.1 TO RETAIN OR NOT TO RETAIN, THAT IS THE QUESTION

Here is an example, which will make things crystal clear. A motor in a process chain in a factory is 11 years old and must now be refurbished or replaced with a similar new one. It has a salvage value (effectively, its economic lifetime within the factory continues, till the point when its salvage value is recovered) of SEK 200. Refurbishment will cost SEK 1000, and post-refurbishment, the useful life of the motor can be extended by another 5 years. Post-refurbishment, the motor's efficiency becomes almost the same as a brand new one. A brand-new motor will cost SEK 2800, and will last for 12 years (technological improvements have resulted in an increase in the useful functional lifetime). Discount rate is 10%. You have this information with you and need to make a quick decision. Here is how you will go about it:

- **New motor**
  - Annual average initial cost 2800 SEK
  - UCR at 10% for 12 years 410.9 SEK
  - Salvage value 200 SEK
  - USF at 10% for 12 years 9.4 SEK
  - Net annual average cost 410.9 – 9.4 = 401.5 SEK

The initial capital cost is distributed over the 12-year lifetime, as annuities. Likewise, the final salvage value is distributed (back) over the 12-year lifetime as annuities. The former stream of annuities are costs and the latter stream of annuities are benefits. Hence, one gets a net annual average cost value by subtracting the latter from the former. We end up with 401.5 SEK.

- **Old motor**
  - The salvage value of the old motor at the end of its useful lifetime is its 'cost'. That means, by not selling it at 200 SEK, you are losing that amount of money, and hence, indirectly paying it (analogous to what has been depicted in Figure 3-1).
  - 'Cost' of old motor 200 SEK
  - UCR at 10% for 5 years 52.8 SEK
  - Repair cost 1000 SEK
  - UCR at 10% for 5 years 263.8 SEK
  - Salvage value at end of 5 years 200 SEK
  - USF at 10% for 5 years 32.8 SEK
  - Net annual average cost 263.8 – 32.8 + 52.8 = 283.8 SEK.

But while the net annual average cost for the new motor is for 12 years from the moment of decision-making, that of the old one is for 5 years from the moment of decision-making. Of course, the motor could be repaired again, and could function for another 5 years, or maybe that would not be possible, necessitating an investment in a new motor. Hence, here, it is the time-frame of decision-making which must be fixed. Is one comparing options for a 5-year time-frame or a 12-year time-frame? This brings us to the so-called chain method which we discuss a little later in this chapter. Before that, we go back to the replacement option which is accompanied (preceded or followed) by the sale of the old motor at its salvage value.

4.4.2 SALVAGE VALUE AND INTRICACIES

The salvage value is also termed as the 'book value', because an accountant would record it (in a 'book') when the capital investment is made, and the asset is incorporated into the setup. The firm can sell the asset at its book value without incurring any tax on the proceeds resulting from the sale. In other words, in our previous example, if the motor was sold at exactly 200 SEK at the end of 11 years, no tax is paid on the 200 SEK earned by the firm.

Now, if there is a strong demand for the old motor (maybe, the copper in it has suddenly become very valuable, with the 'red metal' becoming increasingly scarcer over time), and one sells it at 300 SEK – 100 SEK greater than the book value – the taxable component of this income will be 100 SEK. In a case, where one is not even able to recover the book value and manages to dispose of the old motor for 100 SEK (which is 100 SEK less than the book value), there is a possibility to claim tax deduction for 100 SEK of the total annual income.

Now, let us consider a peculiar case – which may or may not happen generally. The initial cost of the old motor in the previous example (not the same as the 2800 SEK for the new motor), is, say 2500 SEK. If one can manage to sell it at 3000 SEK (500 SEK greater than the initial value), two different types of taxes will come into the picture. The income tax will be on the difference between the initial value and the book value – (2500 – 200) = 2300 SEK. Then, there is what is called a capital gains tax (tax on the gains you have made, over and above the initial capital value itself). This would be levied on the 500 SEK you have gained, over the initial capital value of 2500 SEK. Taxes paid are cost categories as shown in Table 3-1. Table 4-3 sums up the three cases above.

Initial capital value	2500	2500	2500	2500
Salvage value	200	200	200	200
Selling price (SEK)	200	300	100	3000
Income tax rate(%)	I	I	I	I
Capital gains tax rate (%)	C	C	C	C
Tax payable on income from sale of old motor	0	100*I	-100*I (deduction)	2300*I + 500*C

Table 4-3 : Income tax payable, income tax deduction and capital gains tax, related to salvage value

4.5 CHAIN METHOD OF COMPARING LIFETIMES

This links to the question which we posed in 4.4.1. Let us say that the service lifetime equals the economic lifetime (and is not optimised), and ends with the asset having a residual value equal to its book value. There are two alternatives to choose from – both having different service lifetimes. The timeframe of analysis in that case would be the least common multiple of the two. If say, alternative A and B have service lifetimes of 3 years and 4 years respectively, the timeframe for analysis would be 12 years (4 lifetimes of alternative A, and 3 lifetimes of alternative B). In other words, if alternatives A and B are two different pieces of equipment which need to be purchased and used, the comparative analysis would involve 4 purchases of equipment A and 3 purchases of equipment B, over the 12-year time period (Refer Figure 4-7, in which these 'compartments' have been indicated by dotted vertical lines). It is assumed here that the benefit streams from the two alternatives are identical and so, the comparison is just between the cost streams.

Just to make sure that readers are not confused by the heights of the bars in Figure 4-7, it must be stated that for the sake of simplicity, for each alternative, a zero salvage value and constant annual maintenance costs – black bars for alternative A and white bars for alternative B - are assumed. Further, inflation has been totally ruled out and so, the capital cost of each asset remains the same over the 12-year period. **In reality, this is usually never the case.**

It follows thereby that one would opt for the option which has the lower PV of all the cost streams over the 12-year period. Here, the SPW and UPW equations need to be used. The total PV can also be expressed in terms of 12 annuities (or the so-called net annual average costs), for each alternative (using the UCR equation). Further, one would assume in this case, that the project/factory itself would have a lifetime of 12 years or more! (Food for thought - What would happen if this is not the case, and the project itself would last for less than 12 years?)

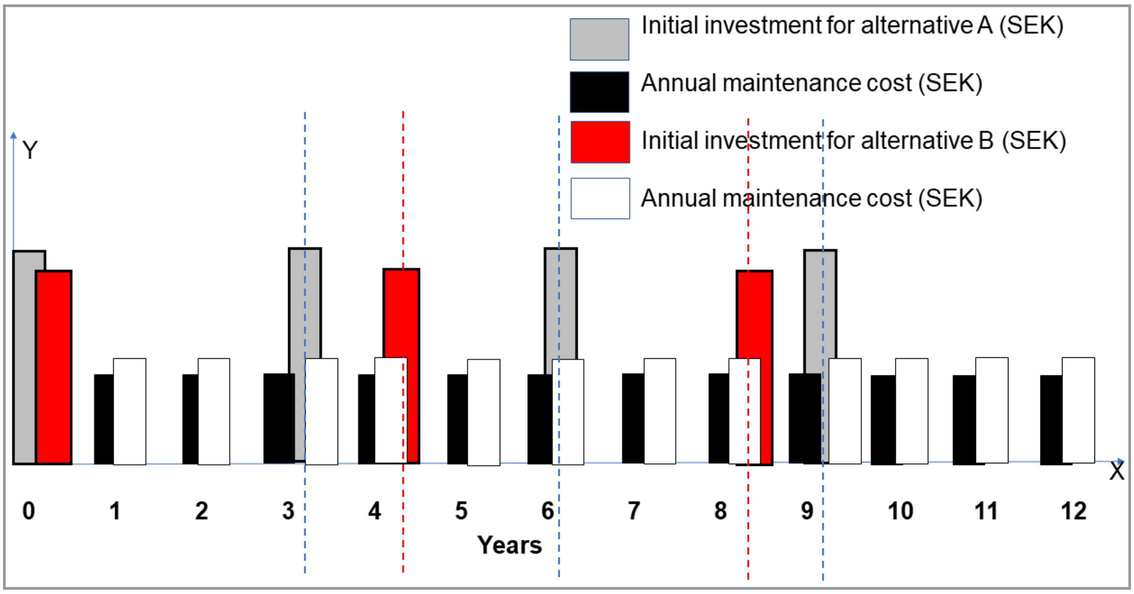


Figure 4-7: Chain method of comparison between alternatives (costs have been indicated on the positive Y-axis for convenience)

4.6 EXERCISE

1. Refer Table 4-2. Try calculating the values listed in that table yourself using the appropriate equations. Identify the depreciation method used in this example.
2. In the previous exercise, consider a different depreciation method (you can choose any), and recalculate the total annual aggregated cost, and the associated optimum service lifetime. Plot the curves in Excel.
3. A decision needs to be made between three alternatives, having lifetimes of 2 years, 3 years and 4 years respectively. The cost streams for each lifetime are given below. Salvage values for all three alternatives at the end of the respective lifetimes are zero.

Assume that they remain the same over the next 20 years. Discount rate considered is 5%. Which of the three alternatives will you choose? Use the chain rule.

<table>
<tr><th colspan="2">Alternative 1</th><th colspan="2">Alternative 2</th><th colspan="2">Alternative 3</th></tr>
<tr><th>Year</th><th>Capital cost (or) Maintenance expense (SEK)</th><th>Year</th><th>Capital cost (or) Maintenance expense (SEK)</th><th>Year</th><th>Capital cost (or) Maintenance expense (SEK)</th></tr>
<tr><td>0</td><td>10000</td><td>0</td><td>12500</td><td>0</td><td>13000</td></tr>
<tr><td>1</td><td>750</td><td>1</td><td>600</td><td>1</td><td>575</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">900</td><td>2</td><td>620</td><td>2</td><td>575</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">700</td><td>3</td><td>575</td></tr>
<tr><td>4</td><td>600</td></tr>
</table>

5 PAYBACK PERIOD

In this chapter, you will learn about the different types of payback on investments – true payback with both discounting and inflation, simple payback without discounting and inflation, payback with only inflation and payback with only discounting, break even analysis and internal rate of return

„It is the good children, Madame, who make the most terrible revolutionaries. They say nothing, they do not hide under the table, they eat only one sweet at a time, but later on, they make Society pay dearly for it!"

– Jean-Paul Sartre

Payback period, simply defined, is the period of time at the end of which the initial investment committed to a business is recovered thanks to the stream of annual benefits. Let us start off with simple payback.

5.1 SIMPLE PAYBACK

An initial investment of SEK 100800 is committed on an equipment which has a service lifetime of 7 years. The constant pre-taxation annual savings (net benefits from operating the equipment) are 40000 SEK. The firm's income tax rate is 40% (in other words, the pre-tax annual savings are taxed at 40%). Straight-line depreciation is adopted and the firm gets tax deduction on the annual depreciation amounts. The time it takes for the cumulative savings to equal the investment amount, is called the payback period. In the case of a simple payback, both the discount rate and inflation rate are assumed to be zero. Refer Table 5-1.

Year	Annual depreciation (SEK)	Tax deduction on depreciation (SEK)	Pre-tax savings (SEK)	Tax paid on savings (SEK)	Cumulative savings (SEK)
1	14400	0.4* 14400 = 5760	40000	0.4*40000 = 16000	24000 + 5760 = 29760
2	14400	5760	40000	16000	59520
3	14400	5760	40000	16000	**89280**
4	14400	5760	40000	16000	**119040**
5	14400	5760	40000	16000	148800
6	14400	5760	40000	16000	178560
7	14400	5760	40000	16000	208320

Table 5-1 : Calculation of the simple payback period

From the last column in Table 5-1, it is seen, that the savings accumulate to 89280 SEK at the end of the third year. By the end of the fourth year, the cumulative savings have exceeded the initial investment made. That would mean that the simple payback period is somewhere between 3 and 4 years. To be exact, **3 + [(100800 – 89280)/29760]** years, which is 3 years and 141 days.

5.2 PAYBACK WITH INFLATION

Now, instead of considering a constant pre-tax benefit, assume that it increases at an annual rate of 4% (owing to inflation).

Year	Annual depreciation (SEK)	Tax deduction on depreciation (SEK)	Pre-tax savings (SEK)	Tax paid on savings (SEK)	Cumulative savings (SEK)
1	14400	0.4* 14400 = 5760	40000	0.4*40000 = 16000	24000 + 5760 = 29760
2	14400	5760	41600	16640	60480
3	14400	5760	43264	17306	**92198**
4	14400	5760	44995	17998	**124955**
5	14400	5760	46794	18718	158792
6	14400	5760	48666	19466	193751
7	14400	5760	50613	20245	229879

Table 5-2 : Calculation of the payback period with inflation and without discounting

Similar to what we saw in Table 5-1, the payback period is somewhere between 3 and 4 years. To be more exact, 3 + [(100800-92198) / (124955-92198)] years, which is equal to 3 years and 95 days. Thus, when an inflation rate of 4% is considered, the payback period is shortened by 46 days (a month and a half).

5.3 DISCOUNTED PAYBACK (NO INFLATION)

Now, inflation goes out of the picture and a discount rate of 10% enters the fray. The calculations look like those in Table 5-3 below. The constant annual benefits are discounted back to year-zero and thereby, the present values decrease by a factor of 1.1, as we move ahead from one year to the next. It follows that the payback period calculated with a discount rate of 10%, increases to 4 +[(100800 – 94335)/(112813-94355)], which is equal to 4 years and 127 days.

Year	Annual depreciation (SEK)	Tax deduction on depreciation (SEK)	Pre-tax savings (SEK)	Tax paid on savings (SEK)	Total annual savings (SEK)	Present value of annual savings (SEK)	Cumulative savings (SEK)
1	14400	0.4* 14400 = 5760	40000	0.4*40000 = 16000	24000 + 5760 = 29760	29760/1.1 =27054	27054
2	14400	5760	40000	16000	29760	24595	51649
3	14400	5760	40000	16000	29760	22359	74008
4	14400	5760	40000	16000	29760	20326	**94335**
5	14400	5760	40000	16000	29760	18478	**112813**
6	14400	5760	40000	16000	29760	16798	129612
7	14400	5760	40000	16000	29760	15271	144884

Table 5-3 : Calculation of the payback period with discounting and no inflation

Now, can an equation be derived for the discounted payback period? Consider an initial investment of C, and constant annual savings of S each. Let the discount rate be r, and the discounted payback period be 'n' years. As per the definition of discounted payback, we can write:

$$C = S/(1+r) + S/(1+r)^2 + S/(1+r)^3 + \ldots\ldots\ldots\ldots\ldots S/(1+r)^n$$

$$C = S * [1/(1+r)]*[1 - (1/(1+r)^n)]/[1-\{1/(1+r)\}]$$

$$1-(C/S)*r = 1/(1+r)^n$$

$$\text{Log } [1-(C/S)*r] = -n \text{ Log } (1+r)$$

$$\mathbf{n = \log [1/\{1-(C/S)*r\}] / \log (1+r)} \qquad \mathbf{(31)}$$

5.4 TRUE PAYBACK (DISCOUNTING AND INFLATION)

When the true payback period is to be calculated, both the discount rate and the inflation rate are factored in – in our example, 10% and 4% respectively. The payback period in this case, as gathered from Table 5-4, is 4 + [(100800-98647)/(119657-98647)] years, which is equal to 4 years and 37 days.

Year	Annual depreciation (SEK)	Tax deduction on depreciation (SEK)	Pre-tax savings (SEK)	Tax paid on savings (SEK)	Total annual savings (SEK)	Present value of annual savings (SEK)	Cumulative savings (SEK)
1	14400	0.4* 14400 = 5760	40000	0.4*40000 = 16000	29760	27055	27055
2	14400	5760	41600	16640	30720	25388	52443
3	14400	5760	43264	17306	31718	23830	76274
4	14400	5760	44995	17998	32757	22373	**98647**
5	14400	5760	46794	18718	33837	21010	**119657**
6	14400	5760	48666	19466	34959	19733	139391
7	14400	5760	50613	20245	36128	18539	157930

Table 5-4 : Calculation of the true payback period with discounting and inflation

5.5 BREAK-EVEN ANALYSIS

Break-even analysis is 'multifunctional', if one may say so. It can be used to find answers to a range of questions. For instance:

1. Given so-and-so (including discount rate), how many years does it take to break even?
2. Given so-and-so (including the number of years), at what discount rate does the project break even?
3. Given so-and-so, how many miles must one drive to break even?
4. Given so-and-so, how many patients must be treated to break-even?
5. Given so-and-so, what must be the price of every unit of service provided to break-even?
6. Given so-and-so, how many units must be sold to break-even?

Among these six, only the first one is related to the payback period!

5.5.1 FOREVER PROJECTS

What could these be? Refer Figure 5-1 below. A project can have a very long lifetime. Theoretically infinite. Take the case of, for instance, the Taj Mahal in Agra (India). It will most likely be around for eternity and will continue to attract tourists every year. Let us assume a fixed expenditure every year, a fixed number of such tourists paying a fixed fee, resulting in a stream of constant annual savings. This is of course imaginable. If the annuity is A and the discount rate is 'r', the uniform present value of these benefits ($UPW_{f.p}$), where 'n' tends to infinity, is equal to:

$$\mathbf{UPW_{f.p} = A/(1+r) + A / (1+r)^2 + A/ (1+r)^3 + \ldots\ldots\ldots\ldots\ldots\ldots A/(1+r)^n}$$

$$\mathbf{= A *[(1+r)^{-1} / \{1- (1+r)^{-1}\}]}$$

$$\mathbf{= A/r} \tag{32}$$

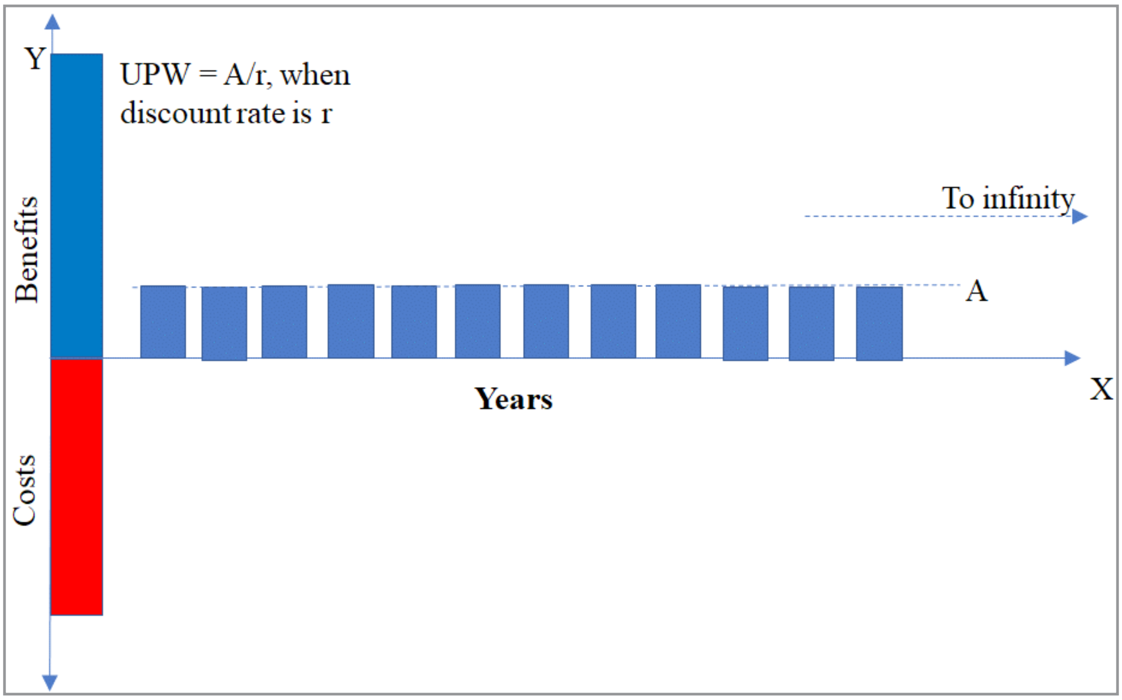


Figure 5-1: Illustration of a forever project

Now, this means that for an initial capital investment equal to **A/r**, the break-even period would be infinity. If it is greater than **A/r**, there can never be a break-even! If less than **A/r**, break-even will happen in finite time.

5.6 EXERCISE

1. Use Equation (31) and try plotting in Excel, curves for different 'r' values, with C/S on the Y-axis and 'n' on the X-axis.
2. C is the initial investment, S is the constant annual benefit, the discount rate is r (fraction and not %) and inflation rate is i(fraction and not %). The variable 'k' can be defined as (1+i)/(1+r). Prove that the true payback period 'n' can be calculated using the equation **n = log [1 + (C/S) {1- (1/K)}] / log k**

3. After having derived the equation in the previous exercise, plot curves in Excel, for different 'k' values (constant inflation rate and different discount rates; constant discount rate and different inflation rates; or different inflation rates and inflation rates), with C/S on the Y-axis and 'n' on the X-axis.
4. A hospital is considering purchase of equipment costing SEK 1 million. Treatment will be given to 2000 people. per year. The equipment should be useful for 20 years. Associated fixed costs will be 210000 SEK per year and the variable costs will be 20 SEK per treatment. What charge per treatment will enable the hospital to break even? The discount rate is 10%.

6 RANKING OF PROJECTS

In this chapter, you will know how projects can be ranked in terms of profitability or economic feasibility. All that you have learnt in the first five chapters culminate in this last one, in which you reach the main goal of an LCC – making a good choice among several possible alternatives.

> *„The ranking – it's just a number"*
>
> – Angelique Kerber, German athlete

It goes without saying that profitability (economic feasibility) is the cornerstone of decision-making when one is confronted with several alternatives. Of course, here we are restricting ourselves just to the economic dimension. One may, for that matter, opt for an alternative which does not rank right on top, in terms of profitability, but is preferred for being environment-friendlier and socially more acceptable (conclusions made based on the other two tools of sustainability analysis – E-LCA and S-LCA respectively).

6.1 MODES OF RANKING

What are the variables (or indicators) used, when projects have to be ranked prior to selection? Here is the quartet which one often chooses from for this purpose:

1. **Net present value or NPV** [Present value (PV) of all benefits - PV of all costs]. This can also be expressed as the difference between PV (net annual benefits) and PV(initial investment). Net annual benefits are calculated by subtracting annual costs from annual benefits, and are sometimes referred to as annual savings. Obviously, the higher the NPV, the more favourable the option.
2. **Savings/Investment Ratio** (S/I ratio). This is the ratio of PV(net annual benefits) to PV (investments). Obviously, the higher the ratio, the better.
3. **Discounted payback period or true payback period** (Refer chapter 5): In this case, the lesser the value, the better.
4. **Internal Rate of Return (IRR).** This has been discussed in detail later, in this chapter

6.1.1 DO ALL MODES YIELD THE SAME RANKING?

Well, the answer is 'not necessarily'. Let us illustrate this with an example. Consider Project A and Project B. Refer to Table 6-1.

Options	Initial investment (I)	PV (net annual benefits) (S)	NPV	S/I	Rank (NPV)	Rank (S/I)
Project A	10000	12000	2000	1.2	1	2
Project B	9200	11100	1900	1.206	2	1

Table 6-1 : Project A, Project B, NPV and S/I

You at once see the conflict there in Table 6-1. You would appreciate that 'the difference between two quantities is greater', does not automatically imply that 'the ratio of the larger to the smaller is also greater'. Likewise, focus on the payback period, narrows down the scope to just the recovery of the initial investment. This may happen faster in one project, but it may still have a lower NPV than another alternative with a longer payback period. Of course, if there is a deadlock – a case where two projects have the same NPV, then the S/I , for instance, can be the tie-breaker! We move on to discuss the IRR, also a measure of the attractiveness of investment in a project.

6.2 INTERNAL RATE OF RETURN (IRR)

The definition of the IRR goes like this: It is the discount rate at which the net life-cycle savings of a project is zero. The net life-cycle savings here, equal the present worth of the annual life-cycle savings (including salvage value), minus the initial capital investment. Refer to Figure 6-1, in which the initial investment I and the net annual savings in years 1,2,3 and 4 (we assume a four-year lifetime) have been depicted. Consider the internal rate of return to be IRR. Then, as per the definition above,

$$\mathbf{I = S1/(1+IRR) + S2/(1+IRR)^2 + S3\,/\,(1+IRR)^3 + S4/(1+IRR)^4} \qquad \textbf{(33)}$$

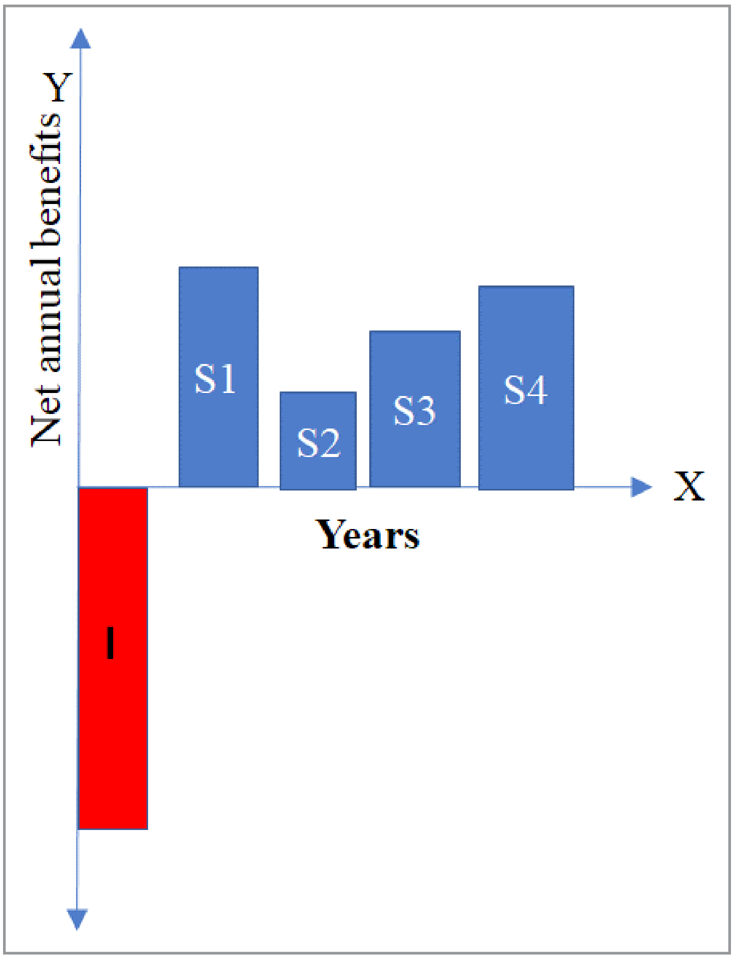


Figure 6-1: Internal rate of return

Equations like (33) above, can be solved by trial and error. For a project with a positive NPV, the summation on the right of (33), with ‘r’ instead of IRR, must be greater than the investment I. That means that ‘r’ must be less than IRR. It follows that the higher the value of IRR, greater the benefits accruing from the project.

6.3 EXERCISE

1. Focus on the payback period narrows down the scope to just the recovery of the initial investment. This may happen faster in one project, but it may still have a lower NPV than another alternative with a longer payback period. Construct hypothetical cases to prove that this is possible.
2. An energy-saving asset which requires an initial investment of 100000 SEK is expected to produce the following costs and benefits over the 3 years of its expected service life. Find the IRR for this investment.

Year of lifetime	Benefits	Costs
1	60000	10000
2	70000	10000
3	80000	10000

APPENDIX 1. GLOSSARY OF USEFUL TERMS[10]

Annual recurring costs	Costs which are incurred each year in an equal amount or in an amount that is increasing at a constant rate throughout the study period
Annual value	Past or future costs or benefits expressed as an equivalent uniform annual amount, taking into account the time value of money
Annuity (A)	Series of equal payments or receipts to be paid or received at the end of successive period of equal time
Base year	Year to which all future or past costs/benefits are converted when present value method is used
Baseline	Condition against which investment opportunities are measured/compared
Constant SEK	SEK values expressed in terms of today's value. They do not reflect cost escalation
Compound interest	Interest which is computed both on the original principal and the accrued interest
Cost-effective	When estimated benefits from say an energy conservation project are equal to or exceed the costs of the investment, when both are computed over the life-cycle of the project
Current SEK	SEK values which reflect cost escalation
Depreciation	Allocation of the original cost of a facility or equipment to the time periods in which it is used.
Differential cost	Simply the difference in the cost of two alternatives
Discount factor	A number which, when multiplied by costs and benefits occurring at different times, will adjust them for the time value of money, from the desired base period of time.
Discount rate	Rate used to relate present and future sums of money. Expressed as a percentage which reduces the value of future money in relation to the present. It reflects the fact that money spent or received in the future are worth less than money spent or received in the present.

Discounted payback period	The time required for the cumulative savings (net of future costs), from an investment, to pay back the investment cost, considering the time value of money
Discounting	Technique for converting costs and benefits occurring over time to equivalent amounts for a common point in time
Economic Life	The period over which an investment is considered to be the lowest cost alternative to satisfy a given need
Equivalent Uniform Annual Cost	The total of all costs for a given decision or alternative, expressed as a uniform annual equivalent over the years in the analysis life-cycle
Financing costs	Costs associated with financing capital investment in facilities – includes both interest and one-time loan and finance charges
Future Worth or Value (FV or F)	The future value of a present sum of money, when the time value is considered
Initial Capital Investment Costs	Costs associated with the initial planning, design and construction of a facility
Interest rate	Annual time value of money and same as the discount rate
Major replacement investment	Any significant future component replacement included in the capital budget which may be incurred during the study period to maintain the investment at a functional level (may be committed at the beginning itself)
Net Present Value (NPV) of investment costs	Present value of the initial investment cost plus the present value of major replacement investments minus the present value of salvage amount
Non-recurring cost	Cost not expected to be repeated at regular intervals
Operation and maintenance costs (O&M)	Costs incurred in the operation and maintenance of the facility itself
Opportunity Rate of Return	Effective annual rate of return an investor is able to obtain on an alternate investment opportunity. It may be used as the discount rate for the investment being analysed
Payback period	Length of time needed to recover the investment on a project
Present value (PV)	Present value is the concept that the sum of money invested today will earn interest and grow over time. An SEK today is worth more than an SEK you would get in the future, by the amount of interest it earns for you.

Present value factor	The number by which an investment cost or a benefit value realised is multiplied to yield its value in today's terms
Rate of return	The interest rate, which over a period of time, equates the benefits derived to the investment cost of the project
Salvage value	Residual value of assets after they have provided the intended service within, or at the end of the analysis life-cycle. Usually expressed as a negative cost in the analysis
Sensitivity analysis	Testing the outcome of an evaluation by altering one of more system parameters from the initially-assumed values
Single compound amount (SCA)	Discount factor used to convert a present sum of money to its future worth, given a discount rate
Single present worth (SPW)	Discount factor used to convert a future sum of money to its present worth, given a discount rate and period of time
Sunk cost	Cost which has already been made and should not be considered in measuring the economic performance of the investment alternative
Time horizon	Cut-off or the last year of the analysis

Time value of money	Difference between the value of an SEK today and its value at a future point in time if it is invested at a given rate of interest
Uniform Capital Recovery (UCR)	Discount factor used to convert a present sum of money to a series of equal annual sums of money, given a discount rate and a length of time
Uniform Compound Amount (UCA)	Discount factor used to convert a series of equal annual sums of money to their future worth, given a discount rate and a length of time
Uniform Present Worth (UPW)	Discount factor used to convert a series of equal annual sums of money to their present worth, given a discount rate and a length of time
Uniform Sinking Fund (USF)	Discount factor used to convert a future sum of money into a series of equal annual sums of money, given a discount rate and a length of time
Useful life	Period of time over which a building element may be expected to give service without major renewal. It may represent physical lifespan or time before technological obsolescence

APPENDIX 2. NUMERICAL EXERCISES

(Solve systematically. Use diagrams. State the equations clearly and the notations used. Monetary units are given in Swedish Kroner, USD or Euros. But that is immaterial!)

1. An amount equal to 1000 SEK is paid at the end of each of the next 6 years. What is the present worth of these payments if interest is computed annually at 7%?

2. A lender is willing to give 30,000 SEK on an 8% 20-year mortgage with annual payments made at the end of each year. What is the annual payment? How would this problem be solved if the payments were made monthly? What would be the difference in payments?

3. Mr Andersson has the following debts:
   a. 20 annual mortgage payments of 2400 SEK
   b. 12 bimonthly (once in two months) payments of 75 SEK on his car
   c. 6000 SEK in debt due in 2 years
   d. 700 SEK due today

   If Mr Andersson wishes to pay back his loans in equal annual amounts, at a discount rate of 12%, over 20 years, what would be the equal annual sums of money?

4. The government of a country is evaluating the possibility of initiating a mass inoculation programme for the immunization against a threatening disease. The disease must be analysed with the economy in mind. The government needs to determine if a 2 million Euro investment with an annual operating cost of 200000 Euros is feasible. The programme is expected to save 500000 Euros every year for the taxpayer. At a 5% discount rate, is the programme economically feasible? What happens when the discount rate is 6%, 7%, 9% and 10%?

5. The Defence department of a country is interested in establishing the life cycle cost of a low-pressure chamber to be used for testing. The initial cost is USD 240000. The chamber will be scheduled every year for 3600 hours, of which there will be some maintenance downtime. The expected mean time between failures is 300 hours and the mean time to repair is 60 hours. This means that there will be failure every 300 hours during the 3600-hour deployment and then 60 hours will be lost in repairs. The labour cost for repairs is USD 20 per hour. One man is needed to operate the chamber and he would charge 25 USD an hour for the entire duration of 3600 hours, even though he would be idle when the chamber is being repaired. Note that the repair-person is different from the operator! Power

required during the operation of the chamber is 18 kW at a cost of 5 USD cents per kWh (only for the hours during which the chamber will be operating). The chamber will be used for three years before it will be sold for a salvage value of USD 90000. Assuming a discount rate of 10%, estimate the life-cycle cost.

6. Maria borrowed SEK 40000 from her uncle for her college education. The loan is to be repaid at the end of 4 years at an interest rate of 8% compounded annually. How much does Maria owe to her uncle? If the interest rate is compounded continuously, how much more would she owe?

7. Bob has SEK 96000 in cash today. He knows that in 4 years he would need 64000 SEK to start a small environmental consulting firm. His savings account in the USA pays him 8% interest on his savings. He also wants to take a vacation with his family to the Caribbean now and stull be able to have money for starting up his firm after 4 years. How much can spend on his vacation in order to be able to do both things?

8. An asset in a manufactory has an initial cost of 200000 SEK. It has a lifetime of ten years and the salvage value at the end of it (essentially only for component resale) is 20000 SEK. Determine the annual depreciation on the basis of:
   a. Straight-line method
   b. Sum-of-years-digits method
   c. Units of production method, when estimated total annual production is 15000 units over the lifetime and the actual production annually is given as under:

Year	Production (units)
1	1400
2	1500
3	1600
4	1450
5	1550
6	1475
7	1525
8	1490
9	1510
10	1500

   d. Double-declining balance method

   Plot this graphically for all the four methods

9. What is discounted payback? Prove that the payback period for discounted payback is given by:

   n = log [1/ (1- (C*r/S)] / log (1+r)

   where n = payback period in years

   C = Initial investment cost

   S = Constant annual savings (recovery in other words)

   r=annual discount rate

   (note that r is less than 1, it is not in % here)

10. Given below are probability distributions for the mean time to repair at two different wage rates. The expected number of repairs per year is 3.5. (A side question to you: If a person is paid more on an hourly basis, would be work faster and better or slower and drag his work on, to earn more?) Analyse and determine what the optimal wage rate would be?

Wage rate per hour	Probability	Time to repair (midpoint of interval)
Wage rate of SEK 220 per hour	15%	1 hour
	50%	4 hours
	25%	7 hours
	10%	10 hours
Wage rate of SEK 240 per hour	20%	1 hour
	55%	4 hours
	15%	7 hours
	10%	10 hours

11. A contractor finds that his loaders provide 8 years of service before breakdowns seriously impede their performance. To find out what the service life must be, he has drawn out the following schedules. A loader costs 80000 USD and his discount rate is 10%.

Year	Trade-in value (residual value of asset), in USD	Maintenance and replacement expenses, in USD
1	60000	Warranty
2	50000	3000
3	40000	4000
4	35000	6000
5	30000	9000
6	25000	14000
7	20000	15000
8	15000	18000

By determining the annual average capital costs and the annual average maintenance expenses for each year, plot the respective curves over the service lifetime of 8 years, and determine the optimum service life.

12. An office building owner is considering installing a 150000 SEK fluorescent dimming system which will automatically maintain a constant light level on the desk surfaces as sunlight entering through windows varies the building's ambient light level. If the dimming system is installed, it is expected to save 45000 SEK annually in electrical costs based on today's prices. Electricity prices are expected to escalate at an annual rate of 7% over the next 15 years. Determine the Internal Rate of Return for the project.

13. Compare two HVAC systems, given the following information. The planning horizon for both is 30 years. The firm's discount rate is 10%.

	HVAC 1	HVAC 2
Initial cost (million SEK)	1.2	0.9
Annual O and M expenses (SEK)	80000	100000
Salvage (SEK)	0	0

Property tax rate payable every year of the lifetime is 80 SEK per 1000 SEK of assessed valuation. Assessed valuation is 40% of the initial cost. The income tax rate of the firm is 40%. Straight-line depreciation is used and there is a tax benefit on the depreciation every year. Which of the two HVACs will you invest in?

14. A firm plans to acquire equipment costing SEK 20 million. Estimated salvage value after 5 years is 1 million SEK. It can borrow SEK 20 million at 10% for 5 years. Straight-line depreciation is used. The firm's marginal tax rate is 40% and there is a tax deduction on the depreciation every year. A lease alternative for 5 years requires prepaid annual rentals of SEK 5 million. The lessee would bear the cost of insurance, maintenance and property taxes. There is tax deduction on the annual rent payments. What must the firm do? Buy or lease?

15. A wastewater treatment plant (WWTP) is faced with a decision on the purchase of a piece of equipment with an expected service life of 6 years or with an expected service life of 4 years. The former (a) will cost SEK 400000 and will have annual

operating and maintenance expenses of SEK 30000, while the latter (b) will cost SEK 300000 and have annual operating and maintenance expenses of SEK 25000. Both will be worth just scrap and thereby have a very low salvage value at the end of their respective lifetimes. Which must the WWTP opt for, using a 10% discount rate? Use the chain method to solve this problem.

16. A homeowner living in Gothenburg wants to heat 60% of his hot water needs for his family of four by solar energy. The remaining 40% hot water requirements will be heated by a back-up electric heater. The following information is known to her.
    a. Hot water requirement: 250 litres per day per family of four
    b. Hot water temperature: 52°C
    c. Cold water temperature: 13°C
    d. Present electricity cost: 0.6 SEK/kWh
    e. Available solar energy: 54 kWh per square foot per year
    f. Installed cost of solar hot water system: SEK 600 per square foot

    Life of the equipment is 15 years. The appropriate interest rate for the project is 10% with electricity prices expected to increase at 9% per year (note that this is an extreme case scenario!)

    Should the project be implemented if the homeowner is to make his decision based on the net present worth saving that can be realised? What will happen if the government provides some subsidies for investments in such projects?

17. A decision must be made whether to install a heat recovery system in a student dining hall in the university. The dining hall has two heating zones : a student dining area and a large kitchen. A 30,000 cubic feet per minute electric resistance heater supplies outside air to both the zones. This heated air is supplied for 12 hours daily for 200 days of the year (approximately 7 months in autumn and winter). During the same period of time, a total of 27,000 cubic feet per minute of air at 26°C through four kitchen exhaust fans having capacities of 8000, 8000, 7000 and 4000 cubic feet per minute respectively. What is the economic feasibility of installing a coil heat transfer loop system that would transfer heat normally exhausted by the four kitchen fans to fresh air intake of the heating and ventilation unit via a pumped solution of glycol? The coil in the HVAC unit will transfer the heat from the glycol to the incoming cold air. Less electrical energy would be needed thereby to raise the temperature of this air to the desired 21°C.

- Initial cost: SEK 280000 for the system and SEK 20000 for the engineering design fee
- Energy cost: Based on an outside average temperature of 5°C during the heating season, it was estimated that the annual savings in electrical energy would be 250000 kWh. The local electricity cost at the time of analysing is 0.7 SEK/kWh. The 1.5 HP pump needed for the system would consume an estimated 2685 kWh per year.
- Maintenance: Labour at 80 SEK per hour (at the time of analysis) for 40 hours per year, undertaken by students themselves
- Taxes: Not relevant for this case
- Lifetime: 20 years
- Salvage value: 0 SEK
- Inflation rate: 8% for both electricity and for labour.

APPENDIX 3. SAMPLE EXAMINATION PAPER – TEST YOURSELF

TEST YOURSELF – TIME YOURSELF WHEN YOU ATTEMPT THESE QUESTIONS (2 HOURS MAXIMUM)

Q. No.		Max. points
1	Define the following common LCC terms. **Support with a diagram or equation wherever applicable:** a) Optimum service life of an equipment in a factory b) Uniform sinking fund factor c) Depreciation of an equipment in a manufacturing unit d) Annuity	6
2	a) What is uniform present worth in general? Explain with a neat diagram. b) Derive the formula for calculating it for discrete cash-flows when annual compounding is used. c) Using this formula, derive the one you would use when continuous compounding is adopted. **Assume suitable notations after defining what they mean clearly.**	6
3	Mr. Andersson wishes to provide your university with enough funds to grant scholarship awards every year, each amounting to **150000 SEK,** for a period of 20 years, to support studies in Sustainable Development. How much money must he donate now in order to accomplish this, if your university can invest the money in a bank at an interest of 0.8% per annum? How many such scholarship awards can be endowed by donating **12 million SEK** to your university today? **Show all the steps clearly.**	3

4.

a) An industrial manufacturer wants to investigate the economics of investing in new energy-saving machinery for its production units in Sweden. The initial cost of the machinery will be 200000 SEK, and it will have an estimated life of 18 years. If the machinery is purchased, it is estimated that there will be operating cost savings (owing to lower energy use) for the first ten years equal to 25000 SEK per year; for the next five equal to 12000 SEK per year and for the last five equal to 6200 SEK per year. The expected salvage value at the end of the lifetime is 20000 SEK. The discount rate is 10%. Is it advisable to purchase the piece of machinery? **Show all the steps and use diagrams to illustrate and support the calculations.** 8

b) Why do the annual operating cost reductions, taper down over the lifetime of the machinery?

c) Would you say that such decisions are easier to make when the energy used comes predominantly from fossil sources? Discuss in brief.

5. Select the right answer from the four alternatives given. **Show the calculations clearly** 8

1. The initial cost of an asset in a waste-handling unit is 150000 SEK. It has a residual value at the end of its lifetime of 15 years of 10000 SEK. If a straight-line depreciation method is used, what is the approximate annual depreciation?
   a) 10000
   b) 9100
   c) 9425
   d) 9330
2. In the above case, if a sum-of-years-digits method is used to depreciate, what is the depreciation amount in the 7th year of the asset's lifetime?
   a) 14500
   b) 10500
   c) 9500
   d) 11225
3. The probability that 'n' repairs will have to be done in a given year is directly proportional to 'n'. The maximum value for 'n' however is 7. Find the average number of repairs one can assume for the year.
   a) 3.8
   b) 5
   c) 4.3
   d) 4.5
4. If the nominal interest rate is 6% per year, what is the effective interest rate when continuous compounding is used?
   a) 6.18
   b) 6.28
   c) 6.08
   d) 6.24

6. a) What is the difference between **payback**, **discounted payback** and **true payback**? Describe in brief. 2

b) Prove that the true payback period can be expressed as: 4

n = log [1+ (C/S)* (1- (1/k))] / log k

where n = payback period in years

C = Initial investment cost

S = Constant annual savings (recovery in other words)

k= (1+i)/(1+r); where i=annual inflation rate and r=annual discount rate

(note that i & r are less than 1, they are not expressed in % here)

7. What is internal rate of return (IRR)? Express it with the help of an equation. Would you go ahead with a project which has a higher IRR than the discount rate considered? 3

Good luck!

APPENDIX 4. ANSWERS TO SELECTED EXERCISES FROM APPENDIX 2

1. 4762 SEK
2. 139703 SEK, 145473 SEK, 5770 SEK greater
3. 3242 SEK
4. Yes. Feasible at all given discount rates
5. 0.529 million USD
6. 54400 SEK, 680 SEK more
7. 48942 SEK
8. 10. 240 SEK/hour
9. 11. 7 years
10. 38%
11. HVAC-1
12. Lease
13. Option (b)
14. The houseowner should not invest.
15. Present worth is 28425 SEK

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He has studied/worked in India, Singapore, Germany, Norway and Sweden, and freelances for a few magazines, newspapers and websites around the world. He can be contacted at venkatesh.govindarajan@kau.se / venkatesh_cg@yahoo.com. His fields of interest include the pure and applied sciences (engineering), the environment, sustainable development, spirituality, cricket and sports in general.

ENDNOTES

1 Venkatesh, G and Arun Kansal (2018). Industrial ecology tools as decision-making aids for phosphorus recovery – A methodology paper. Vatten, 74(3):

2 Environmental LCA – A primer

3 You may refer to ABC of Sustainable Development, a 2015 BookBoon publication by this author

4 Brown, JR. and Yanuck, RR (1985). Introduction to Life-Cycle Costing. Published by Prentice Hall Inc., USA.

5 Capra, F. and Luisi, P.L. (2014). The Systems View of Life – A unifying vision. Cambridge University Press, UK.

6 Modified version of the original from Brown, JR. and Yanuck, RR (1985). Introduction to Life-Cycle Costing. Published by Prentice Hall Inc., USA.

7 $(1+1/n)^n = 1 + nC_1(1/n) + nC_2(1/n^2) + nC_3(1/n^3) + \ldots\ldots nC_n (1/n^n)$

$= 1 + n!/(n-1)!*n + n!/2!*(n-2)!*n^2 + n!/3!*(n-3)!*n^3 + \ldots\ldots 0$

$= 1 + n/n + n(n-1)/2n^2 + n(n-1)(n-2)/6*n^3 + \ldots\ldots 0$

$= 1 + 1 + \{1- (1/n)\}*0.5 + \{1- (1/n)\} \{1- (2/n)\}*0.167 + \ldots\ldots 0$

$= 1 + 1 + 0.5 + 0.167 + 0.04 + \ldots\ldots 0$

tends to 2.71828 or e

8 Sum of a geometric progression with 'n' terms, with first term 'S' and multiplier equal to 'm', is given as: $S*(1-m^n) / (1-m)$

9 Figure sourced from Venkatesh, G (2017). Environmental Life-Cycle Analysis – A primer. BookBoon, Copenhagen, Denmark.

10 Sourced and adapted from Brown, JR. and Yanuck, RR (1985). Introduction to Life-Cycle Costing. Published by Prentice Hall Inc., USA.

11 *https://www.linkedin.com/in/venkatesh-g-27a0683/*
https://www.researchgate.net/profile/G_Venkatesh
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