Multi-criteria Evaluation of Traffic Signal Control

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Background

Questions: Value Orientation…

How to value the delay for pedestrians in comparison to those for cyclists, public transport passengers as well as car drivers and passengers?

How many litres additional fuel consumption and how many grams of exhaust emissions can be accepted, in order to accelerate a bus and reduce the delay for each passenger by about 10 s?

By which criteria can we decide to interrupt a green wave due to a pedestrian request at roadside, although it may lead to disruption of traffic flow as well as increased energy consumption and emissions?

How do we consider the side-effect of a green wave for cyclists that more stops and accelerations of motorized vehicles lead to a significantly higher air pollution concentration?

Shall we use traffic signals to influence modal split? How do we consider negative impacts on other road users and on air pollution? Shall we really deteriorate traffic flow to influence the modal share?
Background

General Conclusions

A comprehensive consideration of **various impacts** on the different road user groups is necessary.

- The impacts must be measured!
- Planning instruments must partially be further developed.

A **fair balance** is required to deal with goal conflicts.

- Rules to value and to weight the different impacts must be established.
Assessment Method

Methods to Estimate/Measure Impacts During Planning

<table>
<thead>
<tr>
<th>Traffic volume</th>
<th>Traffic flow simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric design of intersection</td>
<td>Method in RLS-90</td>
</tr>
<tr>
<td>Signal timing</td>
<td>Accident analysis with data under similar situations</td>
</tr>
</tbody>
</table>

Delay for vehicles
- Delay for individuals
- Queue lengths
- Number of stops
- Average travel speed
- Saturation degree of green times

Emission modelling
- Emissions of air pollutants
- Fuel consumption
- CO₂ emissionen

Modelling of ambient air quality
With dispersion models / statistical models

<table>
<thead>
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<th>Low / middle / high effort</th>
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</table>

Source: own illustration
Assessment Method

Overview – Costs as the Leading Criteria

Cost factors

- Average delay per person
- Number of accidents
- Number of slight injuries
- Number of severe injuries
- Number of fatalities
- PM$_{10}$ emissions
- NO$_x$ emissions
- Fuel consumption
- CO$_2$ emissions

Delay costs

- Delay costs

Accident costs

- Accident costs

Fuel and environmental costs

- Fuel and environmental costs

Sum of costs

- Sum of costs

Weighted delay costs

- Weighted delay costs

Weighted accident costs

- Weighted accident costs

Weighted fuel and environmental costs

- Weighted fuel and environmental costs

Sum of weighted costs

- Sum of weighted costs
Assessment Method
Cost Factors for Delay

Two cost components are considered:
- value of time in private transport,
- time-dependent operation cost.

<table>
<thead>
<tr>
<th>Peak hours</th>
<th>Walking</th>
<th>Cycling</th>
<th>Public transport</th>
<th>Motorised private transport</th>
<th>Heavy transport</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of time in private transport</td>
<td></td>
<td></td>
<td>Bus, tram</td>
<td>Car</td>
<td>LCV</td>
<td>HDV</td>
</tr>
<tr>
<td>Average occupancy rate [p/veh]</td>
<td>-</td>
<td>-</td>
<td>40 (bus)</td>
<td>80 (tram)</td>
<td>1.3</td>
<td>Own calculation based on BVWP 2030 (Dahl et al. 2016)</td>
</tr>
<tr>
<td>Value of travel time saving [€/p-h]</td>
<td>4.21</td>
<td>4.40</td>
<td>4.42</td>
<td>4.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time-dependent operation cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personnel cost [€/p-h]</td>
<td></td>
<td></td>
<td>20.14</td>
<td>17.64</td>
<td>20.14</td>
<td></td>
</tr>
</tbody>
</table>

If possible, the average occupancy rate of public transport vehicles should be estimated site and time specific.

In case of dynamic control strategies, the occupancy rate can be measured in real-time and considered in the online optimisation.

Impending increase in costs due to extra vehicle demand can be taken into consideration through particular weighting (see slide 9).
### Cost Factors for Accident Risks

The German Federal Highway Research Institute (BASt) annually calculates and publishes the **economic costs of traffic accidents** in Germany.

<table>
<thead>
<tr>
<th>Category</th>
<th>Damage Type</th>
<th>Cost factor (at 2012 price)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal injury</td>
<td>Fatality</td>
<td>1,161,892 €/person</td>
</tr>
<tr>
<td></td>
<td>Severe injury</td>
<td>116,151 €/person</td>
</tr>
<tr>
<td></td>
<td>Slight injury</td>
<td>4,829 €/person</td>
</tr>
<tr>
<td>Property damage</td>
<td>Accident with personal injury</td>
<td>15,606 €/accident</td>
</tr>
<tr>
<td></td>
<td>Accident with fatality</td>
<td>43,096 €/accident</td>
</tr>
<tr>
<td></td>
<td>Accident with severe injury</td>
<td>20,782 €/accident</td>
</tr>
<tr>
<td></td>
<td>Accident with slight injury</td>
<td>13,959 €/accident</td>
</tr>
<tr>
<td></td>
<td>Serious accident just with property damage</td>
<td>20,808 €/accident</td>
</tr>
<tr>
<td></td>
<td>Other accident (including alcohol accident)</td>
<td>5,951 €/accident</td>
</tr>
</tbody>
</table>

Source: Baum et al. 2011 and Bundesanstalt für Straßenwesen 2016, own illustration
Assessment Method

Cost Factors for Emissions and Energy Consumption

Cost factors for emissions based on the evaluation method for the German Federal Transport Infrastructure Plan (BVWP 2030) and another study from the Federal Environmental Agency.

<table>
<thead>
<tr>
<th>Air pollutant</th>
<th>Specific damage costs (for CO₂ damage and avoidance costs) [€/t] at 2010 price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>urban</td>
</tr>
<tr>
<td>PM exhaust</td>
<td>364,100&lt;sup&gt;1)&lt;/sup&gt;</td>
</tr>
<tr>
<td>PM&lt;sub&gt;10&lt;/sub&gt; resuspension und abrasion</td>
<td>33,700&lt;sup&gt;2)&lt;/sup&gt;</td>
</tr>
<tr>
<td>NO&lt;sub&gt;x&lt;/sub&gt;</td>
<td>15,400&lt;sup&gt;1)&lt;/sup&gt;</td>
</tr>
<tr>
<td>CO₂</td>
<td>80&lt;sup&gt;2)(3)&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup) Source: BVWP 2030 (Dahl et al. 2016, S. 111)
<sup>2</sup) Source: Methodenkonvention 2.0 zur Schätzung von Umweltkosten (Schwermer 2012a, p 5)
<sup>3</sup) This value corresponds to the middle value given in the literature.

Cost factors for energy consumption according to BVWP 2030 (at 2012 price):

- Petrol and diesel 0.71 €/l (without taxes)
- Electricity rate for private households 17.84 Cent/kWh (without taxes and fees)
# Particular Weighting

A particular weight can be applied due to political or planning reasons (permanent or situation-responsive). **A particular weight must always be justified.**

<table>
<thead>
<tr>
<th>A particular weight can be applied on:</th>
<th>Examples for planning or political reasons:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of time for pedestrians and cyclists</td>
<td>- To promote non motorized traffic</td>
</tr>
<tr>
<td>Value of time for public transport passengers</td>
<td>- To promote non motorized traffic</td>
</tr>
<tr>
<td></td>
<td>- To promote public transport</td>
</tr>
<tr>
<td>Value of time for motorized private transport and heavy transport</td>
<td>- To avoid increase in costs due to extra vehicle demand</td>
</tr>
<tr>
<td>Accident costs</td>
<td>- To promote traffic safety</td>
</tr>
<tr>
<td>Environmental costs</td>
<td>- To strengthen environmental and climate protection</td>
</tr>
<tr>
<td></td>
<td>- Impending exceedance of threshold values</td>
</tr>
</tbody>
</table>
Results from Case Studies

Introduction to Case Study 1: Pedestrian Crossing

- Pedestrian crossing on coordinated corridor
- Originally not integrated in the coordination (status: November 2016)
- Medium number of passing vehicles and low number of crossing pedestrians
- Long queues in the morning peak hours
- Features to generate alternative signal programs:
  - cycle time
  - pedestrian request (active/unactive)
  - coordination

Quelle: Straßenverkehrs- und Tiefbauamt Stadt Darmstadt
Results from Case Studies

Implementation of the Assessment Method: Pedestrian Crossing (1)

Current traffic signal program

Morning peak hour
Variable cycle time
Active pedestrian request
Uncoordinated (for vehicles)

Traffic volume in the investigated hour:
113 Pedestrians
1722 Persons in cars and LCV
17 Persons in HGV

Calculated total costs: 63 €/h

Optimum by applying a particular weighting for pedestrian delay (> factor 11)

- Walking: 3%; 2 €/h
- Motorised private transport: 31%; 19 €/h
- Heavy transport: 1%; 0.7 €/h
- PM Emissions: 4%; 3 €/h
- NOx Emissions: 3%; 2 €/h
- CO2 Emissions: 12%; 8 €/h
- Fuel and environmental costs: 66%
- Fuel consumption: 46%; 29 €/h
- Delay costs: 34%

Source: own illustration
Results from Case Studies

Implementation of the Assessment Method: Pedestrian Crossing (2)

Cost-effective signal program

Morning peak hour
Cycle time 90 s
Unactive pedestrian request
Coordinated (for vehicles)

Traffic volume in the investigated hour:
113 Pedestrians
1722 Persons in cars and LCV
17 Persons in HGV

Calculated total costs:
38 €/h

Optimum by the same weighting for all cost components

- Walking 11%; 4 €/h +2 €/h
- Motorised private transport 9%; 3 €/h -16 €/h
- Heavy transport 1%; 0.2 €/h -1 €/h
- PM Emissions 6%; 2 €/h -1 €/h
- NO\textsubscript{x} Emissions 3%; 1 €/h -1 €/h
- CO\textsubscript{2} Emissions 15%; 6 €/h -2 €/h

Fuel consumption 55%; 21 €/h -8 €/h

Fuel and environmental costs 79%

Source: own illustration
Results from Case Studies

Introduction to Case Study 2: Four-legged Intersection

- Typical four-legged intersection in the urban area
- Medium number of pedestrians
- Separated cycle lanes
- Feature to generate alternative signal programs:
  - Transit signal priority

Source: Straßenverkehrs- und Tiefbauamt Stadt Darmstadt
Implementation of the Assessment Method: Four-legged Intersection (1)

Current traffic signal program

Evening peak hour
Conditional transit signal priority

Traffic volume in the investigated hour:
- 256 Pedestrians
- 105 Cyclists
- 943 Persons in buses
- 2743 Persons in cars and LCV
- 33 Persons in HGV

Calculated total costs: 333 €/h

Results from Case Studies

Delay costs 53%

- Motorised private transport 40%; 132 €/h
- Public transport 7%; 24 €/h
- Heavy transport 2%; 7 €/h
- Accident costs 13%; 44 €/h
- Fuel and environmental costs 34%
- CO₂ Emissions 6%; 21 €/h
- NOₓ Emissions 2%; 6 €/h
- PM Emissions 2%; 8 €/h
- Fuel consumption 24%; 79 €/h

Walking 3%; 8 €/h
Cycling 1%; 3 €/h

Accident costs
Delay costs
Fuel consumption
CO₂ Emissions
NOₓ Emissions
PM Emissions
Walkin
Cycling
Public transport
Motorised private transport

Source: own illustration
Alternative signal program

Evening peak hour
No transit signal priority

Traffic volume in the investigated hour:
- 256 Pedestrians
- 105 Cyclists
- 943 Persons in buses
- 2743 Persons in cars and LCV
- 33 Persons in HGV

Calculated total costs
334 €/h
Conclusions

- **A detailed assessment is needed** to consider the various impacts of traffic control on different road user groups and to gain a fair balance.
- Today´s **simulation tools are very supportive** to allow such assessment.
- The **number of people** that are present in different modes at intersections has significant impacts on the optimisation of traffic signal control.
- The **distribution of cost components** can vary for different intersection types and signal programs. Costs for fuel and emissions are between 1/3 and 2/3 (and unneglectable).
- There is a **correlation between costs of delay and costs of fuel and emissions**, but this correlation is specific for each intersection and situation.
- **Additional research** is necessary to reflect
  - the impacts of traffic signal control on mode choice,
  - the impacts in a network scale,
  - the impacts on public transport operations.
- With adaptations of the cost values, the general approach seems to be **transferable to other countries**.
Thank you for your attention!