Transportation systems

Introduction

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Introduction to transportation systems

Why do we need transportation systems?

Discussion: Why do we need transportation systems?

Why do we need transportation systems?

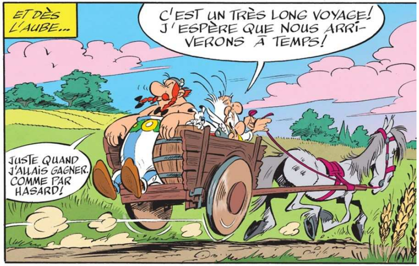
Main objectives

- Mobility: save travel time as a resource.
- Accessibility: induce more travel.

Motivation

Generates social and economic growth.

History



4000 BC	Horses
3500 BC	Wheel, river boats
2000 BC	Chariots
312 BC	Paved road (Romans)
1662	Horse-drawn public bus
1783	Hot air balloon
1801	Steam road locomotive
1814	Steam-powered railway train
1816	Bicycle
1900	Airship (Zeppelin)
1904	Airplane
1908	Ford car

Source: www.twinkl.ae/teaching-wiki/transportation

History

Observations

- 1904: airplane
- Since then, technological developments have been incremental.
- No fundamentally new mode of transportation.
- Recently, tendency to promote slow modes (walking, etc.)

Discussion: Why aren't technological advances in transportation engineering similar to those in computers and telecommunications?

Why no recent breakthrough in transportation technology?

Costs

- Maglev train (Shanghai airport → Longyang Road station). Started 2004. Speed: 430km/h. 7.2km/min. 30km. Travel time: 8 mins. It should be 4 minutes, right? Average speed: 225km/h because of acc. and dec..
- Headway: 15 minutes. In average, total travel time: $8 + 7.5 = 15.5$ min.
- Should be used on long distance. But, building cost=$40K million per km.

Demand

- What is the demand?
- Most people don't go to Longyang Road station.
- Shanghai: taxi or metro: about 30 minutes. But more flexibility.

Other examples

- Concorde, Hyperloop.

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Motivation

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Costs and externalities

Monetary costs

- Paid by the users.
- Paid by the operators.
- Paid by the tax payers/government.

Externality

A side effect or consequence that affects other parties without this being reflected in the costs.

Discussion: What are the externalities?

Externalities

Positive

- Social growth.
- Economic growth.
- Equity.

Negative

- Space consumption.
- Energy consumption.
- Pollution: emission, noise.
- Safety.
- Inequity.

Example

Space consumption

- Swiss transport infrastructure: 800 km^2.
- 2% of the Swiss territory.
- 1/3 of the surface for housing and infrastructure.
- Roads: 84000 km.
- Rails: 5200 km.

Role of the engineer

Design
Long-term

Maintain
Medium-term

Operate
Short-term

Performance indicators

Level of service

- Travel time.
- Comfort.
- Convenience.
- Flexibility.
- etc.

Externalities

- Positive.

Costs

- Design and construction.
- Maintenance.
- Operations.

Externalities

- Negative.

Design example: 40-story building

Mobility

- Time to walk to the top?
- 15 sec/floor: 10 minutes.
- 22 sec/floor: 15 minutes.

Accessibility

- Nobody buys/rents the apartments on top floors.
- They are deemed inaccessible.

Solution: a transportation system

Install elevators

- Objective: minimize travel time
- One direct elevator for each floor.
- Assume 5 sec. per floor.
- Travel time from floor 0 to floor 40: 200 seconds ($\sim$3 min).

Discussion: Analysis of the proposed solution

Analysis of the proposed solution

Design

- How many elevators do we need?
- 40 elevators: huge cost, huge volume usage.
- 1 elevator: huge waiting time.
- Trade off between level of service and cost/externalities.

Importance of demand

- Are all floors equally important?
- What if there is an entrance at the 4th floor?
- What if there is a observation desk at the top floor?

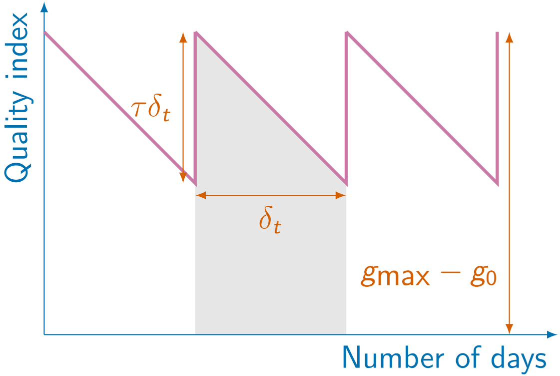
Maintenance example

Road maintenance

- Quality index: from g_0 to $g_{\max}$.
- Constant degradation rate: τ.
- Repairing costs: $c(t) = c_f + c_v \tau t$

Discussion: At what frequency should the road be repaired?

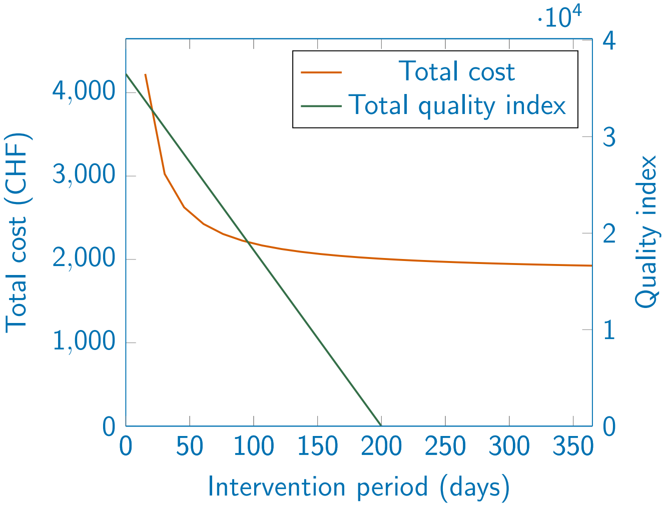
Maintenance example: a model



- Deterioration rate τ.
- Decision: maintenance interval δ_t
- Horizon: t_H
- Constraint: $\delta_t \leq (g_{\text{max}} - g_o)/\tau$
- Number of interventions: t_H/δ_t
- Quality during one interval: $g_{\text{max}}\delta_t - \frac{\tau\delta_t^2}{2}$
- Total quality: $t_H(g_{\text{max}} - \frac{\tau\delta_t}{2})$
- Cost of one intervention: $c_f + c_V\tau\delta_t$
- Total cost: $t_H(c_f/\delta_t + c_V\tau)$

Maintenance example

$\tau = 1,\ g_{\max} = 100,\ t_H = 365,\ c_f = 100,\ c_v = 5$



Maintenance example

Trade-offs

- If the quality increases, the costs increase as well.
- What is a good trade-off?
- How do we value the road quality?
- Similar discussion about level of service:
    - Decreases with quality.
    - Decreases during interventions.

Operations example: a shuttle service

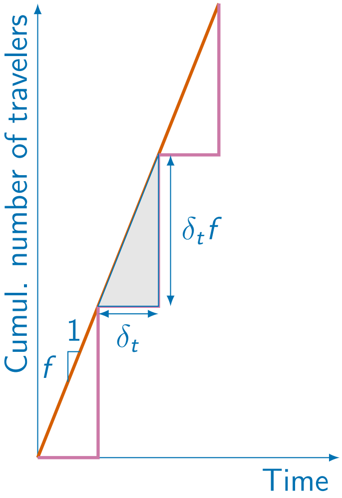
End of football game

- Shuttles from stadium to parking.
- Uniform flow of people: f persons/min.
- Cost of running one shuttle: c.

Discussion: At what frequency do we run the service?

Proposed strategies for the shuttle service

Operations example: a model

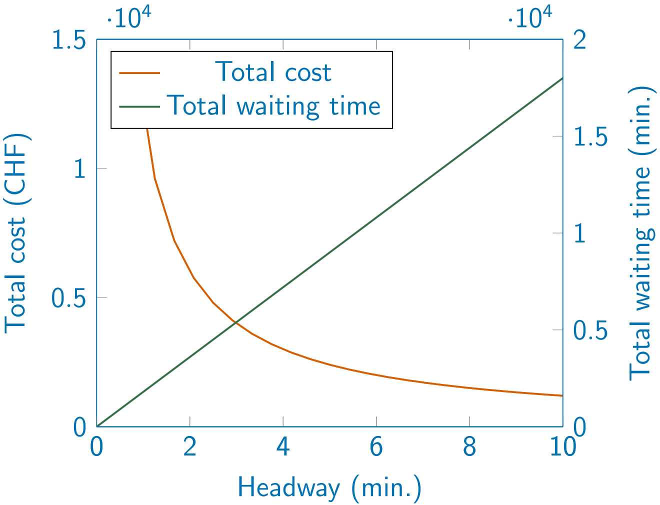


Model

- Travelers arrival: f pax/min.
- Horizon: t_H min.
- Total number of travelers: ft_H pax.
- Decision: headway δ_t min.
- Number of trips: t_H/δ_t.
- Travelers per trip: $\delta_t f$ pax.
- Cost per trip: c CHF.
- Total cost: $t_H c/\delta_t$ CHF.
- Waiting time per trip: $\delta_t^2 f/2$ pax min.
- Total waiting time: $t_H \delta_t f/2$ pax min.

Operations example: a model

$t_H = 60$ min., $f = 60$ pax/min., $c = 200$ CHF

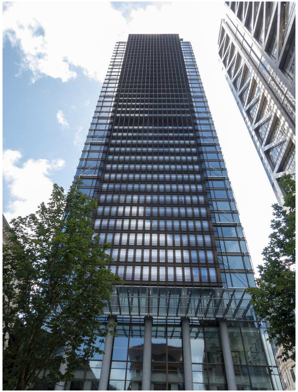


Operations example: a shuttle service

Trade-offs

- If the level of service increases, the costs increase as well.
- What is a good trade-off?
- How do we value the level of service?
- In other words, what is the value of a minute lost waiting for the bus?

Operations example: 40-story building



Discussion: How do we organize the elevators?

Proposed operations strategies for the elevators

Ideas

- All elevators stop at each floor at a given schedule.
- All elevators serve all floors, on-demand.
- One elevator serves floor 40. One elevator serves all other floors.
- One free elevator, one with a fee.

Objectives of the discussion:

- importance of the demand,
- costs and benefits, but for whom?

Summary

Engineering challenges

- Design and build.
- Maintain.
- Operate.

Indicators

- Level of service.
- Costs.
- Externalities.
- Different units.
- Complex Trade-offs.

Stakeholders

- Travelers.
- Operators.
- Tax payers/government.

Importance of the demand

- Who needs the service?
- Who will benefit from the service?
- Who is willing to pay for the service?