# Cost benefit analysis

## Calculating projects value

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Introduction to transportation systems

EPFL

# Example: airline


## Project

- Buy a new aircraft.
- Operate a new line GVA-LHR.
- Is it worth it?

## Boeing 737-300

- Fixed costs (loan, 120 months): \$403'765
- Variable costs (maintenance, fuel): \$2'875'072
- Total annual costs: \$3'278'837

Source: aircraftcostcalculator.com

# Example: airline


## Service

- GVA-LHR: 1h35
- 2 flights per day.
- 5 days per week.
- 520 flights per year.
- 823.3 hours per year.

## Crew costs

- \$2'000 per hour.
- Total: \$1'646'666

# Example: airline


## Revenues

- 120 passengers per flight
- Average ticket price: \$100.
- Revenues per flight: \$12'000.
- Annual revenues: \$6'240'000

# Example: airline


## Annual costs

- Aircraft: K$3'279.
- Crew: K$1'647.
- Total: K$4'926.

## Annual revenues

- K$6'240.

## Annual benefits

- K$1'314.

# Example: airline


## Break even

- Revenues = costs = K$4926.
- Revenues per flight: K$4926/520 = $9'473.

## Break even indicators

- 120 passengers @ $79.
- 94 passengers @ $100.

# Example: airline

## Comments

- Extremely important for business decisions.
- Methodology: spreadsheet calculation.

## Main difficulties

- Scenarios.
- Cost estimation.
- Include everything.

# Example: Gotthard base tunnel

## Tunnel

- 59.07 km.
- Uri $\rightarrow$ Ticino.
- Open 2016.
- Two tubes.
- Reduces travel time Zürich-Milano by 30 minutes.
- Cost: 12.2 billions CHF.
- Benefits: ?

Source: Wikipedia, Hannes Ortlieb.

# Example: Gotthard base tunnel

## What if a toll per train is charged?

- 25'000 freight trains per year (first year).
- 20'000 passenger trains per year (first year).
- 1000 CHF per train.
- Revenues per year: 45'000'000 CHF
- Number of years to recover the costs: 271.
- Remember: with a toll, the traffic will decrease.

# Example: Gotthard base tunnel

## SBB analysis 1974

- *"It is possible to derive the point in time, known as the utilization threshold, at which the annual freight yields reach or exceed the additional costs."*
- *"However, this method does not provide any indication of the economic viability of the project."*
- *"Because it is impossible fully to demonstrate economic profitability, there is a need for an overall societal perspective."*

Source: [Diemant, 1974]

# Examples

## Comments

- Society is not a business.
- Mix between technical analysis and political prerogatives.
- Main objective of evaluation: provide information to help decision-makers reach informed decisions that provide the greatest public good.

# Cost-benefit analysis

## Objectives

- Go/no go decision.
- Choice among variants of a project.

## Data collection

- Who? Identification of the stakeholders.
- What? Identification of important aspects.
- How? Identification of the indicators.

## Analysis

- Combination of indicators.
- Comparison of alternatives.

# Stakeholders


## Who?

- Travelers.
- Transport operators.
- Public authorities.
- Everybody else, the society at large.

## Note

A cost for somebody may be a benefit for somebody else.

# Indicators: costs

## Long term: $\geq 1$ year

- Design and engineering.
- Construction.
- Vehicles.
- etc.
- Note: need to adjust for inflation.

## Mid and short term: $< 1$ year

- Recurring costs.
- Operations.
- Maintenance.

# Indicators

## Monetary indicators

- Fare.
- Tolls.
- Taxes.

## Non monetary indicators

- Travel time savings.
- Accidents.
- Noise.
- $CO_2$ emissions.
- Pollution.
- Land usage.
- Spatial impacts.

# Example: hyperloop between Geneva and Zürich


## Project

- Vacuum sealed tube.
- Pod with magnetic propulsion.
- Maximum speed: 1220 km/h.
- Geneva-Zurich: 30 minutes for 280 km.

# Example: hyperloop between Geneva and Zürich

| | Travelers | Operators | Authorities | Society |
|---|---|---|---|---|
| Capital | | Cost | Cost | |
| Operations, maintenance | | Cost | | |
| Fare / toll | Cost | Benefit | | |
| Taxes | | Cost | Benefit | |
| Travel time | Benefit | | | Cost/benefit |
| Pollution | | | | Cost/benefit |
| Land | | | | Cost |
| Spatial impacts | | | | Cost/benefit |

# Comments

## Public vs private projects

- In the Easyjet example, we looked only at column "Operators".
- When analyzing public investment, we need to look at all columns.

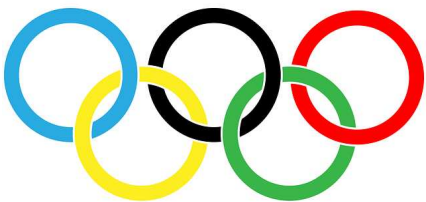
## Issues with monetary costs

- In general, large infrastructure projects fail in estimating correctly the costs.
- Most of the time, significantly underestimated.

## Issues with non monetary costs and benefits

- How do we compare them?
- How do we combine them?

# Monetary costs



## Olympic games

| OG | Budget | Real costs | |
|---|---|---|---|
| London 2012 | 3.4 M £ | 11.6 M £ | $\times$3.4 |
| Beijing 2008 | 1.9 M \$ | 43–45 M \$ | $\times$23.7 |
| Athens 2004 | 4.6 M € | 6 M € | $\times$1.3 |
| Sydney 2000 | 3.4 M \$ | 6.6 M \$ | $\times$1.9 |

[Andreff, 2012]

# Monetary costs

## Poor estimation

- 90% of very large infrastructure projects have underestimated costs.
- Rail projects: 45 percent more.
- Tunnels and bridges: 34 percent more.
- Roads: 20 percent more.
- Transportation projects: 28 percent more.
- Cost underestimation has not decreased over time; no learning seems to be taking place.

Source: [Flyvbjerg et al., 2003]

# Non monetary costs and benefits


## How do we compare them?

- Method 1: transform everything into monetary units.
- Method 2: multi-criteria analysis.

# Non monetary costs and benefits

## Transforming into monetary units

- Behavioral approach.
- Cost for society.
- Shadow price.
- Market price.

[Duong, 2009]

# Behavioral approach

## Consumer surplus

- Difference between willingness to pay and actual price.
- Rule of half.

## Contingent valuation

- Willingness to pay for a modification of a variable in the utility function.
- Ex: Value of travel time savings.
- Maybe asymmetric: willingness to pay $\neq$ willingness to accept.

## Risk mitigation

- Willingness to pay to mitigate the risks.
- Ex: value of injuries, value of life: insurance premium.

# Value of life in Switzerland

## Methodology

- From OECD.
- Willingness to pay for small reduction of mortality risks.
- Stated preference surveys.

## Value of Statistical Life

- 2010: 6'400 kCHF.
- 2021: 6'900 kCHF.

[OECD - Organisation for Economic Co-operation and Development, 2012], [ARE - Office fédéral du développement territorial, 2022]

# Risk mitigation: behavioral

## Value of life in the USA

| | |
|---|---|
| 1940 | 713-996 |
| 1950 | 1'122-1'755 |
| 1960 | 1'085-2'132 |
| 1970 | 2'792-4'937 |
| 1980 | 4'144-5'347 |

In 1990s K$. Source: [Costa and Kahn, 2004]

# Risk mitigation: cost for society

## Value of a year of life

If Medicare paid an additional $129'000 to treat a group of patients, on average, group members would get one more quality-adjusted life year, which is about two years of life on dialysis.

Source: [Kingsbury, 2008]

# Shadow price

## Politically negotiated value. Example: $CO_2$

- Switzerland 2021: CHF 96 per ton.
- Switzerland 2022: CHF 120 per ton.
- EU 2021: CHF 46 per ton.
- First country to introduce it: Finland, 1990.

# Market price

## Create a market

- Need for a permit to generate negative externalities.
- Public authorities emit a limited number of permits.
- They then let the market regulate itself.

## Examples

- Lead phase down, US (1979–1996): remove lead from oil.
- Ecopoint, Austria (1995–2006): limit pollution and noise.
- Low Emission Vehicle and Zero Emission Vehicle, California (1990–): speed-up the adoption of electric vehicles.
- etc.

# Transforming into monetary units

## Comments

- Not a unique way to do it.
- Subjectivity plays a role.

# Non monetary costs and benefits

## Multi-criteria analysis

- Use of multiple indicators for project $i$: $q_1^i$, $q_2^i$, $\ldots$, $q_K^i$.
- We assume that $q_k^i < q_k^j$ if $q_k^i$ is better than $q_k^j$.
- We try to minimize each indicator.
- If not, just change the sign of the indicator.
- Indicators cannot be compared.

## Example

- $q_1^i$ and $q_1^j$: cost of projects $i$ and $j$.
- $q_2^i$ and $q_2^j$: travel time for projects $i$ and $j$.
- $q_3^i$ and $q_3^j$: $CO_2$ emissions for projects $i$ and $j$.
- $-q_4^i$ and $-q_4^j$: consumer surplus for project $i$ and $j$.

# Multi-criteria analysis

## Dominance

Consider projects $i$ and $j$. $i$ is dominating $j$ if

1. $i$ is no worse in any indicator:

$$\forall k \in \{1, \ldots, K\}, q_k^i \leq q_k^j,$$

2. $i$ is strictly better for at least one indicator:

$$\exists k \in \{1, \ldots, K\}, q_k^i < q_k^j.$$

## Notation

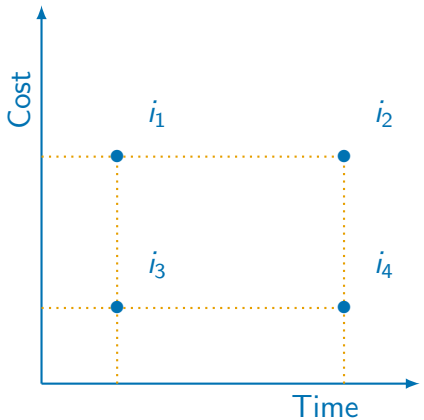
$i$ dominates $j$: $i \prec j$.

# Dominance

## Properties

- Not reflexive: $i \not\prec i$
- Not symmetric: $i \prec j \not\Rightarrow j \prec i$
- Instead: $i \prec j \Rightarrow j \not\prec i$
- Transitive: $i \prec j$ and $j \prec \ell \Rightarrow i \prec \ell$
- Not complete: $\exists i, j$: $i \not\prec j$ and $j \not\prec i$

# Dominance: example




$i_3 \prec i_2$

$i_3 \prec i_1$

$i_1 \not\prec i_4$

$i_4 \not\prec i_1$

# Optimality

## Pareto optimality

Consider a set of projects $\mathcal{C}$. The project $i^* \in \mathcal{C}$ is Pareto optimal if it is not dominated by any other project:

$$\nexists j \in \mathcal{C} \text{ such that } j \prec i^*.$$

## Intuition

$i^*$ is Pareto optimal if no indicator can be improved without degrading at least one of the others.

# Project selection

## Pareto optimal set

$$P^* = \{i^* \in \mathcal{C} | \nexists j \in \mathcal{C} : j \prec i^*\}$$

## Procedure

- Consider only projects in the Pareto optimal set.
- Selection within the set is based on political preferences and trade-offs.
- Subjectivity plays a role.
- If needed, additional indicators can be involved and the Pareto set updated.

# Example

## The multi-objective railway timetable rescheduling problem

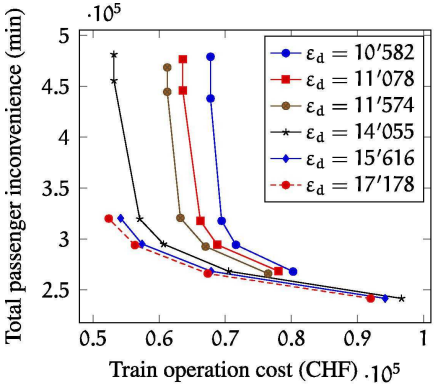
- A major disruption occurs in the railway operations.
- A disposition timetable must be implemented.
- Trains can be fully or partially canceled.
- Trains can be delayed.
- Trains can be rerouted.
- Additional emergency trains can be operated.

## Objectives

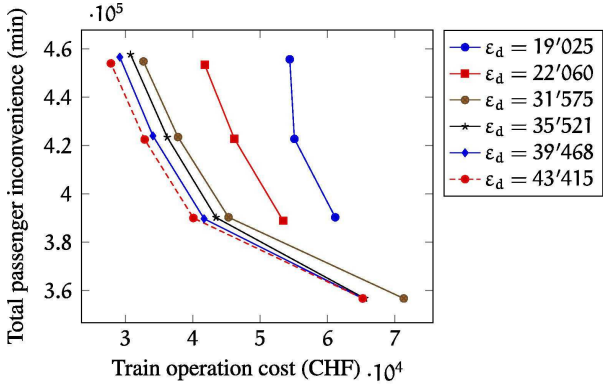
- Minimize passenger inconvenience (lost of time).
- Minimize the costs.
- Minimize the deviations from the original timetable.

# Example

## The multi-objective railway timetable rescheduling problem




**(a)** Pareto frontier for disruption Gouda-Utrecht (Gou-Utr).




**(b)** Pareto frontier for disruption Den Haag-Leiden- Schiphol (DeH-Lei-Sch).

Source: [Binder et al., 2017]

# Summary

## Objectives

- Go/no go decision.
- Project selection.

## Data

- Stakeholders.
- Indicators.

## Analysis

- Transform all indicators in monetary units.
- Multi-criteria analysis.

## Issues

- Under evaluation of costs.
- Role of subjectivity.

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