Motivation: Bus lanes vs. Road pricing?

“[...] reserved bus lanes and, inferentially, separate expressway ramps and other forms of preferential access by buses to road capacity are capable of substantially ameliorating our apparent political inability to price peak-period road services efficiently. “

(Mohring, 1983)

Berglas et al. (1984) showed that under certain assumptions the mixed-traffic operation is never superior and is more likely to be inferior than providing separate lanes for buses and cars.

“[...] car congestion pricing, optimal transit subsidization and dedicated bus lanes produce an important and relatively similar social benefit”

(Basso and Silva, 2010)

How can agent-based simulation tools be used to evaluate policy gains from dedicated bus lanes vs. first-best road pricing?
MATSim: Multi-Agent Transport Simulation

- Stochastic User Equilibrium
- Boundary/initial conditions (land use, transport network, demographics, etc.)
- List of choice dimensions that are adapted
- Parallel Queue Model Approach
- Time step: 1sec over 24h period

Choice dimensions

- Route choice
- Mode Choice
- Departure time choice
- (Secondary activity-location choice)

Constraints

- Flow and storage capacity of the network
- Bus vehicle capacity
- Dwell times

Supply data
Facilities
Population
Demand

Initial demand

Execution
Scoring

Relaxation process

Replanning

Evaluation

Initial demand modeling

Relaxed demand

Stochastic User Equilibrium
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MATSim: Details of Public Transport and Road Pricing

Public Transport
- Interaction of bus and cars (incl. bus bays)
- Frequency and Fare
- Vehicle capacity
- Dwell times
- No overtaking
- No comfort variability (e.g. crowding, seat availability)

Road Pricing
- Additional cost of every or selected links


External cost: \[ C(t_0) \approx t^e(t_0) - \tau^{\text{free}} - t_0. \]

Queue encountered when entering the link at \( t_0 \) to dissolves at \( t_e(t_0) \)
Corridor scenario - Supply

3 Scenarios:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base scenario</td>
<td>3 mixed lanes</td>
</tr>
<tr>
<td>Bus lane scenario</td>
<td>2 car lanes 1 bus lane</td>
</tr>
<tr>
<td>First-best road pricing</td>
<td>3 mixed lanes</td>
</tr>
</tbody>
</table>

Lane capacity: 1000 veh/h
Bus lane capacity: \(143 \times \frac{60 \text{ min}}{2 \text{ min}} = 4290 \text{ pax/h}\)

- 20000 agents (10% captive pt riders)
- Distance between bus stops: 600m
- Bus frequency: 2 min
- Bus capacity: 139
- Bus length: 12m
- Dwell time per passenger: 1 sec
Initial Demand and Behavioral parameters

\[
\begin{align*}
\beta_{0,\text{car}} &= -0.3 \text{ [utils]} \\
\beta_{\text{tr,walk}} &= -0.27 \text{ [utils/h]} \\
\beta_{\text{earlyDeparture}} &= -2.88 \text{ [utils/h]} \\
\beta_{\text{lateArrival}} &= -2.88 \text{ [utils/h]} \\
\beta_{\text{lineSwitch}} &= -0.016 \text{ [utils]} \\
\end{align*}
\]

Car: 0.40 cent / km
PT: 3.50 AUD per ride

## Corridor Scenario – Key Numbers

<table>
<thead>
<tr>
<th></th>
<th>Base scenario</th>
<th>Bus lanes scenario</th>
<th>First – best pricing</th>
</tr>
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<tbody>
<tr>
<td><strong>Avg. Car Speed</strong></td>
<td>22.72 km/h</td>
<td>23.96 km/h</td>
<td>36.92 km/h</td>
</tr>
<tr>
<td><strong>Avg. Bus Speed</strong></td>
<td>28.24 km/h</td>
<td>37.24 km/h</td>
<td>36.72 km/h</td>
</tr>
<tr>
<td><strong>Avg. Journey Travel Time</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>27.97 min</td>
<td>27.34 min</td>
<td>14.00 min</td>
</tr>
<tr>
<td>Bus</td>
<td>58.30 min</td>
<td>55.84 min</td>
<td>47.08 min</td>
</tr>
<tr>
<td>Walk</td>
<td>39.18 min</td>
<td>39.87 min</td>
<td>36.44 min</td>
</tr>
<tr>
<td><strong>Avg. In-vehicle Distance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>7894 m</td>
<td>7941 m</td>
<td>7558.11 m</td>
</tr>
<tr>
<td>Bus</td>
<td>6432 m</td>
<td>6789 m</td>
<td>6433 m</td>
</tr>
<tr>
<td></td>
<td>+ (1559 m)</td>
<td>+ (1693 m)</td>
<td>+ (1559 m)</td>
</tr>
<tr>
<td>Walk</td>
<td>1507 m</td>
<td>1533 m</td>
<td>1401 m</td>
</tr>
</tbody>
</table>
Corridor – Mode share

Where do the “mode switchers” come from?

- **Base**: 24.93% (bus), 41.33% (bus lanes), 28.12% (First best pricing)
- **Bus lanes vs. base**: 69.33% (bus), 51.68% (bus lanes), 66.45% (First best pricing)
- **First – best pricing vs. base**: Bus: 75.36%, Car: 16.85%, Walk: 6.10% (bus), 36.94% (car), 2.04% (walk)
Corridor – Travel time changes compared to base scenario

Bus lanes vs. base

Avg. travel time change in minutes

Bus lanes vs. base

Avg. travel time change in minutes
Corridor – In-vehicle distance of mode changers

How far do persons who switch modes go?

Bus lanes vs. base

First – best pricing vs. base

Number of persons

Travel distance

Travel distance
Corridor – Travel time distribution

<table>
<thead>
<tr>
<th>Travel time (min)</th>
<th>Number of journeys</th>
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Legend:
- bus
- car
- walk
Corridor – Bus Occupancy – Service starting at 08.10 am

Bus capacity constraint

Buses are full during the peak hour - travelers have to wait for the next service ➔ benefit loss
Buses are too cheap or should run at even higher frequency?
Corridor – Bus Bunching

Significant bus bunching - running higher frequency might not be a solution
Corridor Departure Times – Morning peak

Bus lanes

First – best pricing

All modes

Car

Bus

0 500 1000 1500

0 500 1000 1500

0 500 1000 1500

0 500 1000 1500

6.0 7.0 8.0 9.0 10.0 11.0

6.0 7.0 8.0 9.0 10.0 11.0

6.0 7.0 8.0 9.0 10.0 11.0

6.0 7.0 8.0 9.0 10.0 11.0

Base scenario Bus lanes First – best pricing
Extended Sioux Falls Scenario

- 817864 agents (10% captive pt riders)
- Distance between bus stops: 600m
- Bus frequency: 6 min
- Bus capacity: 90
- Bus length: 17.6m
- Dwell times: 1 sec

Extended Sioux Falls Network with public transport according to Abdullal and LJ LeBlanc (1979)

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<tr>
<td>Bus lane scenario</td>
<td>1-2 car lanes 1 bus lanes</td>
</tr>
<tr>
<td>First-best road pricing</td>
<td>2-3 mixed lanes</td>
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Lane capacity: 510 – 1740 veh/h
Bus lane capacity: $90 \times \frac{60 \text{ min}}{6 \text{ min}} = 900 \text{ pax/h}$
Sioux Falls Simulation
## Sioux Falls Scenario – Key Numbers

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<tr>
<td><strong>Avg. Car Speed</strong></td>
<td>21.41 km/h</td>
<td>24.29 km/h</td>
<td>31.51 km/h</td>
</tr>
<tr>
<td><strong>Avg. Bus Speed</strong></td>
<td>25.59 km/h</td>
<td>26.17 km/h</td>
<td>42.51 km/h</td>
</tr>
<tr>
<td><strong>Avg. Journey Travel Time</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Car</td>
<td>33.99 min</td>
<td>35.17 min</td>
<td>18.73 min</td>
</tr>
<tr>
<td>Bus</td>
<td>58.39 min</td>
<td>55.59 min</td>
<td>51.48 min</td>
</tr>
<tr>
<td>Walk</td>
<td>50.42 min</td>
<td>50.72 min</td>
<td>46.50 min</td>
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<tr>
<td><strong>Avg. In-vehicle Distance</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>10656 m</td>
<td>10765 m</td>
<td>10496 m</td>
</tr>
<tr>
<td>Bus</td>
<td>3201 m + (1547 m)</td>
<td>3277 m + (1480 m)</td>
<td>3366 m + (1503 m)</td>
</tr>
<tr>
<td>Walk</td>
<td>1931 m</td>
<td>1942 m</td>
<td>1786 m</td>
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Sioux Falls – Mode share

Where do the “mode switchers” come from?

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<tbody>
<tr>
<td>Bus</td>
<td>13.77%</td>
<td>17.37%</td>
<td>15.61%</td>
</tr>
<tr>
<td>Car</td>
<td>72.87%</td>
<td>68.83%</td>
<td>72.63%</td>
</tr>
<tr>
<td>Walk</td>
<td>13.36%</td>
<td>13.80%</td>
<td>11.76%</td>
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Bus lanes vs. base

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<th>Mode</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Bus</td>
<td>61.01%</td>
</tr>
<tr>
<td>Car</td>
<td>20.56%</td>
</tr>
<tr>
<td>Walk</td>
<td>11.59%</td>
</tr>
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First – best pricing vs. base

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<td>Bus</td>
<td>44.27%</td>
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<tr>
<td>Car</td>
<td>23.18%</td>
</tr>
<tr>
<td>Walk</td>
<td>6.78%</td>
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</table>
Sioux Falls Departure Times – Morning peak

- **Bus lanes**
- **First – best pricing**

**All modes**

- **Car**
- **Bus**

**Base scenario**  |  **Bus lanes**  |  **First – best pricing**
Sioux Falls – Spatial Distribution of Travel Time Changes

Travel time changes (home – work – home) in min according to home location
Conclusion

1. Introduction of bus lanes **increases avg. travel speed for car and buses**, but can decrease avg. travel time (mode switch from car to slower buses)

2. Bus lane achieves higher avg. speed predominantly through **mode shift**, where road pricing uses other dimensions as time choice, route choice

3. Based only on travel times bus lanes seems to have negative welfare effect, but lower congestion might have **positive effects not captured by the model**
   - More comfortable travel experience
   - Less accidents
   - Less pollution

4. Agent-based approach is **scalable** and allows to conduct cost-benefit analysis on the large scale networks

5. Classical welfare analysis in agent-based simulations remains challenging
Outlook

Can we trust these results?
- Need to determine confident intervals with various simulations using different random seeds
- Investigation of sensitivity to behavioral parameters
- Investigation of sensitivity to supply constrains (e.g. public transport fares, headways)
- Investigation of demand dependency (how much congestion and how many bus users per bus lane do we need to justify bus lanes?)

→ Computationally intensive tasks
- Additional degree of realism (user heterogeneity, variable dwell times)
- Superposition of policies (road pricing and bus lanes)
- Would first-best pricing improve by incorporating delay caused to public transport users?