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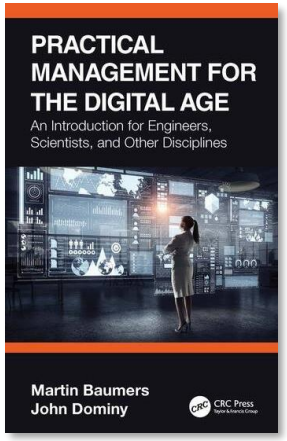
Department of Mechanical, Materials and Manufacturing Engineering

Life cycle thinking

What we will talk about today:

Life cycle thinking

- *What is life cycle thinking?*
- *Profile evaluation*
- *The cash flow shape technique*
- *Whole-life cost*
- *Cost-benefit analysis*
- *Sustainability and life cycle assessment*



Lecture builds on Chapter 6 in Baumers and Dominy (2021) – Please read!

Definition and background

"A life cycle is a series of distinct stages through which an object, such as a business, a product or a service offering, passes during its existence."

- Products, services, projects, and even businesses exist in time
- Decision makers must weigh positive and negative effects occurring across the series of stages that make up the life cycle
- An optimal decision maximizes the positive impacts occurring throughout the life cycle while minimizing the negative impacts

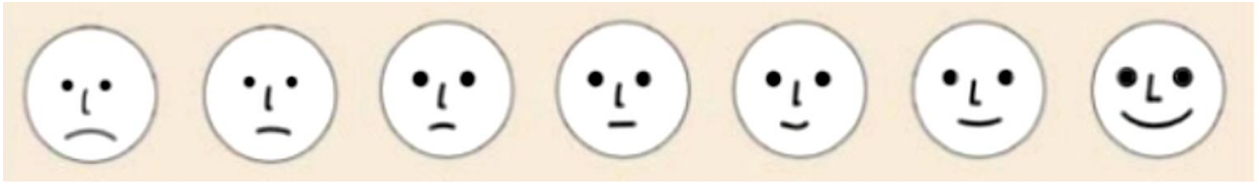
We could do a very simple graphical analysis called

“Profile Evaluation”

→ Splitting the project up into different factors, for example:

- Marketing and sales
- Technology aspects
- Production / operations
- Finance

→ Elements are assessed separately for suitability, using discrete categories



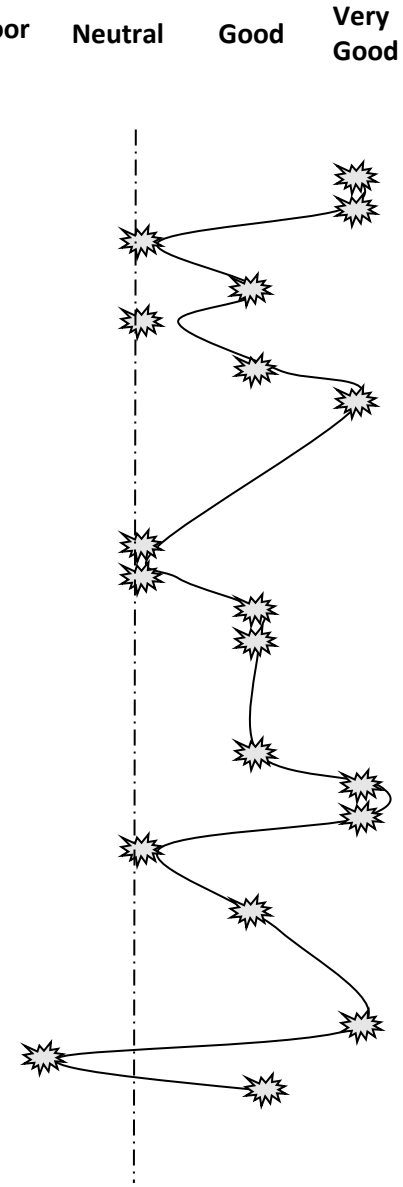
(“Likert scales”)

- **Marketing and Selling**
  - Compatible with current resource
  - Continuous improvement
  - Effect on competitors
  - Complements current products
  - Competitive price
  - Potential for licensing
  - Public acceptance

- **Technical**
  - Patent potential
  - Competing patents
  - Perceived technology
  - Availability of resource

- **Production**
  - Within existing capability
  - Supply chain established
  - Work force acceptability
  - No conflict with current products
  - Cost effect on product range

- **Financial**
  - Acceptable project investment
  - Acceptable break even time
  - Finance in place



What's wrong with this analysis

- It's superficial
- No numerical evaluation, just visual impression
- No indication of relative importance of individual factors
- However, it does at least tell us that, in this case, most of the factors are to the right of neutral, i.e. better than average

→ Really just a visual tool at this point…

Profile evaluation can be taken further

So what do we do?

- Introduce numerical ratings (e.g. based on discrete numbers, i.e. 1,2,3,….)
- Add weighting factors that indicate the relative importance of the points (also in discrete numbers)
- Can also add a time horizon to see when the impact occurs…

Makes Profile evaluation much more useful as a decision tool as different aspects can now be weighed against each other

Introducing rating factors for profile evaluation

- Rating factors ("weightings") reflect the **relative** importance of an aspect, have no meaning in isolation
- Can only be positive
- Discrete numerical weightings: 1 (low importance), 2 (intermediate importance) and 3 (high importance)
- Again, we use a range of discrete categories from -2 (very poor) to +2 (very good)

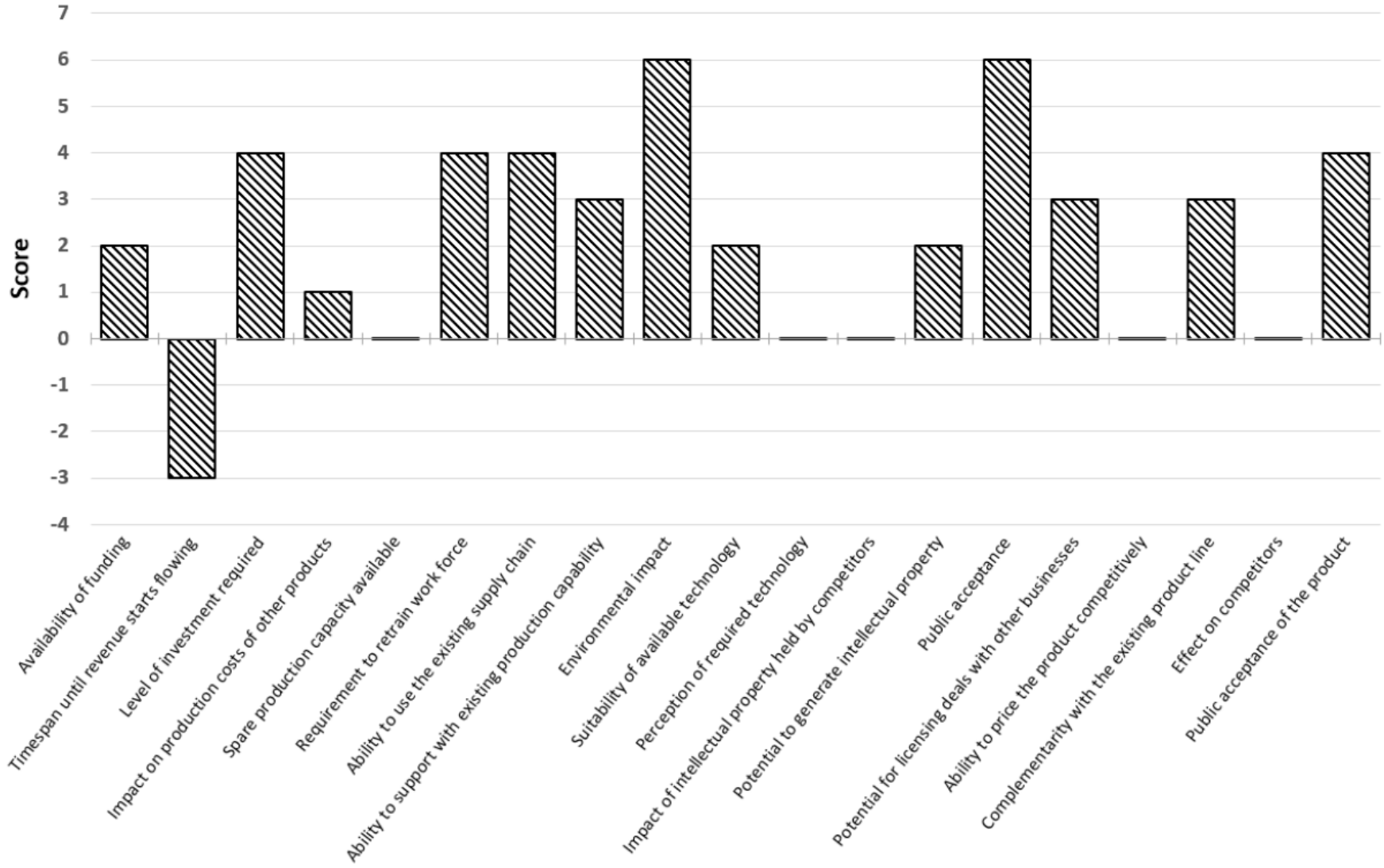
Finance

Production

Technology

Marketing / Sales

Heading	Characteristic	Time horizon	Quality rating	Numerical rating	Weighting factor	Score
Financial aspects	Availability of funding	Immediate	Good	1	2	2
	Timespan until revenue starts flowing	Short term	Poor	-1	3	-3
	Level of investment required	Immediate	Very good	2	2	4
Production aspects	Impact on production costs of other products	Immediate	Good	1	1	1
	Spare production capacity available	Immediate	Neutral	0	2	0
	Requirement to retrain work force	Immediate	Very good	2	2	4
	Ability to use the existing suppliers	Immediate	Very good	2	2	4
	Ability to support with existing production capability	Immediate	Good	1	3	3
	Environmental impact	Long term	Very good	2	3	6
Technological aspects	Suitability of available technology	Immediate	Good	1	2	2
	Perception of required technology	Short term	Neutral	0	1	0
	Impact of intellectual property held by competitors	Short term	Neutral	0	1	0
	Potential to generate intellectual property	Short term	Good	1	2	2
Marketing and sales aspects	Public acceptance	Long term	Very good	2	3	6
	Potential for licensing deals with other businesses	Long term	Good	1	3	3
	Ability to price the product competitively	Short term	Neutral	0	3	0
	Complementarity with the existing product line	Short term	Good	1	3	3
	Effect on competitors	Long term	Neutral	0	2	0
	Public acceptance of the product	Long term	Very good	2	2	4


Score
7
6
5
4
3
2
1
0
-1
-2
-3
-4
Availability of funding
Timespan until revenue starts flowing
Level of investment required
Impact on production costs of other products
Spare production capacity available
Requirement to retrain work force
Ability to use the existing supply chain
Ability to support with existing production capability
Environmental impact
Suitability of available technology
Perception of required technology
Impact of intellectual property held by competitors
Potential to generate intellectual property
Public acceptance
Potential for licensing deals with other businesses
Ability to price the product competitively
Complementarity with the existing product line
Effect on competitors
Public acceptance of the product

How can a decision be made with Profile evaluation?

- Need to sum up the scores
- Doing this for different projects will allow comparison

Generally we have to do this for different projects to make a decision

Profile evaluation is a simple tool that can easily be overcomplicated. In particular, it doesn't clearly give information on the benefits that we can obtain from choosing a project.

So, what does an investor want from a project? This can be assessed using the cash-flow shape technique

Generally, investors seek a financial return on investment:

- Needs to be adequate to attract the investor's interest
- Break-even as soon as possible

Note that the return might not be cash – consider also, for example, sports sponsorship, etc.

→ This is broadly applicable because many commercial activities can be viewed as "private ventures"

Product Lifecyle Management (PLM)

In turn, the idea of a generalizable product life cycle has led to its own distinct field in management known as product life cycle management (PLM)

- Focuses on strategies supporting a product or service as it progresses through its life cycle

- PLM can be defined as:

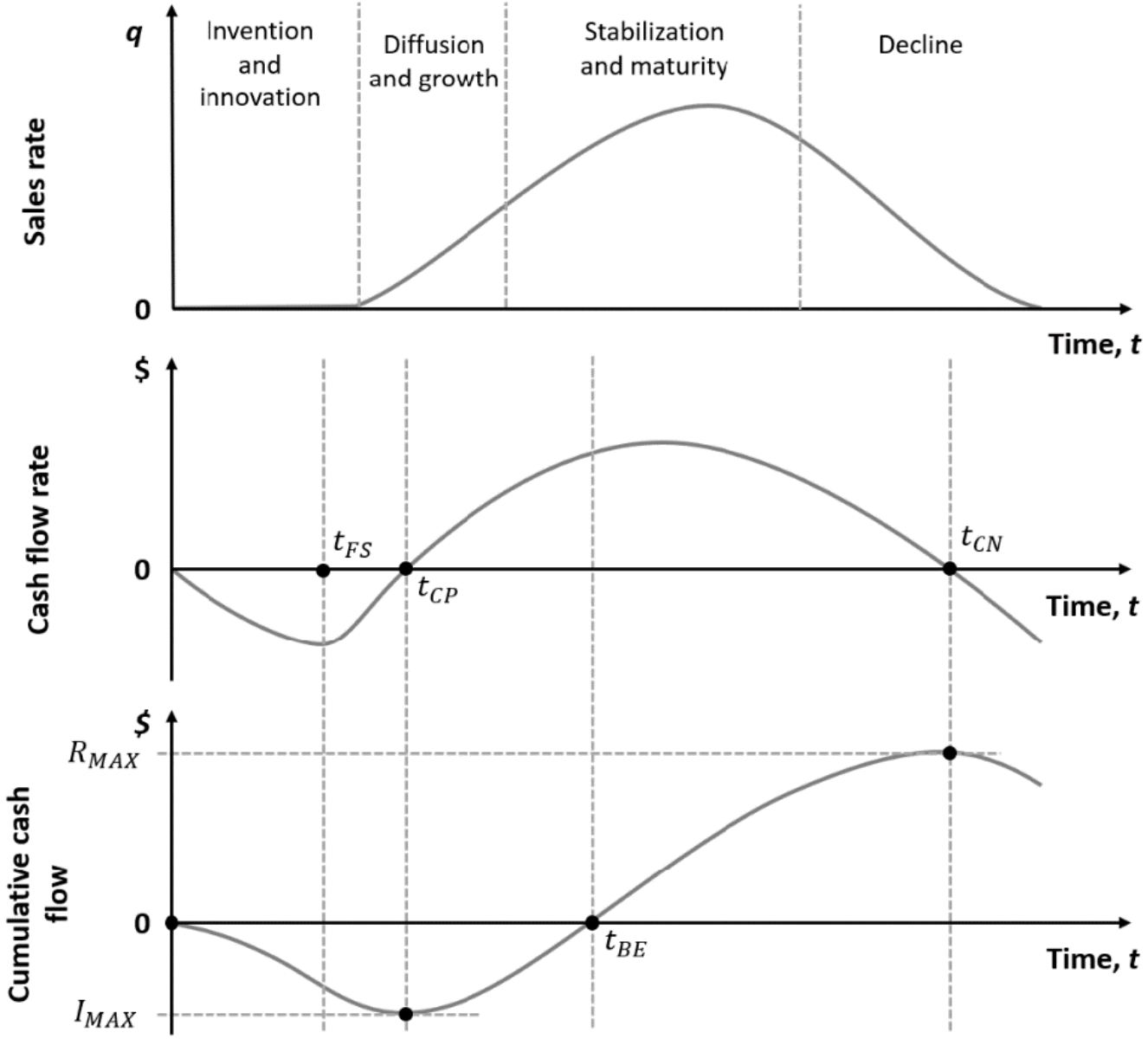
"Product lifecycle management is the activity of managing the full life cycle of a product or service offering from invention, through design and provision, to in-life support and disposal."

The product life cycle and the cash flow shape

The Y-axis shows the product's sales rate

The Y-axis shows the company's revenue **as a rate**

The Y-axis shows the company's **total** ("cumulative") cash flow



Important insights from the cash flow shape

- *Maximum investment and average rate of investment:* Both the maximum investment (I_{MAX}) and the average rate of investment (I_{MAX} / t_{CP}) indicate the ability of the company to support the project.

- *Maximum return and the end ratio:* Both the maximum return R_{MAX} and the end ratio (R_{MAX} / I_{MAX}) indicate how attractive the project is.

- *Average rate of recovery and average rate of return:* The average rate with which cash will be generated by the product, service or project is given by the average rate of return ($R_{MAX} / (t_{CN} - t_{CP})$) and the average rate of recovery ($I_{MAX} / (t_{BE} - t_{CP})$) shows how quickly the initial investment is recovered.

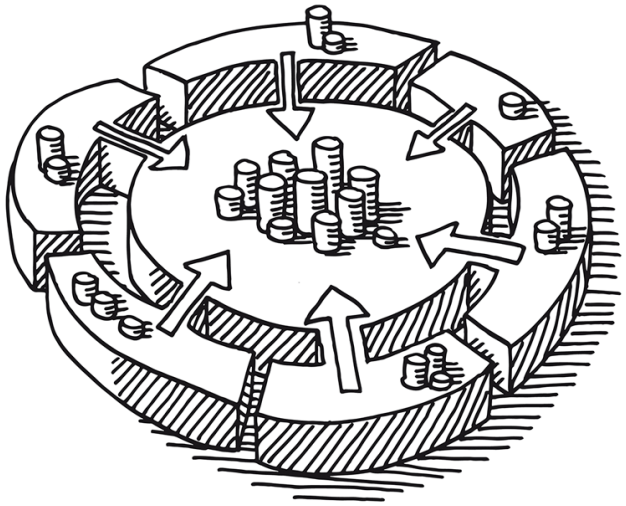
→ *MORE DETAIL IN THE BOOK!*

Whole-life cost

Whole-life cost is the total cost of owning an object over its life cycle as determined by financial analysis. It includes costs from purchase to disposal.

- Takes into account a diverse range of costs such as shipping and logistics, opportunity costs, taxes, tax incentives and customer-oriented costs such as those arising through supplier visits.

- Whole-life cost is particularly useful in the evaluation of capital investments.



Consider the purchase of a car:

- Should we buy new car or a second-hand one?
- Should we buy a cheap car or one that is more expensive in the hope that the servicing costs might be lower due to greater reliability?
- **Should we lease it or buy it?**

Whole-life costing can be used to help answer this question

- There are many methods of analysing cost of ownership
- The method presented below is simply one of many
- In our case we will look at the ***cost per mile*** but other people might be more interested in total cost or cost per year
- Alternatively, a measure of interest may be cost per passenger mile:

  → Cost per mile / average number of passengers

In our simplified analysis we will consider the following points

- Purchase price $20,000
- Will be owned for a maximum of five years
- Tax
- Fuel
- Servicing, tyres etc.
- Loss of value (“depreciation”)
- Annual mileage – 10,000 miles

In total:
$1,500 per year

Option 1: Outright purchase

In this case the buyer pays $20,000 upfront to acquire the car and then operates the vehicle for a total of five years.

→ As the car is fully owned, it can be disposed of after each year at residual value.

$$Cost\ per\ mile_i = \frac{TCLV_i + TOC_i}{TM_i}$$

EOY	Purchase cost	Residual value	Loss of value	Operating costs	Miles travelled
1	$20,000	$12,000	$8,000	$1,500	10,000
2	-	$6,000	$6,000	$1,500	10,000
3	-	$3,000	$3,000	$1,500	10,000
4	-	$2,000	$1,000	$1,500	10,000
5	-	$1,500	$500	$1,500	10,000

Ownership duration, i	Total costs of lost value after i years, $TCLV_i$	Total operating costs after i years, TOC_i	Total Mileage after i years, TM_i	$Cost\ per\ mile_i$
1	$8,000	$1,500	10,000	$0.95
2	$14,000	$3,000	20,000	$0.85
3	$17,000	$4,500	30,000	$0.72
4	$18,000	$6,000	40,000	$0.60
5	$18,500	$7,500	50,000	$0.52

Option 2: Hire purchase (also known as an "instalment" plan)

In this scenario the buyer agrees to pay $7,000 to the seller as a leasing fee during each of the first three years, after which the buyer has the option to buy the car for $1,000 or simply give it back.

- It is important to note that up to the sale, the seller owns the vehicle so incurs the depreciation.

$$Cost\ per\ mile_i = \frac{TLF_i + TCLV_i + TOC_i}{TM_i}$$

EOY	Leasing fee	Purchase cost	Residual value	Costs of loss of value	Operating costs	Miles travelled
1	$7,000	-	-	-	$1,500	10,000
2	$7,000	-	-	-	$1,500	10,000
3	$7,000	-	-	-	$1,500	10,000
4	-	$1,000	$2,000	$-1,000	$1,500	10,000
5	-	-	$1,500	$500	$1,500	10,000

Ownership duration, i	Total leasing fees after i years, TLF_i	Total costs of lost value after i years, $TCLV_i$	Total operating costs after i years, TOC_i	Total Mileage after i years, TM_i	$Cost\ per\ mile_i$
1	$7000	-	$1,500	10,000	$0.85
2	$14,000	-	$3,000	20,000	$0.85
3	$21,000	-	$4,500	30,000	$0.85
4	$21,000	$-1,000	$6,000	40,000	$0.65
5	$21,000	$-500	$7,500	50,000	$0.56

But:

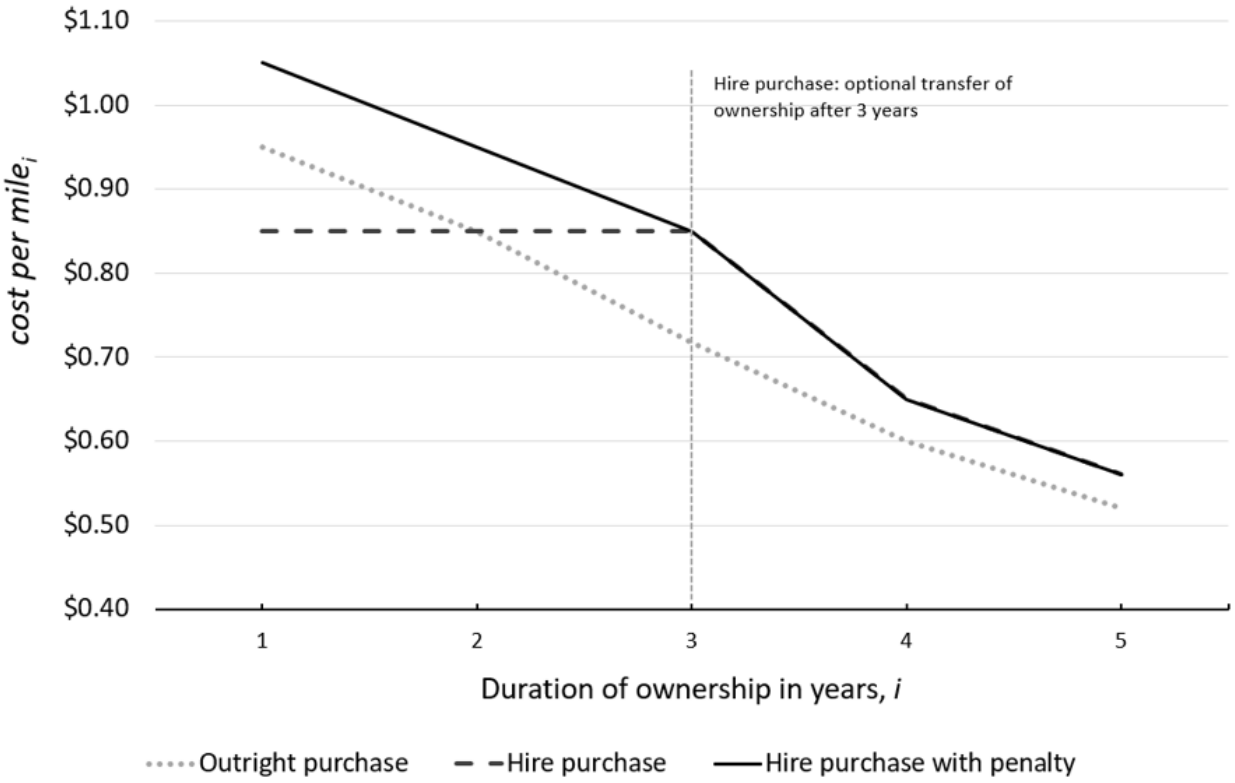
Normally it is agreed that if the buyer terminates the agreement before the first three years have elapsed (i.e. at the end of year 1 or 2) a penalty must be paid.

- In our case the penalty is a one-off payment of $2,000.

Ownership duration, i	Total leasing fees after i years with penalty, $TLFP_i$	Total costs of lost value after i years, $TCLV_i$	Total operating costs after i years, TOC_i	Total Mileage after i years, TM_i	$Cost\ per\ mile_i$
1	$9,000	-	$1,500	10,000	$1.05
2	$16,000	-	$3,000	20,000	$0.95
3	$21,000	-	$4,500	30,000	$0.85
4	$21,000	$-1,000	$6,000	40,000	$0.65
5	$21,000	$-500	$7,500	50,000	$0.56

Now we can construct our comparison

Outright purchase vs. Hire purchase without penalty vs. hire purchase with penalty



- *We see that hire purchase is favourable in the beginning (EOY 1) if there is no penalty*
- *After this period outright purchase is the cheapest option*

Cost-Benefit Analysis

The methods presented so far aim at internal, or private, advantages and disadvantages

- This perspective can be expanded to additional, outside, individuals or parties by applying a process known as Cost-Benefit Analysis (CBA)

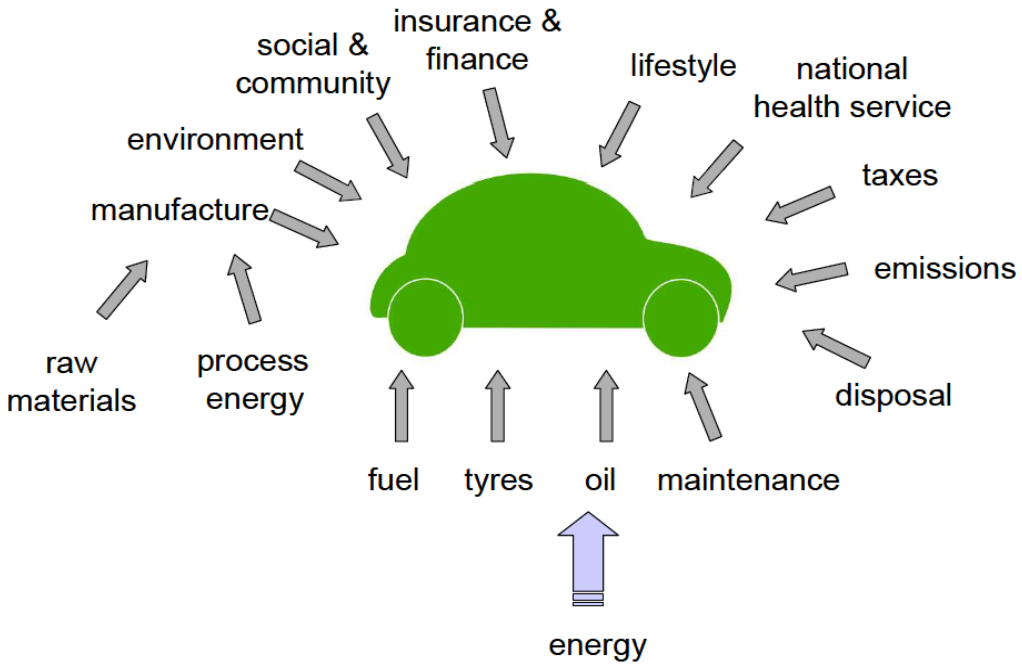
- CBAs investigate how positive aspects, i.e. benefits, are balanced against negative aspects, i.e. costs

  → Note here that 'cost' is use in a wider sense which is not restricted to financial costs but can include other negative impacts

Back to buying a car

At first it might seem to be a decision based simply on purchase price, depreciation, costs and mileage, as seen in whole-life costing

→ But, in reality there are usually many more issues to consider. One of the first activities of CBA is to decide what all of these issues are…



The generic structure of a CBA

- CBAs normally involve the following steps:

1. Define the goals and objectives of the course of action or project
2. List other alternative options
3. Identify the individuals and parties affected
4. Select measurement metrics and all necessary cost and benefit data
5. Predict outcome of costs and benefits over the relevant time period
6. Convert all costs and benefits into a common metric
7. Modify the value of future costs and benefits to reflect their value at present
8. Perform a sensitivity analysis
9. Generate a recommendation for choosing a particular project or course of action

Some important points about CBAs

- Both costs and benefits are likely to be highly diverse, even in seemingly simple examples
  - The costs tend to be the more accurately known elements due to the availability of commercial data and market information
  - Benefits are usually evaluated by capturing all parties affected and establishing the positive or negative value that they ascribe to the effect on their welfare…

    → *Usually in financial terms*

Introducing the Stakeholder

Any person, group or organization with a potential interest (or “stake”) in the project or activity is a stakeholder

→ Importantly, this is not limited to individuals or parties that are involved commercially, such as vendors, employees and customers…

Group	Definition	Examples
Primary (internal) stakeholders	Individuals or groups engaged in economic transactions with the project or business	Shareholders, customers, suppliers, creditors, and employees, the state (through taxation)
Secondary (external) stakeholders	Interested individuals or groups not engaged in economic exchange with the project or business	Affected members of the public, parents, prospective customers, people located nearby
Excluded stakeholders (i.e. not stakeholders)	Disinterested individuals or groups that are unaffected by the project or business	Unaffected businesses and unaffected members or the public

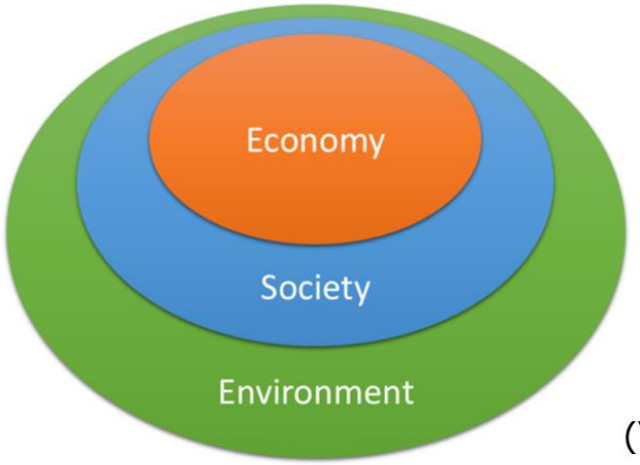
Life Cycle Assessment (LCA)

LCA aims to provide answers to questions such as “will an array of solar cells produce more energy than was used in the manufacturing process?”

→ *Generally used in the assessment of environmental impacts and sustainability but can also be used in the assessment of costs*

Context: sustainability-focussed evaluation

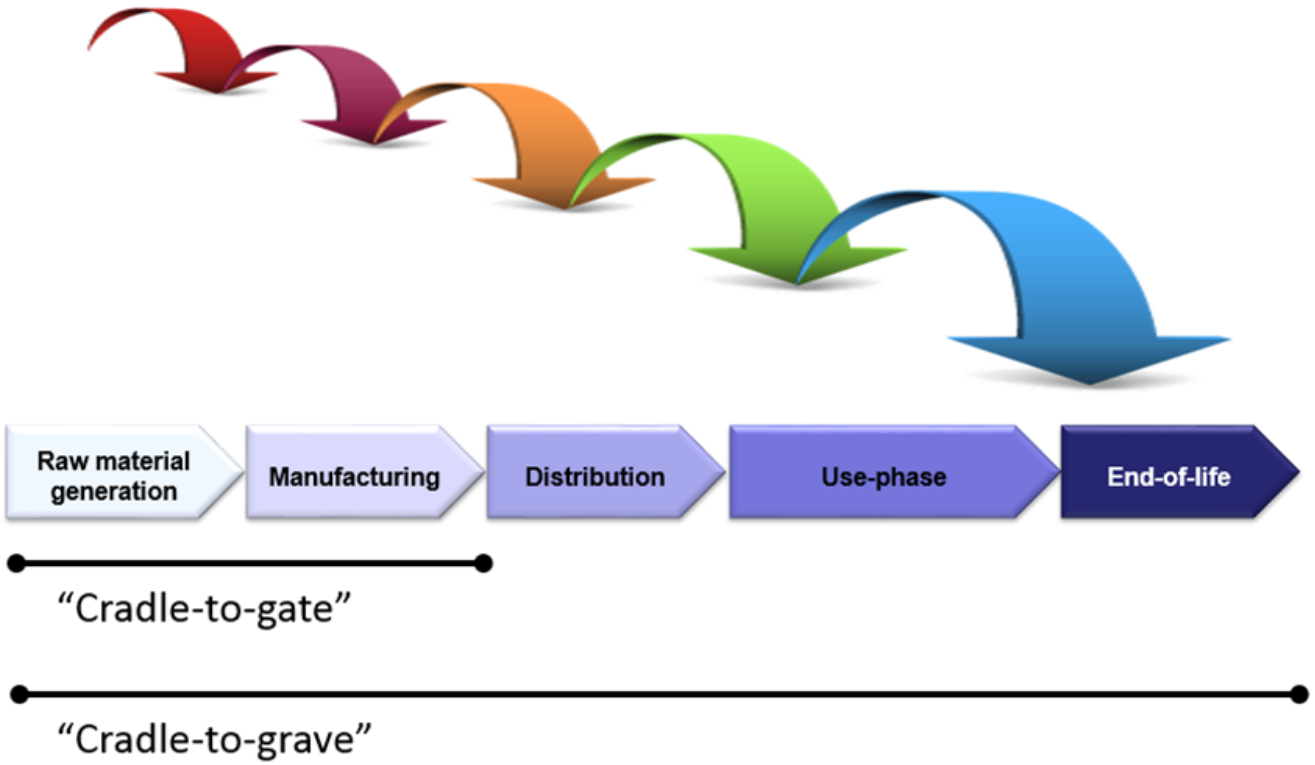
- Sustainability is essentially the ability of a system to endure over time
- It is of particular relevance in ecology which studies long term biological systems – including the human population
- In more recent decades it has become important as we seek more sustainable processes to support human economic and industrial development



("Three pillars of sustainability")

Stages in the life cycle

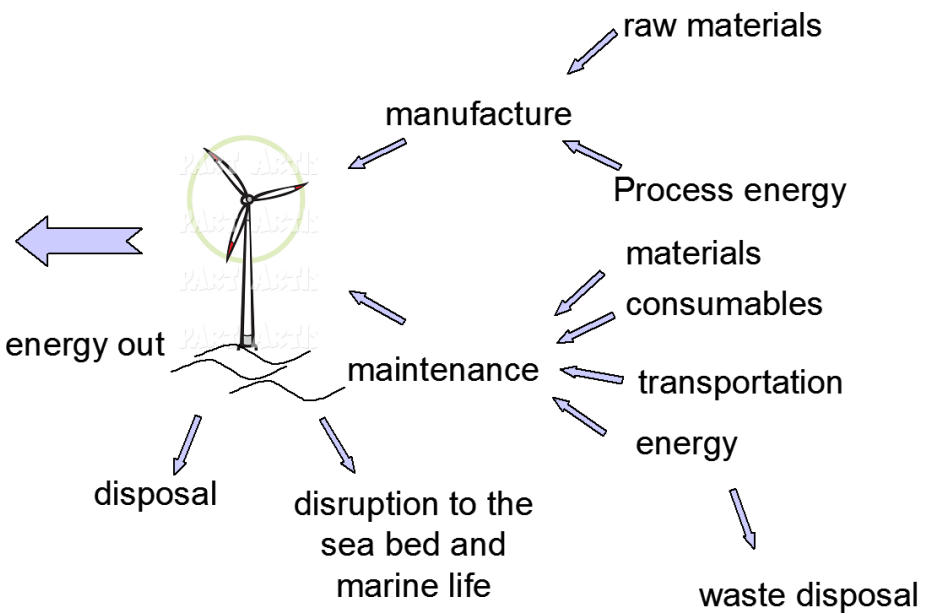
It is usual to carry out an LCA over the whole of a product life. To be able to construct such analysis, it is necessary to structure the investigated life cycle into distinct phases, or stages:



- But many other specifications are possible!

An example: offshore wind power

- An energy company is considering developing and installing offshore wind turbines for electrical generation
- An obvious question is how much energy can the turbine be expected to produce during its life span?
- However, there are many other energy and environmental issues to be considered
- How much energy is used during the development and manufacturing phases of the project?
- What is the environmental impact of servicing and maintaining the turbine?
- How much energy is used to process the raw materials used to make it?



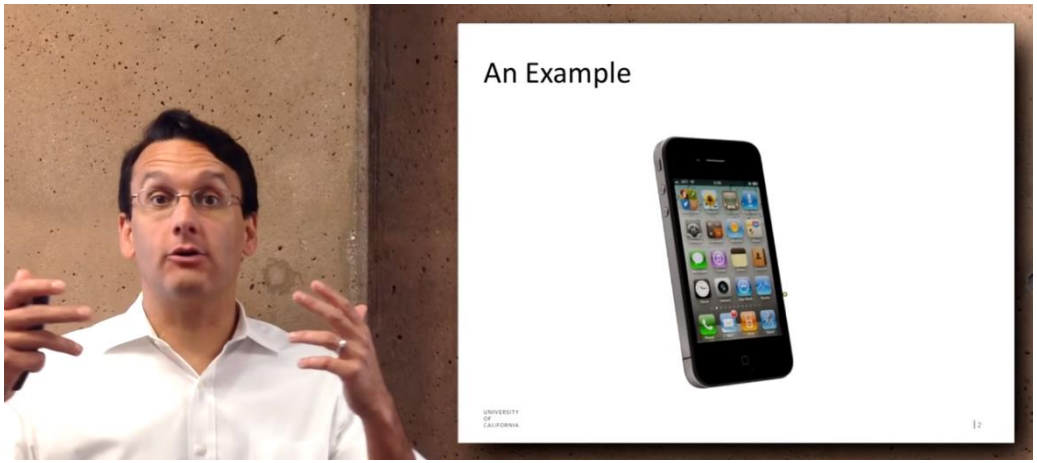
To be environmentally beneficial, the Life Cycle Assessment has to therefore show that there is a sufficient "environmental benefit"

→ This means the environmental benefit of the turbine must outweigh it environmental cost

Another example…

https://www.youtube.com/watch?v=zFaG4QZpzIs

0:15 – 2:05



Source: University of California, "ICS 5: Global Disruption and Information Technology“, 2014

Constructing LCAs

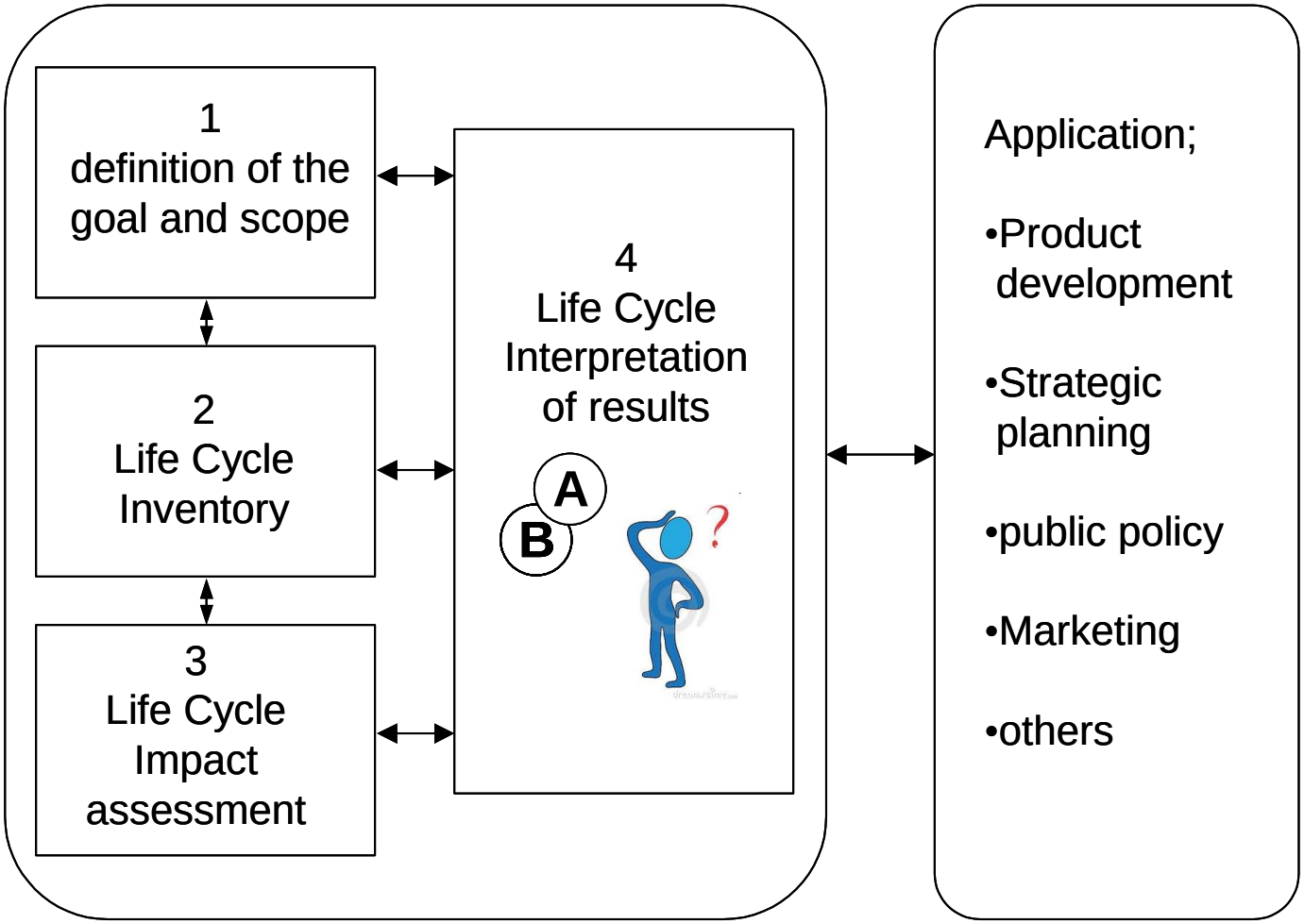
- A difficulty in completing an LCA is the choice of units
- The wind turbine example includes measurable units:
  - Kilowatts of power (kW)
  - Carbon Dioxide released (t)
- Sometimes, its hard to find useful units: how should the disruption to the seabed and marine life be quantified?

  → In the early days of LCA type analyses there was often confusion regarding units

- This is addressed in the ISO 14000 family of standards

ISO14000

The ISO method divides the study into four phases:



Phase 1: **Definition of the goal and scope**

- Should be an explicit statement of purpose, goal, functional units and system boundaries

- This is a key step because the ISO standard requires that that the goal and scope of the LCA should be clearly defined and consistent with the application

- Also, the goal and scope will include adequate technical information to guide the analysis

Phase 1: Definition of the goal and scope (continued)

- The functional units define what is being studied, and the units in which they will be evaluated
- This is important because the appropriate choice of functional unit allows one element of the analysis to "communicate" with another
- This phase will list any assumptions or limitations of the analysis and the categories of impact that will be considered, for example CO_2 emissions or energy balance

Phase 2: **Life Cycle Inventory**

- This is where the environmental balance is defined
- It creates an inventory ("takes stock") of all the flows to and from nature for the product → this can be complex…
- In the example of the wind turbine, the inventory back to nature is the energy of generating electricity
- Inventory flows from nature would include:
    - Extraction raw materials
    - The energy expended for processing them
- Will require the analysts to work their way up the supply chain to understand the flows associated with intermediate products and the raw materials used to create these

Phase 3: **Life Cycle Impact Assessment**

- At this stage all of the Inventory Flows are assessed and quantified
- The ISO requires the following mandatory elements:
  - Selection of impact categories, category indicators and characterisation models
  - Classification, where the inventory parameters are sorted and assigned to specific impact categories
  - Results need to be evaluated using one of numerous methodologies that have been developed under the control of the ISO
  - The inventory flows are then summed to provide an overall impact category total

→ *Note that the ISO is specific as to what can and cannot be included. This allows an equitable comparison between published LCAs, possibly from different sources*

Phase 4: the ISO interpretation phase is a methodical system to identify, evaluate, check and quantify data from the Life Cycle Inventory and Impact assessments

- The outcome is a set of conclusions and recommendations from the LCA. Under the ISO method, the interpretation will include:
  - Identification of significant issues based on the inventory and impact assessments
  - An evaluation of the study itself considering its completeness, and including sensitivity checks
  - Conclusions, recommendations and statement of any limitations of the study

Lecture summary in three points

- Have been introduced to the idea of a life cycle…
- Have learnt about various different methods of investigating life cycles, all based on the idea of investigating what happens as an object of interest moves through its life cycle.
- These methods have different boundaries:
  - Some are constrained to private, commercial costs and benefits
  - Others are extremely wide and can include impacts on non-human actors (e.g. animals)

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Thank you!