Keynote Topic Area C
“Traffic Management, Operations, and Safety”

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WCTR 2019 Mumbai
Multi-criteria Assessment of Traffic Signal Control

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Challenge 1
Considering All Relevant Impacts

- delay for vehicles (motorized and not motorized)
- delay for individuals
- number of stops
- queue lengths
- comfort

The impacts must be measured!

- number of traffic accidents
- number of slight injuries
- number of severe injuries
- number of fatalities

- average travel speed
- saturation degree of green times

Satisfaction of mobility needs

Improvement of economic efficiency

Increase of traffic safety

Reduction of environmental pollution

- emission of air pollutants
- ambient air quality
- noise level
- energy consumption, CO₂ emission
Challenge 2
Considering All Relevant Road Users

The number of people in each road user group must be known (or estimated).

In addition, the needs of residents must be considered.
Challenge 3
Identifying Goal Conflicts

Goal conflicts cannot be avoided.

**Example:**
Measures to promote pedestrians or cyclists at traffic signals are having impacts on other road users:
- Delay, number of stops, and queue lengths in motorized individual traffic
- Delay in public transport
- Emissions of noise and air pollutants in motorized individual traffic and heavy vehicle traffic (where applicable also roadside noise and air pollution levels)
- Fuel consumption and CO$_2$-Emissions in motorized individual traffic and heavy vehicle traffic

➔ Measures to promote one mode must always consider the impacts on other modes.
➔ Need for quantification of multiple impacts.
Challenge 4
Achieving a Fair Balance

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?

Promoting pedestrian traffic, 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?

A fair balance is required to deal with goal conflicts.
Transparent and comprehensible consideration of negative and positive impacts.
Challenge 5
Weighting and Aggregation of Impacts

Aggregation of same indicators for different modes:
- Simple accumulation (e.g. air pollution)
- Person-based aggregation (e.g. delay)

Consolidation of impacts on different goals and indicators:
- Scaling the indicators based on a command variable (cost, delay, …).
- Derivation of quantitative conversion factors from literature.

Basically, the resulting values can be aggregated with the same weight.

A particular weight can be applied (but must be justified!)
- to consider otherwise intangible effects or
- due to political or planning reasons.

Rules to value and to weight the different impacts must be established.
Challenge 6
Prioritizing Specific Modes

General promotion of walking, cycling and public transport due to less environmental impacts.

Absolute priority for one single traffic mode is not appropriate. Instead, overall impacts of measures must be considered to avoid inadequate negative impacts on other modes and parameters.

As we already consider all impacts on the different road user groups, a further prioritization is simply not necessary.

Example:
Priority for a fully occupied bus is self-evident due to the potential delay for a high number of passengers, to low fuel consumption and low emissions.

➔ Under comprehensive consideration of all impacts there is usually no need for any further prioritization.
➔ We need to apply conditional priority instead of absolute priority.
Challenge 7
Considering Impacts on Mode Choice

Mode Choice is very important for the sustainability of the transport system.

In principle, measures at traffic signals must consider the indirect impacts by medium-term or long-term changes in mode choice.

However, changes in mode choice caused by specific measures at traffic signals are hard to prove with available methods. Need for research!

- To deteriorate traffic flow for individual car traffic with intent is no suitable means of influencing mode choice! There are too many negative impacts (congestion, delay, noise and air pollution, negative health impacts, …).
- Preference for measures to influence mode choice without negative environmental impacts.
Examples for considering the specific situation in traffic signal control:

**Traffic volume**
Consideration already widely applied.
The above mentioned comments on impact estimation and fair balance should be considered.

**Number of passengers in public transport vehicles, position of public transport vehicles before/behind schedule**
From absolute priority to conditional priority!

**Air pollution levels**
Higher weight for emissions in situations with critical air quality.

**Road-side land-use and facilities**
Using signal programs which reduce the number of stops and accelerations at places and in times with higher need for noise protection.

➔ Promotion of situation-responsive, adaptive traffic signal control.
Challenges

Wrap-up – Summary of Challenges

Challenge 1  Considering all Relevant Impacts
Challenge 2  Considering all Road Users
Challenge 3  Identifying Goal Conflicts
Challenge 4  Achieving a Fair Balance
Challenge 5  Weighting and Aggregation of Impacts
Challenge 6  Prioritizing Specific Modes
Challenge 7  Considering Impacts on Mode Choice
Challenge 8  Considering Specific Situations

➡️ Which methods could be used to cope with these challenges?
Proposed Multi-criteria Assessment Method for Traffic Signal Control

Potential Methods for Impact Assessment

**Satisfaction of Mobility Needs**
- Calculations, e.g. based on Highway Capacity Manual
- Traffic Flow Simulation (macroscopic/microscopic)
- Qualitative Estimation of Comfort Levels
- Questionnaire surveys

**Increase of Traffic Safety**
- Accident Analysis based on Accident Data from comparable Situations
- Using Auxiliary Quantities (such as number of stops)

**Reduction of Environmental Pollution**
- Emission Modelling (Noise and Air Pollution)
- Modelling of Ambient Air Quality

**Improvement of Economic Efficiency**
- Traffic Engineering Calculation
- Traffic Flow Simulation (macroscopic/microscopic)
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Methods to Estimate/Measure Impacts During Planning

- Traffic volume
- Traffic flow simulation
- Geometric design of intersection
  - Method in RLS-90
- Signal timing
  - Accident analysis with data under similar situations
- 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 emissions
- Modelling of ambient air quality
  - With dispersion models / statistical models
- Ambient air quality

- Traffic volume
  - Number of traffic accidents
  - Number of slight injuries
  - Number of severe injuries
  - Number of fatalities

Source: own illustration
Proposed Multi-criteria Assessment Method for Traffic Signal Control

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

Cost factors:
- Delay costs
- Accident costs
- Fuel and environmental costs

Particular weighting:
- Weighted delay costs
- Weighted accident costs
- Weighted fuel and environmental costs

Sum of costs:

Sum of weighted costs:
Proposed Multi-criteria Assessment Method for Traffic Signal Control

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></td>
<td></td>
<td></td>
<td>Bus, tram</td>
<td>Car</td>
<td>LCV</td>
<td>HDV</td>
</tr>
<tr>
<td>Value of time in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>private transport</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average occupancy</td>
<td>-</td>
<td>-</td>
<td>40 (bus)</td>
<td>80 (tram)</td>
<td>1.3</td>
<td>Own calculation based on BVWP</td>
</tr>
<tr>
<td>rate [p/veh]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2030 (Dahl et al. 2016)</td>
</tr>
<tr>
<td>Value of travel</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 saving [€/p-h]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time-dependent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>operation cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personnel cost</td>
<td></td>
<td></td>
<td>20.14</td>
<td>17.64</td>
<td>20.14</td>
<td></td>
</tr>
<tr>
<td>[€/p-h]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></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.
## Cost Factors for Traffic Accidents

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>Description</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
Proposed Multi-criteria Assessment Method for Traffic Signal Control

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)&lt;/sup&gt;&lt;sup&gt;3)&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>rural</td>
</tr>
<tr>
<td>PM exhaust</td>
<td>122,800&lt;sup&gt;1)&lt;/sup&gt;</td>
</tr>
<tr>
<td>PM&lt;sub&gt;10&lt;/sub&gt; resuspension und abrasion</td>
<td>11,000&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)&lt;/sup&gt;&lt;sup&gt;3)&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

1) Source: BVWP 2030 (Dahl et al. 2016, S. 111)
2) Source: Methodenkonvention 2.0 zur Schätzung von Umweltkosten (Schwermer 2012a, p 5)
3) 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 und fees)
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 (activated/deactivated)
  - coordination

Source: 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
Activated 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)

Source: Boltze/Jiang 2017
Results from Case Studies

Implementation of the Assessment Method: Pedestrian Crossing (2)

Cost-effective signal program

Morning peak hour
Cycle time 90 s
Deactivated 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
- NOₓ Emissions 3%; 1 €/h -1 €/h
- CO₂ Emissions 15%; 6 €/h -2 €/h

Fuel and environmental costs 79%
Delay costs 21%

Source: Boltze/Jiang 2017
Introduction to Case Study 2: Four-leg Intersection

- Typical four-leg 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
Results from Case Studies

Implementation of the Assessment Method: Four-leg 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

Source: Boltze/Jiang 2017
Results from Case Studies

Implementation of the Assessment Method: Four-leg Intersection (2)

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

Calculation of costs:
- Walking: 3%; 8 €/h
- Cycling: 1%; 3 €/h
- Public transport: 12%; 39 €/h
- Motorised private transport: 36%; 122 €/h
- Heavy transport: 2%; 6 €/h
- CO₂ Emissions: 6%; 21 €/h
- NOₓ Emissions: 2%; 6 €/h
- PM Emissions: 2% €/h
- Accident costs: 13%; 44 €/h
- Fuel consumption: 23%; 77 €/h
- Fuel and environmental costs: 34%
- Delay costs: 53%
- Accident costs: 13%
- Motorised private transport: 36%; 122 €/h
- Public transport: 12%; 39 €/h

Source: Boltze/Jiang 2017
Results from Case Studies

Conclusions from the Case Studies

- **Challenges can be tackled** by detailed assessment of traffic signal control
  - considering *all most* relevant impacts (Challenge 1),
  - considering all road users (Challenge 2),
  - identifying goal conflicts (Challenge 3), and
  - achieving a fair balance (Challenge 4).

- **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.

- **Weighting and aggregation of impacts can be done by monetarization.** (Challenge 5)

- Additional prioritization of specific modes is not needed. (Challenge 6)

- **Medium/long-term impacts on mode choice need additional research.** However, deterioration of traffic flow is not a proper mean to influence mode choice. (Challenge 7)

- Considering specific situations calls for **flexible, adaptive control.** (Challenge 8)
Final Remarks

- **Making things better is our intrinsic motivation** to do research and to work as a transport planner or traffic engineer.

- Although it needs significant efforts, careful and **comprehensive impact assessment** is most important to make our work really beneficial for our societies.

- With adaptations of the cost values, the presented approach seems to be **transferable to other countries and to other traffic engineering systems**.

- **International exchange** on research and best practice in traffic engineering and specifically on assessment methods is very important.

Special Session of SIG C2 (ID: C2_SS1a, C2_SS1b)
**International Practice on Road Traffic Signal Control**
Room: LC 101, Time: 09:30~12:20, May 28, 2019
Thank you for your attention!