Exploring the safety level of a signalized roundabout with crossing BRT: an observational pilot, in Israel*

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Background: Public transport for sustainable urban mobility

- **Bus priority systems** ~ common solution to promote public transport use in big cities, Bus Rapid Transit (**BRT**) ~ the ultimate form

- BRT systems ~ in Brazil, Colombia, India, Turkey, China, Australia, USA

- The implementation requires substantial changes in **urban road infrastructure**

- Beside evident improvement of PT services, the impacts on traffic safety can be mixed ~ a possible increase in traffic injury of other road users - vehicles, pedestrians*

  - In Israel: one of the main policies promoted by the Ministry of Transport
    - 2013: a BRT system “Matronit” introduced in Haifa metropolitan area
    - over 40 km of bus priority routes for the operation of articulated buses

*Duduta et al., 2015; Vecino-Ortiz and Hyder, 2015; Gitelman et al., 2020*
Background: further extension of the BRT network

- **New setting** - a signalized multi-lane roundabout with a bi-directional BRT running through its center, and traffic lights at the points of crossing the BRT route.

- **Not familiar** to Israeli drivers. **Concerns** regarding its safety: incompliance with traffic lights by vehicles; drivers not understanding the new arrangement.

- **In the world**: experience of roundabouts with traffic lights and/or giving priority to a BRT crossing*; but **little information** about the effects on driver behaviours and safety.

- MOT in Israel decided to conduct a **pilot** ~ initial operation of the setting, at one site, accompanied by an observational study.

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*Finn et al., 2011; Brilon, 2011; Fontaine et al., 2015; Jurewicz et al., 2015; Soteropoulos & Stadlbauer, 2017*
The study topic

**Aim:** to explore the safety level of a signalized roundabout with crossing BRT based on observations of driver behaviours.

- **Focus** on safety-related behaviours: red-light violations, interactions in the roundabout entrance areas, giving right-of-way to pedestrians
- New arrangement, a “before-after” comparison not possible

The study sought to characterize the safety level of the setting by estimating risky behaviours observed and comparing them with indicators reported in the literature, e.g. for signalized intersections.

- **The pilot setting** - a four-legged two-lane roundabout, with a central bi-directional BRT route. Next to one side ~ **BRT stops**. Pedestrian crosswalks ~ at three entrances.
- **Traffic lights ~ in two areas:** two standard three-color lights for vehicle traffic; BRT traffic lights (a tram-signal style); standard traffic lights for pedestrians near the BRT stops. All traffic lights - synchronized and **activated by approaching BRT**
Methodology: Data collection

- **Video-records** for the study ~ by the traffic control center, starting from the third week of the BRT operation.
- Camera records - at **4 areas** of the roundabout: 2 near the traffic lights, 2 in the entrance areas; zones *not identical*
Methodology: Data preparation and analysis

- **In each area**, 30 hours of video-records in weekdays, btw hours 8-18
- Vehicle samples extracted to characterize **driver behaviours**:
  - In the traffic lights' areas, when the BRT passes ~ **drivers' compliance with a red light**
  - In the traffic lights' areas, without the presence of a BRT ~ **unusual driver behaviours**, e.g. stopping or slowing down during a green/yellow light
  - In the entrance areas, with and without the BRT presence in the roundabout ~ **interactions btw an incoming vehicle and vehicles traveling in the roundabout or a crossing pedestrian**
- Using pre-defined forms and rules ~ **google forms**.
- First, all the times when the traffic lights changed to red documented. Subsequently, vehicles sampled* to reflect behaviours **in 5 situations**:
  - **Case 1** – vehicles that approached the traffic lights in ± 10 sec before and after the appearance of a red signal
  - **Case 2** – vehicles that passed through the traffic lights' area during a green signal
  - **Case 3** – vehicles that entered the rbt when the traffic lights were red**
  - **Case 4** – vehicles that entered the rbt when the traffic lights were green and other vehicles were present**
  - **Case 5** – vehicles that entered the rbt when the traffic lights were green and no other vehicles present

* Sample size required acc. to common rules, SPI Manual (2007) ~ of 150-300 vehicles, a uniform selection over all the hours.
** Traffic conditions' categories: flowing, slow, standing
Methodology: Data preparation and analysis (cont.)

- If, in W2/E4, a red-light running identified, a detailed re-examination of each case
- If, in W1/E3, the vehicle did not slow down and traffic was present in the roundabout, a re-examination of each interaction, to identify conflicts

Conflict ~ braking and/or change in the direction of vehicle travel to prevent a collision

- Descriptive data analyses ~ summary values of behaviour indicators, with confidence levels. Behaviour indicators ~ a percentage of a certain feature out of the sample collected.

  Compared under various traffic conditions ~ z-test for proportions

- The values observed in the study compared with behaviour indicators in the literature
Results: Traffic characteristics in the roundabout

<table>
<thead>
<tr>
<th>Zone</th>
<th>Total # of red light appearances</th>
<th>Average # of red light appearances, per hour</th>
<th>Red lights' duration, seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>mean</td>
</tr>
<tr>
<td>W1-W2</td>
<td>393</td>
<td>13.1</td>
<td>14.2</td>
</tr>
<tr>
<td>E3-E4</td>
<td>575</td>
<td>14.4</td>
<td>12.9</td>
</tr>
</tbody>
</table>

During the day, the mean number of traffic light closures btw 12–15 per hour ~ on average, BRT passed **every 4-5 minutes**.

**Traffic conditions:**

- in **E3** ~ 100% of the entering vehicles under *flowing* traffic conditions within the roundabout.
- in **W1** ~ 82% of the entering vehicles under *flowing*, 9% under *slow* and about 9% - under *standing* traffic conditions.
- Total samples: 1,240 vehicles in the traffic lights' areas, 1,555 vehicles in the entry areas. Mostly, **passenger/small commercial cars**: 91%–97% in W zones, 89%–94% in the E zones.
- In various samples: **trucks** ~ between 2% and 8%, **motorcycles** ~ between 1% and 3%.
- Pedestrian/ bicycles presence ~ rare.
Results: Drivers' noncompliance with a red-light

<table>
<thead>
<tr>
<th>Zone</th>
<th>dates</th>
<th>Sample of vehicles that arrived at red</th>
<th>Rate of noncompliance to red-light: mean (sd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2</td>
<td>various</td>
<td>52-78</td>
<td>6% - 20%</td>
</tr>
<tr>
<td></td>
<td>total</td>
<td>194</td>
<td>14.4% (2.5%)</td>
</tr>
<tr>
<td>E4</td>
<td>total</td>
<td>38</td>
<td>0</td>
</tr>
</tbody>
</table>

- **In W2**: 14% of noncompliance ~ **1 driver out of 7**, or **1-2 red-light violations, per hour**. The rate is not low, but not exceptional compared to **signalized intersections**: e.g. Retting et al. (2003) – international summary ~ 0.28–0.34 per a traffic-lights' cycle, or **1 out of 3 cycles**
  Dias and Dissanayake (2014), USA: **1-2 red-light violations per hour**

- **Most events** (86%) **within 1-2 seconds** of the red-light appearance. **In literature**: safety risk is mainly attributed to the events in > 3 seconds after the red-light appearance (Lum and Wang, 2003; Fitzsimmons et al., 2015; Lindheimer et al., 2016)

- No hour associated with a higher rate of such events (at 0.05 sig.)

*In this event, a vehicle crossed the BRT route after the BRT has passed*
Results: Drivers' noncompliance with a red-light (cont.)

- A detailed examination of the red-light running events (28): risk of collision was in one case (3.6%), btw 2 following vehicles

- Among all the events - the BRT (bus) slowed down or stopped, while approaching the common zone, in 3 cases (10.7%); in no case “near collision” - the vehicle cleared the BRT route sufficient time before the BRT arrival.

- Can be site-specific: the traffic lights activated by approaching BRT, the BRT speeds in the roundabout not high + sufficient sight distance for BRT within the roundabout island before crossing the "vehicle zone"
Results: Unusual vehicle behaviours near the traffic lights

<table>
<thead>
<tr>
<th>Zone, Case</th>
<th>Traffic light</th>
<th>Sample of vehicles</th>
<th>Slowed down</th>
<th>Stopped</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2, Case 1</td>
<td>green</td>
<td>468</td>
<td>1.3%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>yellow</td>
<td>114</td>
<td>0</td>
<td>1.8%</td>
</tr>
<tr>
<td>W2, Case 2</td>
<td>green</td>
<td>201</td>
<td>1.5%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>yellow</td>
<td>11</td>
<td>0</td>
<td>27.3%</td>
</tr>
<tr>
<td>W2, total</td>
<td>green</td>
<td>669</td>
<td>1.4%</td>
<td>--</td>
</tr>
<tr>
<td>E4, Case 1</td>
<td>green</td>
<td>48</td>
<td>10.4%*</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>yellow</td>
<td>11</td>
<td>0</td>
<td>27.3%#</td>
</tr>
<tr>
<td>E4, Case 2</td>
<td>green</td>
<td>166</td>
<td>6.6%*</td>
<td>0.6%</td>
</tr>
<tr>
<td>E4, total</td>
<td>green</td>
<td>214</td>
<td>7.5%**</td>
<td>--</td>
</tr>
</tbody>
</table>

*p<0.05, **p<0.01, *p<0.06 in comparison with W2 zone

- In **W2**: rare ~ 1% slowed down at a green light and ~ 2% stopped at a yellow light.
- In **E4**: more vehicles slowed down at a green light ~ 8%, and 27% stopped at a yellow light (mostly, sig. differences vs. W2).
- In **E4**: lower vehicle traffic, full compliance with the red light and “excessive caution” - vehicles passing at green/ yellow lights tended to slow down or stop more than usual.
Results: Vehicle behaviours at roundabout entrances

<table>
<thead>
<tr>
<th>W1</th>
<th>Traffic conditions in the roundabout</th>
<th>Sample of vehicles</th>
<th>Slowed down</th>
<th>Stopped</th>
<th>No speed change (# of cases)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case 3</td>
<td>Flowing &amp; in red</td>
<td>75</td>
<td>33%</td>
<td>59%</td>
<td>8% (6)</td>
<td>0.16*</td>
</tr>
<tr>
<td>slow</td>
<td></td>
<td>12</td>
<td>50%</td>
<td>50%</td>
<td>0%</td>
<td>--</td>
</tr>
<tr>
<td>standing</td>
<td></td>
<td>31</td>
<td>16%</td>
<td>68%</td>
<td>16% (5)</td>
<td>0.02'</td>
</tr>
<tr>
<td>no vehicles</td>
<td></td>
<td>20</td>
<td>10%</td>
<td>0%</td>
<td>90%</td>
<td>0.61#</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>138</td>
<td>28%</td>
<td>51%</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>Case 4</td>
<td>flowing in green</td>
<td>525</td>
<td>34%</td>
<td>63%</td>
<td>3% (18)</td>
<td>0.00'</td>
</tr>
<tr>
<td>slow</td>
<td></td>
<td>54</td>
<td>26%</td>
<td>74%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>standing</td>
<td></td>
<td>30</td>
<td>10%</td>
<td>90%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>610</td>
<td>32%</td>
<td>65%</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Case 5</td>
<td>no vehicles</td>
<td>141</td>
<td>6%</td>
<td>1%</td>
<td>94%</td>
<td></td>
</tr>
</tbody>
</table>

- **No traffic** in the roundabout: most entering vehicles (~ 90%) did not slow down, unaffected by the traffic signal.

- **In the presence of traffic**: rates of not slowing down substantially lower. But "no speed change" in 3%–16% in W1 and 12%–23% in E3; higher under the red vs. green lights.

- **Events re-examined to identify conflicts**: in most cases, when a vehicle entered the rbt, there was no vehicle traveling in the nearby lane, or entering vehicles used the rbt for a right-turn. In 1 case & the vehicle that entered caused the vehicle inside the roundabout to brake (a conflict). The prevalence of conflicts (1%) not high but comparable to other traffic arrangements.
Results: Giving right-of-way to pedestrians

<table>
<thead>
<tr>
<th>Zone, Case</th>
<th>Sample of vehicles observed</th>
<th>Pedestrian was present</th>
<th>Vehicle did not give right-of-way to pedestrian</th>
<th>Rate of pedestrian presence</th>
<th>Rate of not giving right-of-way to pedestrian</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1 + E3, all Cases</td>
<td>1295</td>
<td>8</td>
<td>3</td>
<td>0.6%</td>
<td>37.5%</td>
</tr>
</tbody>
</table>

- In < 1% of the cases of vehicles entering the roundabout, there was a pedestrian present at the crosswalk. In ~ 38%, the driver did not give right-of-way to a pedestrian.
- Not surprising, as not-yielding to a pedestrian is known phenomenon, especially at multi-lane crosswalks* and in multi-lane roundabouts**

*e.g. Gitelman et al., 2019
**Salamati et al., 2013; Jurewicz et al., 2015
Conclusions

- The safety level of the study roundabout was comparable to other settings, yet risky driver behaviours were present both near the traffic lights and in the entrance areas.

- The compliance of drivers with a red-light in the roundabout was similar to that at a signalized intersection. In light of the red-light violations, the BRT’s speed should not be increased.

- The study did not support the concerns about the development of risky situations due to drivers' confusion by the new arrangement.

- The study found substantial rates of not slowing down by vehicles entering a multi-lane roundabout, with possible safety risks ~ the topic needs future research.

- To proceed with the operation of the study site. The question of expanding the pilot experience to other sites ~ more complex, as some findings seem to be site-specific.

- For practical needs, further research ~ to better fit infrastructure design solutions to various traffic and road conditions.
Thank You for Your Attention!

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