Life cycle cost
Total ownership cost

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Introduction

Some definitions

Life cycle: All development stages of an item of equipment or function, from when the study commences up to and including disposal

Life cycle cost (LCC): Discounted cumulative total of all costs incurred by a specified function or item of equipment over its life cycle

Life cycle costing: Process of economic analysis to assess the life cycle cost of a specified function or item of equipment over its life cycle or a portion thereof

Life cycle cost is sometimes called "Total ownership cost"

ISO 15663 and IEC 60300-3-3

Objectives of LCC analysis

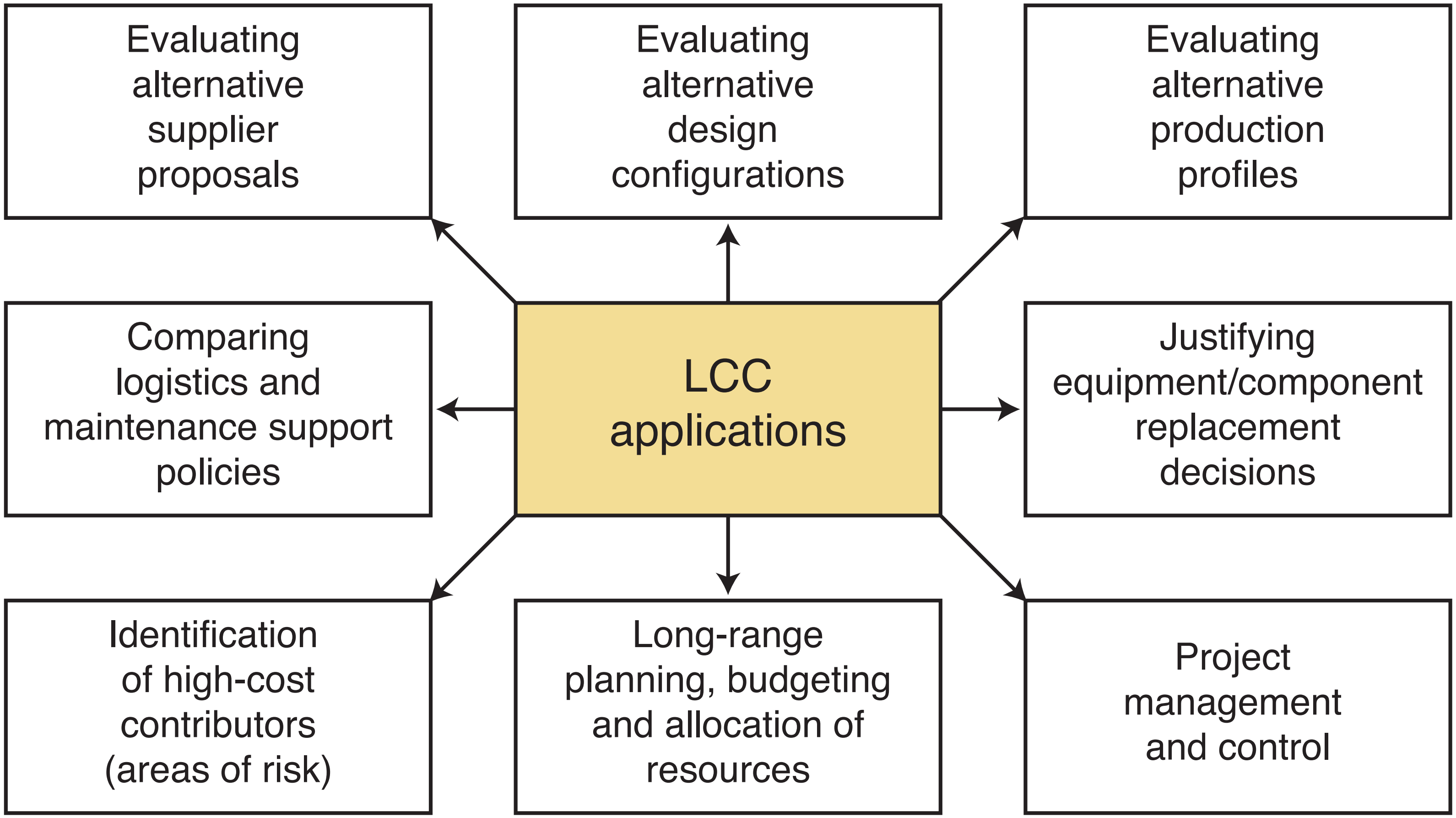
To provide information for decision-making related to:

- Feasibility study
- Design
- Purchasing
- Operation
- Disposal planning

Note that an LCC focuses on costs and not profits or benefits. The LCC is sometimes supplemented by a life cycle profit (LCP) analysis.

This presentation is partly based on a joint work with Dr. Yoshio Kawauchi, Toyo Engn., Japan

LCC applications



Adapted from Blanchard and Fabrychy (1998)

LCC perspectives

- Engineering – show non-redundancy costs
- Purchasing – buy right rather than buy cheap
- Process engineering – show operating costs
- Maintenance – calculate maintenance costs
- Reliability engineering – define improvements
- Management – operate for lowest long term cost of ownership rather than cheapest initial cost

Adapted from Paul Barringer (2007)

The initial cost is not the last cost

Do never be tempted by the attraction of an initially cheap system! There are usually more costs:

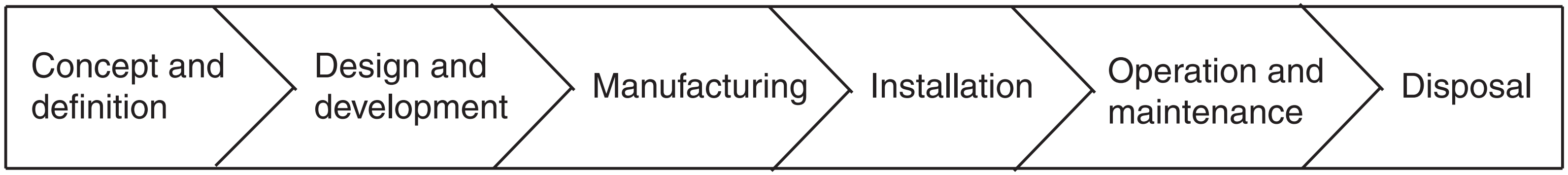
- Cost of low productivity
- Cost of low reliability
- Cost of lost production
- High logistics cost
- High maintenance cost
- High operating cost

Adapted from Paul Barringer (2007)

Some LCC standards

- IEC 60300-3-3, Dependability management – Application guide – Life cycle costing (2nd ed. 2004)
- ISO 15663 Petroleum and natural gas industries – Life cycle costing
  - Methodology
  - Guidance on application of methodology and calculation methods
  - Implementation guidelines
- SAE-ARP-4293 Life cycle cost – Techniques and applications

Life cycle phases



The various standards and guidelines are defining slightly different life cycle phases.

"From cradle to grave"

Interest rate

An investment of PV (present value) will increase to $\mathrm{FV}(1)$ (with interest) after one year. The *interest rate* r in year no. 1 is then:

$$r = \frac{\mathrm{FV}(1) - \mathrm{PV}}{\mathrm{PV}}$$

such that

$$\mathrm{FV}(1) = \mathrm{PV} \cdot (1 + r)$$

After 2 years the future value, with constant interest rate, is

$$\mathrm{FV}(2) = (\mathrm{PV} \cdot (1 + r)) \cdot (1 + r) = \mathrm{PV} \cdot (1 + r)^2$$

and after t years the future value $\mathrm{FV}(t)$ is

$$\mathrm{FV}(t) = \mathrm{PV} \cdot (1 + r)^t$$

Note that $\mathrm{PV} = \mathrm{FV}(0)$

Discount rate

Discounting is a means of comparing costs and benefits that occur at different points of time.

If we get the value $\mathrm{FV}(1)$ after one year and this corresponds to the present value PV, then the annual *discount rate* is

$$d = \frac{\mathrm{FV}(1) - \mathrm{PV}}{\mathrm{FV}(1)}$$

The present value, PV, of an investment $\mathrm{FV}(1)$ in year 1 is therefore:

$$\mathrm{PV} = \mathrm{FV}(1) \cdot (1 - d)$$

and the present value PV, of an investment $\mathrm{FV}(t)$ in year t is

$$\mathrm{PV} = \mathrm{FV}(t) \cdot (1 - d)^t$$

Discounting

We note that the discount rate is different from the interest rate, but that they have the following relationship:

$$d = \frac{r}{1+r} \qquad r = \frac{d}{1-d}$$

If the interest rate is $r = 0.05$ the discount rate is $d \approx 0.0476$. In many cases, we do not distinguish between the two rates and use the same value for both.

The discount rate is "the rate of interest reflecting the investor's time value of money." Basically, it is the interest rate that would make an investor indifferent as to whether he received a payment now or a greater payment some time in the future.

Limit value

Assume now that interest is paid and added, not once a year, but n times a year. Since the interest rate is constant, the value after the first period is (the interest rate is given per year):

$$\mathrm{FV}(1) = \mathrm{PV} \cdot \left(1 + \frac{r}{n}\right)^n$$

After t years this becomes

$$\mathrm{FV}(t) = \mathrm{PV} \cdot \left(1 + \frac{r}{n}\right)^{nt}$$

If we let $n \to \infty$

$$\mathrm{FV}(t) = \lim_{n \to \infty} \mathrm{PV} \cdot \left(1 + \frac{r}{n}\right)^{nt} = \mathrm{PV} \cdot e^{rt}$$

Note that this approach will not give exactly the same answer as the previous approach since we get "interest of interest"

Limit values – Example

Assume that we invest 100 Euros at time $t = 0$ with interest rate 5%. The value after one year is then

$$\mathrm{FV}(1) = 100 \cdot (1 + 0.05) = 105$$

If we split the interval into $n = 6$ and hence add interest every second month, the value after one year is

$$\mathrm{FV}(1) = 100 \cdot \left(1 + \frac{0.05}{6}\right)^6 \approx 105.11$$

If we approximate by using the exponential function we get

$$\mathrm{FV}(1) = 100 \cdot e^{0.05} \approx 105.13$$

Approximation

This means that we approximately have

$$\text{PV} = \text{FV}(t) \cdot e^{-rt}$$

or, more correctly: the interest rate r should be replaced by the discount rate d.

On a previous slide we found that $\text{PV} = \text{FV}(t) \cdot (1-r)^t$. Since we know that the exponential function can be written as a Maclaurin series, $e^{-r} = \sum_{k=0}^{\infty} \frac{(-r)^k}{k!}$ and since r is a small number, we have that $e^{-r} \approx 1 - r$, and we can therefore deduce the above result by using approximation to the exponential function.

Instantaneous interest rate

Let $i(t)$ be the accumulated interest of PV at time t. We then have that $\mathrm{FV}(t) = \mathrm{PV} + i(t)$. The rate of change of the accumulated interest at time t (if $\mathrm{FV}(t)$ is differentiable) is

$$\lim_{\Delta t \to 0} \frac{\mathrm{FV}(t + \Delta t) - \mathrm{FV}(t)}{\Delta t} = \frac{d\mathrm{FV}(t)}{dt}$$

The annual interest rate in the year $(t, t+1)$ is (assume now that $(\Delta t = 1)$:

$$r_1(t) = \frac{1}{\mathrm{FV}(t)} \cdot \frac{\mathrm{FV}(t + \Delta t) - \mathrm{FV}(t)}{\Delta t}$$

By letting $\Delta t \to 0$, we get the *instantaneous interest rate*

$$r(t) = \frac{1}{\mathrm{FV(t)}} \cdot \frac{d\mathrm{FV}(t)}{dt}$$

Future value

If we "know" the interest rate as a function of time, we may now find $\mathrm{FV}(t)$ from the differential equation

$$\mathrm{FV}'(t) = r(t) \cdot \mathrm{FV}(t) \quad \Rightarrow \quad \frac{\mathrm{FV}'(t)}{\mathrm{FV}(t)} = \frac{d}{dt} \ln \mathrm{FV}(t) = r(t)$$

Since we know $\mathrm{FV}(0) = \mathrm{PV}$, the solution will be

$$\mathrm{FV}(t) = \mathrm{PV} \cdot e^{\int_0^t r(\tau)\, d\tau}$$

and the present value of an investment/loss at time t is

$$\mathrm{PV} = \mathrm{FV}(t) \cdot e^{-\int_0^t r(\tau)\, d\tau}$$

(In the last expression we should use the discount rate instead of the interest rate)

Criticism of the present value approach

The approach of discounting future costs has been criticized when used for environmental impacts and accidents with a very high consequence and a low frequency. An accident that occurs 100 years from now and implies a cost of, e.g., 100 million Euros, will – with a discount rate of 5% – have a present value of approximately 592 000 Euros. The situation is much worse for extreme accidents with a very, very low frequency.

> If we use present value arguments to decide whether or not to install equipment to prevent major accidents, the world will not be a very safe place to live!

Financing horizon

Let τ denote the financing horizon of a prospect. For an offshore oil and gas installation the financing horizon is often around 20 years. For infrastructure facilities, the financing horizon lies typically at the end of the useful service life or design life – in the order of 50–100 years.

Niels Lind (2007) has proposed an alternative discounting scheme to avoid the present value problem for accidents with a low frequency (see previous slide). He proposes to let the discount/interest rate $r(t)$ be equal to 0 after the financing horizon. This mean that an accident that occur at time t will have the same present value for all $t \geq \tau$.

In some guidelines the financial horizon is called "study period"

Equivalence principle

"All persons, now and at any time in the future, are equally worthy of risk reduction" (Rackwitz, 2003)

(Comment to the previous slide)

Accidents modeled by a Poisson process

Consider a specific type of accidents. We assume that the occurrence of accidents may be modeled as a homogeneous Poisson process with rate λ. The number $N(t)$ of accidents in a time interval of length t then has the probability distribution

$$\Pr(N(t) = n) = \frac{(\lambda t)^n}{n!}\, e^{-\lambda t} \qquad \text{for } \; n = 0, 1, 2, \ldots$$

The mean number of accidents in an interval of length t is $E(N(t)) = \lambda t$. The total cost related to an accident is denoted C. The mean accident cost in year no. i is therefore $(t = 1)$, $C\lambda$, and the present value of this accident is $\text{PV}_i = C\lambda(1 - d)^i$, where d is the discount rate.

Accidents modeled by a Poisson process

Assume that the total life of the system is n years. The present value of the total mean accident cost is then

$$\mathrm{PV} = \sum_{i=1}^{n} \mathrm{PV}_i = C\lambda \sum_{i=1}^{n} (1-d)^i = C\lambda\, \frac{(1-d)-(1-d)^{n+1}}{d}$$

Assume now that the financial horizon of the system is $m < n$ years. By following Niels Lind's approach, the present value of the total mean accident cost is

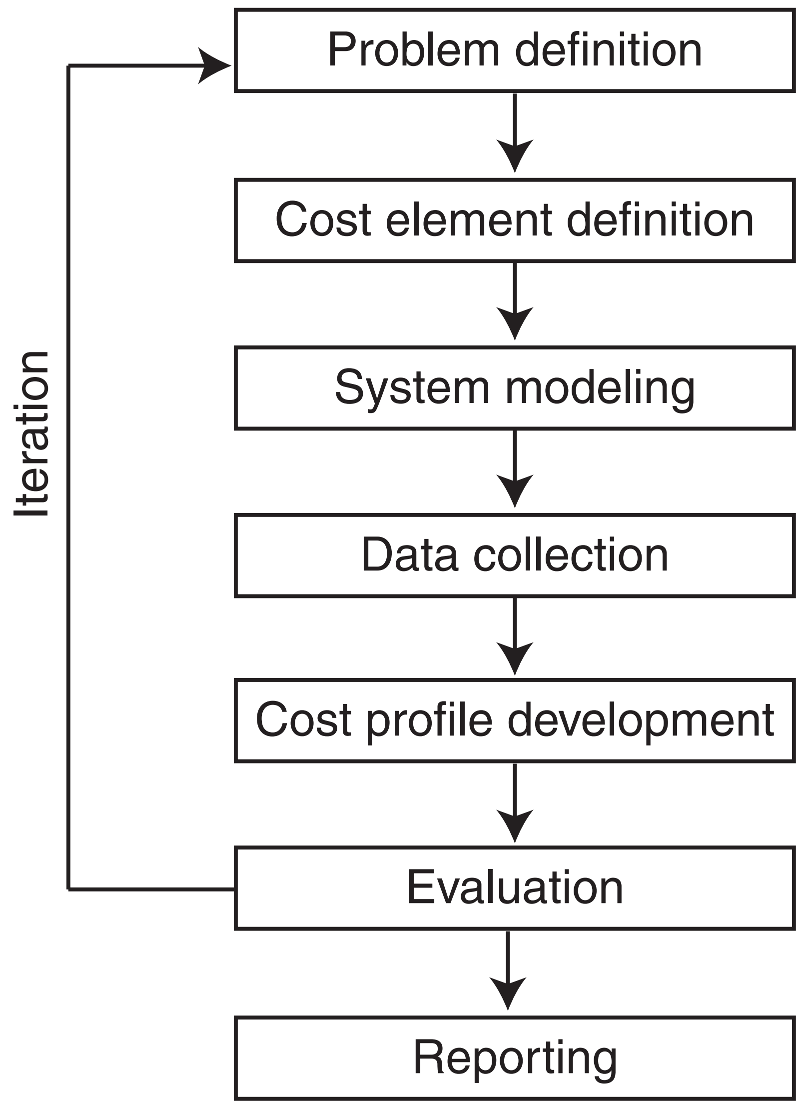
$$\widetilde{\mathrm{PV}} = \sum_{i=1}^{n} \mathrm{PV}_i = C\lambda\, \frac{(1-d)-(1-d)^{m+1}}{d} + (n-m)(1-d)^m \cdot C\lambda$$

With $n = 40$, $m = 20$ and $d = 5\%$, the "difference" between the two approaches is

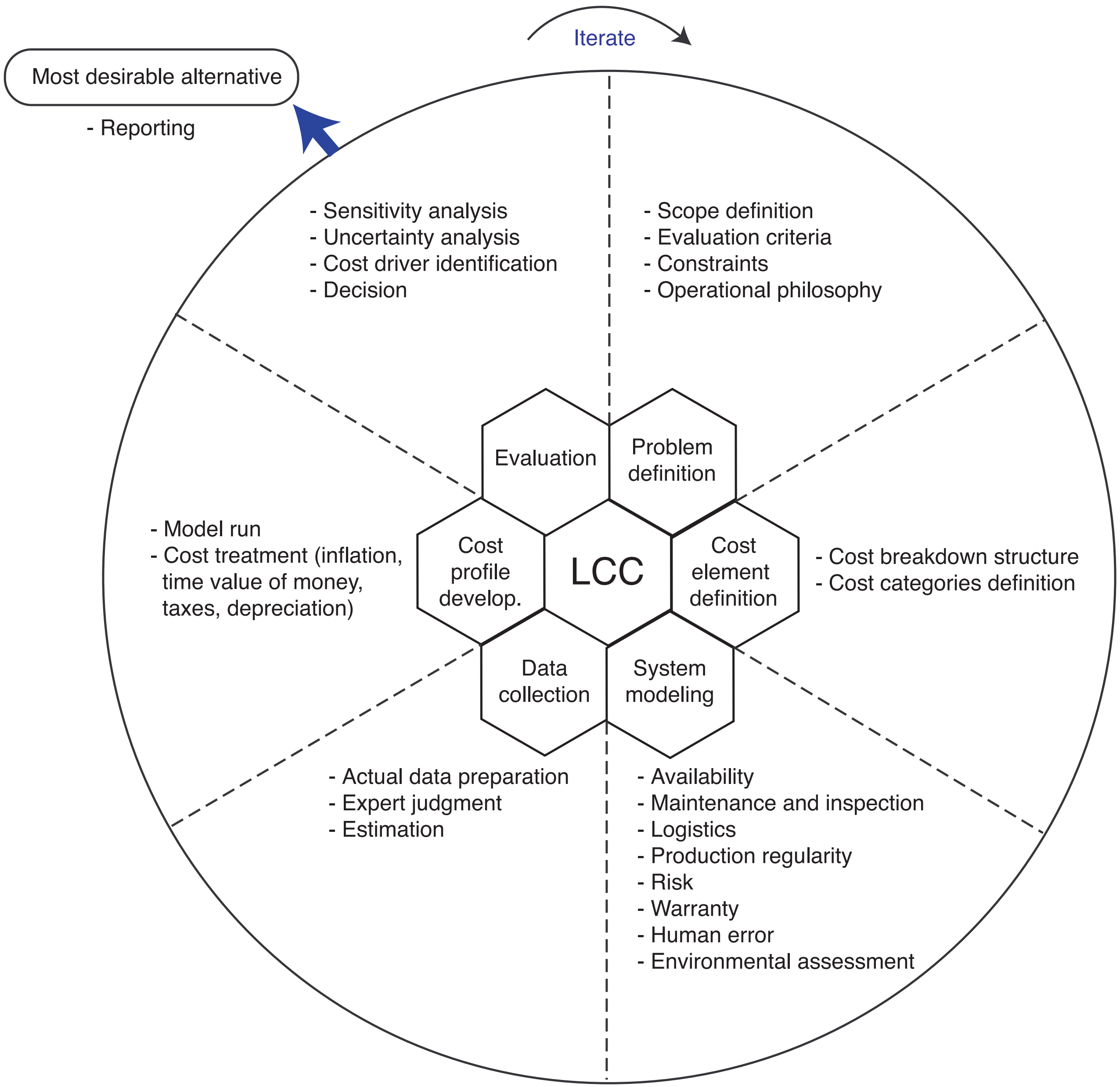
$$\widetilde{\mathrm{PV}}/\mathrm{PV} \approx 1.17$$

LCC work process

The basic process of LCC analysis



LCC process illustration



1. Problem definition

- Define the objectives of the analysis
- Define requirements and application limits of the function/equipment
- Describe the system life cycle and identify the activities in each phase
- Define the scope of the analysis
- Identify constraints (project, technical, budgetary)
- Establish decision criteria
- Identify and screen potential options
- Define costs to be included in the analysis

2. Cost element definition

- Define cost categories to be considered
- Establish cost breakdown structure (CBS), i.e., a hierarchical structure that includes all relevant categories of cost. All life cycle activities must be covered.

See example on the next slide.

Several spreadsheet models are available that include a CBS required formulas. Some commercial programs are listed on http://www.ntnu.no/ross/info/software.php

Cost breakdown structure (CBS) (Example)

1. Life acquisition cost (LAC)
    (a) Equipment purchase cost
    (b) Installation cost
    (c) Commissioning cost
    (d) Design and administration cost
2. Life ownership cost (LOC)
    (a) Man-hour cost
        i. Corrective maintenance
        ii. Preventive maintenance
        iii. Servicing
    (b) Spare part consumption cost
        i. Corrective maintenance
        ii. Preventive maintenance
        iii. Servicing
    (c) Logistic support cost
    (d) Energy consumption cost
    (e) Insurance cost
3. Life loss cost (LLC)
    (a) Cost of deferred production
    (b) Hazard cost (Liability cost)
    (c) Warranty cost
    (d) Loss of image and prestige cost

Alternative CBS

Acquisition costs	Operation and support cost	Phase-out
Research and development Management Engineering Design and prototyping Engineering design Fabrication Testing and evaluation Production Manufacturing Plant facilities and overheads Marketing and distribution	Operations Facilities Operators Consumables (energy, etc) Unavailable time, downtime Support Repair resources Supply resources Repairables Expendables Tools, test and support eq. Failure costs Training Technical data	Disposal costs Residual value

Adapted from Ebeling (1997)

Alternative cost breakdown structure

Another way of classifying costs:

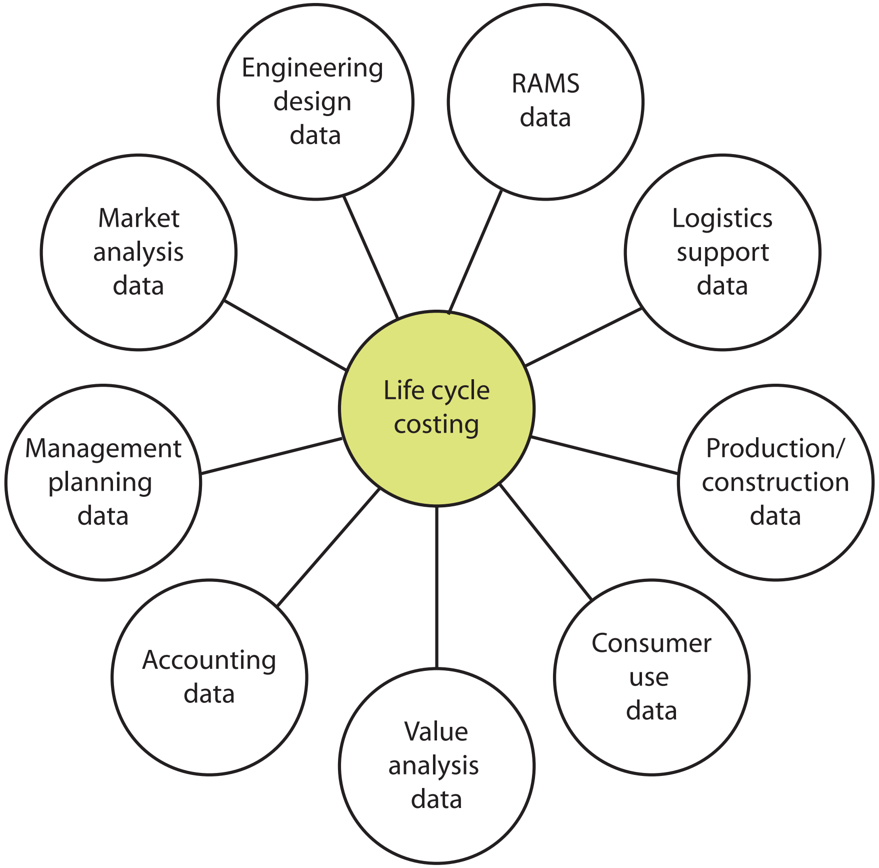
CAPEX - Capital expenditure (= initial investment)
OPEX - Operating expenditure
RAMEX - RAM expeniture
RISKEX - Risk expenditure
ENVEX - Environmental expenditure

3. System modeling

- Reliability and availability modeling
- Maintenance modeling
- Logistics modeling
- Risk and vulnerability modeling
- Human reliability/interaction modeling
- Environmental impact modeling

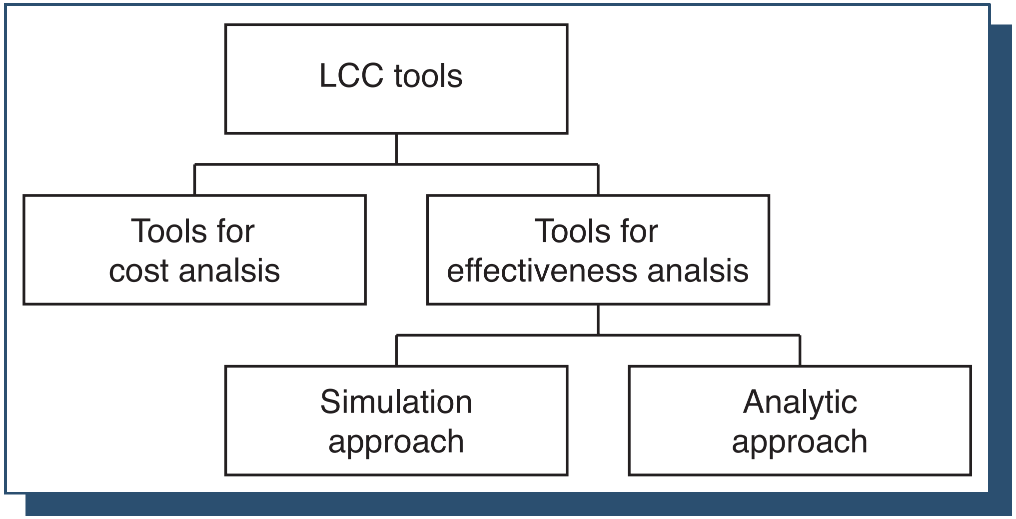
4. Data collection

- Identify data input requirements in the models (step 3)
- Compile data incl. expert judgments
- Prepare a data dossier (include uncertainty assessment)



From Blanchard and Fabrychy (1998)

- Model run



- Cost treatment
  - Inflation
  - Time value of money (discounting)
  - Taxes
  - Depreciation

6. Evaluation

- Perform sensitivity analyses (input data, model, and completeness uncertainties)
- Conduct uncertainty analysis
- Identify high-cost contributors and establish cause-effect relationships
- Construct a Pareto diagram and identify priorities for problem resolution
- Select the preferred option

Report contents

1. Executive summary
2. Purpose and scope
3. LCC model description
4. LCC model analysis
5. Discussion
6. Conclusions and recommendations