Light rail transit systems
61 lessons in sustainable urban development

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Spårvågsforum 2019 Uppsala

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Transport and Planning

- **Smart Mobility Lab**
- **Transportation Resilience Lab**
- **Traffic and Transportation Safety Lab**

- **DiTTLab**
  - **UMO Urban Mobility Lab**
  - **AMS Living Lab**

http://www.smartPTlab.tudelft.nl/

Logos of Arriva, Keolis, Gemeente Amsterdam, and Mobike.
Optimal mix of modes
Challenge the future

Light rail explained: Better public transport & more than public transport

Light Rail Transit Systems
61 Lessons in Sustainable Urban Development

Big data supports light rail in Utrecht

TU Delft
Cases worldwide
Europe
Lessons learned: 61 cases

- Light rail has been successfully implemented in many urban regions worldwide.

- Several light rail projects were not that successful or even failed.

- There is much debate on the (societal) cost-benefit ratio of these systems.
General findings: succes

*Project conception*
- Focus on ‘why’ the project (short term and long term);

*Politics*
- The timeframe of contracts for the project must be consistent with political timeframes;

*Communication*
- Residents and citizens must be involved in the project;
General findings: failure

Project conception
• Too few project variants or alternatives. Solutions for a good project are often found in the combination of different alternatives.

Politics
• Changing political climate;

Communication
• A technocratic attitude jeopardizes the project;
Justification of public transport

Framework of 5 E’s

- Effective mobility
- Efficient city
- Environment
- Economy
- Equity

Van Oort et al. 2017
Challenge the future
Efficient cities

- All kinds of (indirect) effects:
  - Urban planning & design
  - (Restructuring) the city
  - Quality of the city
  - Livability
  - Image & perception of the city
Life without driverless cars

Life with driverless cars

All hail the revolution!
Environment+Health

- More efficient regarding:
  - Energy consumption
  - (Direct) emissions
  - Land use
  - Bicycle+transit

![Diagram of mobility comparisons](image)
Impact of PT quality on catchment areas

Brand, J., et al. (2017)
Economy

- Land value
- Real estate value
- Retail turnover & quality
- Employment
- Property development

Increase due to high quality public transport accessibility

<table>
<thead>
<tr>
<th></th>
<th>+ 5%</th>
<th>+ 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>House value</td>
<td>+ 2%</td>
<td>+ 5%</td>
</tr>
</tbody>
</table>
Equity

- Social access & connection:
  - Contra-segregation
  - Social mobility
Passengers in the Netherlands

- 6% of Dutch population: Have difficulties walking larger distances

- 2.5 million people: Have difficulties reading, writing and/or lack digital skills

KiM (2016) www.lezenenschrijven.nl
Effective mobility

- Quality of service
  - Travel speed
  - Transfers
  - Service reliability
  - Robustness
  - Comfort
  - ...

Challenge the future
A  Light rail  19 minutes

B  Bus  15 minutes

C  Streetcar  16 minutes
Rail bonus

- Research TU Delft (Bunschoten et al. 2013)

- Additional attractiveness of a rail system compared to a bus system with similar characteristics

<table>
<thead>
<tr>
<th>Source</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scherer (2011)</td>
<td>Slight pref. rail</td>
</tr>
<tr>
<td>Scherer (2009)</td>
<td>Slight pref. rail</td>
</tr>
<tr>
<td>Cain (2009)</td>
<td>Slight pref. rail</td>
</tr>
<tr>
<td>Ben Akiva (2002)</td>
<td>No difference</td>
</tr>
<tr>
<td>Welschen (2002)</td>
<td>0-10%</td>
</tr>
<tr>
<td>Megel (2001)</td>
<td>Slight pref. rail</td>
</tr>
<tr>
<td>Axhausenen (2001)</td>
<td>Slight pref. rail</td>
</tr>
<tr>
<td>Berschin (1998)</td>
<td>+30%</td>
</tr>
<tr>
<td>Arnold en Lohrmann (1997)</td>
<td>+15%</td>
</tr>
<tr>
<td>Hüsler (1996)</td>
<td>+54%</td>
</tr>
</tbody>
</table>
Rail Bonus: approx. 5-15%
The value of Light rail
light rail

Tip: Alleen in het Nederlands zoeken. U kunt uw zoektaal instellen in de Voorkeuren
“Light rail is a rail-bound mode of public transport, which is used on the spatial scale of urban regions and cities. Contrary to train and metro, light rail is by definition able, up to a certain level, to integrate in the public space and mix with regular road traffic.”

Van der Bijl et al. 2018
Pros light rail

Compared to bus /BRT
CONS Light rail

- Initial investment
- Above ground
- Specific infrastructure systems
- Cost
- Fixed infrastructure
- Speed
- Not flexible
- Accessibility more disruptive
- Expensive
- Less flexible
- Investment
- Flexibility
- Dedicated units
- Inflexibility
- Space
- Hybrid
- Unclear definition
- Noise pollution
- Inflexible
- Are usually
- Infrastructure rigid
- High operation cost
- Operators on same line
- High cost
Light rail system types

<table>
<thead>
<tr>
<th>Light rail</th>
<th>Non-light rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Regional) tram</td>
<td>6 Train</td>
</tr>
<tr>
<td>2 TramTrain</td>
<td>7 Metro</td>
</tr>
<tr>
<td>3 TrainTram</td>
<td>8 MetroTrain</td>
</tr>
<tr>
<td>4 TramMetro</td>
<td>9 TrainMetro</td>
</tr>
<tr>
<td>5 MetroTram</td>
<td></td>
</tr>
</tbody>
</table>
A — Light Rail Operation

Tram/Regiotram (Type 1)

French-style second-generation trams, Dublin, Ireland.
Tram-train (Type 2)

A pioneer tram-train is the famous Karlsruhe system, Germany.
Train-tram (Type 3)

Train shares tracks and terminus of the local city tram, Zwickau, Germany.
Metro-tram (Type 4)

Metro-tram LRV of line 51 in Amstelveen, Amsterdam region, Netherlands.
**Tram-metro (Type 5)**

LRV using metro-style infrastructure and stations, Düsseldorf, Germany.
Tram- train types

Mixed operation with conventional trains on regional tracks

Mixed operation with conventional streetcars on urban tracks

A
B
C
D

# Tram-Train examples

<table>
<thead>
<tr>
<th>Germany</th>
<th>France</th>
<th>Netherlands</th>
<th>United Kingdom</th>
<th>Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karlsruhe (network)</td>
<td>Mulhouse (line)</td>
<td>Hoekse Lijn (line)</td>
<td>Sheffield (line)</td>
<td>Cádiz (line)</td>
</tr>
<tr>
<td>Kassel (network)</td>
<td>Nantes (network)</td>
<td>RijnGouweLijn (line)*</td>
<td>Cardiff (line)</td>
<td></td>
</tr>
<tr>
<td>Chemnitz (network)</td>
<td>Paris (line)</td>
<td>RandstadRail (network)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nordhausen (line)</td>
<td></td>
<td>Groningen (network)*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* System was proposed but not implemented.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line length</td>
<td>32.6 km</td>
<td>30.6 km</td>
<td>7.9 km</td>
<td>64 km</td>
</tr>
<tr>
<td>Number of stops</td>
<td>24.8</td>
<td>22.5</td>
<td>5</td>
<td>54</td>
</tr>
<tr>
<td>Stop spacing</td>
<td>1.7 km</td>
<td>1.3 km</td>
<td>0.7 km</td>
<td>6.4 km</td>
</tr>
<tr>
<td>Average speed</td>
<td>36.6 km/h</td>
<td>35 km/h</td>
<td>23 km/h</td>
<td>58 km/h</td>
</tr>
<tr>
<td>Trip time</td>
<td>54.5 minutes</td>
<td>51.5 minutes</td>
<td>18 minutes</td>
<td>98 minutes</td>
</tr>
<tr>
<td>Frequency</td>
<td>3.1 tph</td>
<td>2 tph</td>
<td>1 tph</td>
<td>12 tph</td>
</tr>
</tbody>
</table>

Light rail = hybrid
Light rail infrastructure

- Traditional street-based;
- Shared-space;
- Traffic lane;
- Separate tramway;
- Metro style tramway;
- Railway for tram-train.
Street-based (Almaty, Kazakhstan)
Shared space (Reims, France)
PT Lane (Edinburgh, Scotland)
Separated tramway (Berlin, Germany)
Metro track (Rotterdam, Netherlands)
Train track (Gouda, Netherlands)
2 light rail cases
Case 1: Utrecht Uithoflijn
Decision making in public transport

- Most PT projects aim at enhanced reliability
- Service reliability is often missing in CBA and transport models
- We developed:
  - Methodology to incorporate passenger impacts of service reliability:
    - Transport models (reliable forecasts)
    - Cost benefit analyses
- Applied in Utrecht
Case: Uithoflijn (line 12)

Central Station

City of Utrecht

“De Uithof”
- University
- Hospital

Utrecht
- Centrally located in the Netherlands
4th largest city
300,000 inhabitants
Problem analysis

- Busiest bus line in the Netherlands: 27,000 passengers per day
- Frequency of 23x/hour/direction using double-articulated buses: 30x/hour/direction necessary
- Poor reliability and lack of capacity

- Mobility is still growing
  - +25% planned property in the Uithof: +8,000 students, +10,000 employees
  - Total: 53,000 students, 30,000 employees and 3,500 visitors (hospital)
  - No additional parking space
  - Demand forecast: 46,000 passenger per day

Solution
Introduction of a light rail line: 16-20x/hour
Poor reliability

Scheduled headway

Frequentie

Headway [s]

Avg. = 2,5 min; \( \sigma = 1,3 \) min
New tram line

Connected CAF vehicles (2x37.5 m)

7,5 km
Operations are planned to start in 2018; delayed to 2019
Ministry requires CBA

- Regional parties agreed with plans and finances
- €110 million of Minister of Transport available (about 1/3 of total costs)
Our approach

• Calculations of:
  • Future demand, including tram bonus impacts
  • Costs (infrastructure and operations)
  • Benefits
    • Travel time gains
    • Reliability gains

Van Oort, 2011
Three step approach

AVL data

Service dynamics

Schedule adherence

APC data

Passenger impacts

Additional travel time and variance

VOT / VOR

Monetary impacts

EU

Van Oort, 2016
## Results CBA

<table>
<thead>
<tr>
<th></th>
<th>Value compared to reference case (millions in 2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs</td>
<td>€222</td>
</tr>
<tr>
<td>Operating costs</td>
<td>€66</td>
</tr>
<tr>
<td><strong>Total costs</strong></td>
<td><strong>€288</strong></td>
</tr>
<tr>
<td>Additional ticket revenues</td>
<td>€40</td>
</tr>
<tr>
<td>Increased travel time</td>
<td>€67</td>
</tr>
<tr>
<td>Service reliability effects</td>
<td></td>
</tr>
<tr>
<td>- Less waiting time</td>
<td><strong>€123</strong></td>
</tr>
<tr>
<td>- Reduction in distribution</td>
<td>€78</td>
</tr>
<tr>
<td>- Increased probability of finding a seat in the vehicle</td>
<td>€4</td>
</tr>
<tr>
<td>External effects (emissions, safety, etc.)</td>
<td>€8</td>
</tr>
<tr>
<td><strong>Total benefits</strong></td>
<td><strong>€330</strong></td>
</tr>
<tr>
<td>Benefits costs</td>
<td>€48</td>
</tr>
<tr>
<td><strong>Benefit cost ratio</strong></td>
<td><strong>1.2</strong></td>
</tr>
</tbody>
</table>

Additional waiting time due to unreliability

Distribution of travel time due to unreliability

Service reliability effects are over >60% of all benefits!

This method was approved by the Dutch Ministry and the Minister provided the €110 million
Case 2: controlling RandstadRail
90,000 travelers per day
Two lines; 33 and 27 km | 41 and 31 stops
5 min headway per line per direction
50 Low floor vehicles
Why controlling?

- High level of quality and reliability
- In urban area
  - Poor punctuality
  - Poor regularity
- High number of vehicles per hour per direction (>24)
- Signalling applied: limited capacity
- Shared tracks with tram and metro
- Operational targets of transit authority

![Chart showing deviation in punctuality]
Without controlling?

- Bunching -> Increase in average waiting time
- Overcrowding -> Probability of having a seat decreases
- Uncertainty -> Less satisfied travellers
How to deal with deviations?

Disturbances

Preventing → Coping → Adjusting
Main elements

Preventing unplanned stopping
Punctuality
Dwelling
Timetable
Dispatching room
Actual effects

- Continuous monitoring operational quality
  - To optimize timetable
  - To find and remove bottlenecks

Improvements
- Variation of driving time
- Punctuality
- Customers satisfaction
Variation of driving times

Unplanned stopping

Average delay \(90 \text{ s} \rightarrow 20 \text{ s}\)

Standard deviation \(-50\%\)
Variation of driving times (2)

Dwelling

Average dwell time: 28 s → 24 s

Standard deviation: 70%
Punctuality

Departure punctuality: 70% → 93% <-1, +1>
Driving ahead of schedule: 50% → 7% ↔,0>

15% less waiting time for passengers
Customers satisfaction

![Bar chart showing customers' satisfaction for Line 3 and Line 4 from 2005 to 2008.](chart.png)
Summary

• Light rail is a valuable addition to the PT planning tool box

• Light rail is flexible and hybrid

• Lessons from light rail projects: justification and broader scope than transport

• Framework of 5 E’s
  • Efficiency
  • Effectiveness
  • Economy
  • Environment
  • Equity

Cases
• Light rail enables increase in service realibility
• Little attention to service reliability in cost-benefit analyses
• Service reliability benefits made the difference in Utrecht
References: [https://nielsvanoort.weblog.tudelft.nl/](https://nielsvanoort.weblog.tudelft.nl/)


- Van Oort, N. and R. van Nes (2009), Control of public transport operations to improve reliability: theory and practice, *Transportation research record*, No. 2112, pp. 70-76.
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Van der Bijl, Van Oort, Bukman 2018
Elsevier

Available via www.Elsevier.com
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Amsterdam May 2019

http://ppts-course.org/