Theoretical investigation of emission and delay based intersection controlling and synchronizing in Budapest

Ferenc Meszaros / Adam Torok

1 Introduction

Vehicle flows carry people, distribute industrial freight and work equipment on road network elements (Torok, Berta, 2010). Majority of these road vehicles are driven by internal combustion engines; therefore besides practical use they also create a lot of problems, such as air pollution and particulate matter by combustion products, noise and vibration. Various problems caused by vehicles are discussed in the article written by Makaras (Makaras, et. al., 2011). Wang (Wang. et. al., 2008) presented various methods of fuel consumption and engines’ emission measuring as well as coefficients of efficiency. Szendro (Szendro, et. al., 2012) investigated climate fluctuation changes and energy consumption in Hungary. Smit (Smit, et. al., 2008) presented and generalize three emission models, where the impact of congestions on motor vehicles’ emission is evaluated differently and present indicators to identify transport congestions. Jakimavičius, and Burinskienė (Jakimavičius, M.; Burinskienė M., 2010) investigated vehicle flow optimization methods and their application possibilities when informing traffic users about the situation in the city. Signal control is a traditional method to improve traffic efficiency at intersection areas, and the related signal design problems have been investigated for several decades. According to the traffic flow state, two categories of signal design problems are addressed so far: static-flow-based problems and dynamic-flow-based problems (Ren et. al., 2013). In order to define the level of service of intersections, it is necessary to know some of the basic parameters of traffic flow, like flow intensity, vehicles velocity and density (Bogdanović et. al., 2013). Social cost intersection controlling is an up-to-date research topic as it could increase the level of intersection (Meszaros, Markovits-Somogyi, Bokor, 2012). This article gives an example of applying models of traffic controlling in the basis of emission and delay based controlling and can be a solid base of further tolling development (Torok, Siposs, Meszaros, 2011). The article not only investigates one intersection, but the possibility of synchronising the controlled intersections.
2 Methodology

An intersection can be characterized by directions and lanes. When describing traffic flows, a traffic lane is used as a key word. An assumption is taken that cars cannot drive on an opposite traffic lane; therefore, the road is split into separate traffic lanes and two-way roads are described in the mathematical model as a separate one-way road with one or several traffic lanes (Juņevičius, Bogdevičius, Torok, 2011). In this model a traffic lane segment is taken as a finite-length line that ends in the intersection. Traffic flow was measured and emission and delay based cost was calculated as follows (1), (2):

\[ TTS_i = \sum_{k=1}^{p} \left( v_{i,k} \cdot \tau_{i,k} \right) \]  

(1)

where,

- \( TTS_i \): Estimated cost or revenue of travel time saving by direction i. [HUF]
- \( v_{i,k} \): Value of travel time for passenger k at direction i. [HUF/s]
- \( \tau_{i,k} \): Waiting time in the lane at direction i. [s]

\[ EC_i = \sum_{j=1}^{m} \sum_{l=1}^{n} \left( \varepsilon_{j,l} \cdot \tau_{i,k} \cdot \rho_{i,j} \right) \]  

(2)

where,

- \( EC_i \): Estimated Environmental Cost of direction i. [HUF];
- \( \varepsilon_{j,l} \): Environmental emission factor of vehicle category j in directory i. [g/s] (Csikos, Varga, 2011), (Zolody, 2011), (Bereczky, 2012), (Barabas, Todorut, 2011), (Negoiţescu, Tokar, 2013), (Makarevičienė, et. al., 2013);
- \( \tau_{i,k} \): Waiting time in the lane at direction i. [s] (Gal, 2012);
- \( \rho_{i,j} \): Cost of environmental emission for pollutant l [HUF/g] (Tánczos, Bokor, 2004)

For modeling purposes not only the detailed plan of each intersection was available but the plan of signaling as well (Fig. 1).

Authors have conducted a traffic measurement of each intersection in peak-time in order to estimate the traffic related social costs.

3 Results

3.1 Place 1: Gellert sqr

Authors firstly determined the optimal green time for intersection (place 1: Gellert sqr.) in case of minimizing delay (1), (Tab. 1.). For the optimal green times the total cost was determined (Tab. 2.). Authors determined the optimal green time for intersection (place 1: Gellert sqr.) in case of minimizing environmental pollution (2), (Tab. 3.). For the optimal green times the total cost was determined (Table 4.)
### Tab. 4. Cost of environmental emission

<table>
<thead>
<tr>
<th>Direction 1: from Budafoki str</th>
<th>Direction 2: from Gellert sqr</th>
<th>Direction 3: from Múgyetem quay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental emission cost of current signalling [HUF/h]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Car</td>
<td>196.91</td>
<td>47.56</td>
</tr>
<tr>
<td>Goods Vehicle</td>
<td>9.57</td>
<td>2.32</td>
</tr>
<tr>
<td>sum of direction</td>
<td>206.19</td>
<td>49.88</td>
</tr>
<tr>
<td>total sum</td>
<td>307.69</td>
<td></td>
</tr>
<tr>
<td>Environmental emission cost of new signalling [HUF/h]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Car</td>
<td>147.61</td>
<td>70.76</td>
</tr>
<tr>
<td>Goods Vehicle</td>
<td>7.25</td>
<td>3.48</td>
</tr>
<tr>
<td>sum of direction</td>
<td>154.57</td>
<td>74.24</td>
</tr>
<tr>
<td>total sum</td>
<td>297.83</td>
<td></td>
</tr>
<tr>
<td>Change [%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sum of direction</td>
<td>-25.08%</td>
<td>48.81%</td>
</tr>
<tr>
<td>total sum</td>
<td>-3.14%</td>
<td></td>
</tr>
</tbody>
</table>

### Tab. 5. The current and optimal (minimized environmental pollution) green times

<table>
<thead>
<tr>
<th>Direction 1: from Petőfi bridge</th>
<th>Direction 2: from Gellert sqr</th>
<th>Direction 3: from Alsorakpart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current green time [s]</td>
<td>35</td>
<td>37</td>
</tr>
<tr>
<td>Optimal in case of minimal delays [s]</td>
<td>42</td>
<td>44</td>
</tr>
</tbody>
</table>

### Tab. 6. Cost of delay

<table>
<thead>
<tr>
<th>Direction 1: from Petőfi bridge</th>
<th>Direction 2: from Gellert sqr</th>
<th>Direction 3: from Alsorakpart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time delay cost of current signalling [HUF/h]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Car</td>
<td>23152</td>
<td>25396</td>
</tr>
<tr>
<td>total sum</td>
<td>73705</td>
<td></td>
</tr>
<tr>
<td>Travel time delay cost of new signalling [HUF/h]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Car</td>
<td>14587</td>
<td>15607</td>
</tr>
<tr>
<td>total sum</td>
<td>68486</td>
<td></td>
</tr>
</tbody>
</table>

### Tab. 7. The current and optimal (minimized environmental pollution) green times

<table>
<thead>
<tr>
<th>Direction 1: from Petőfi bridge</th>
<th>Direction 2: from Gellert sqr</th>
<th>Direction 3: from Alsorakpart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current green time [s]</td>
<td>35</td>
<td>37</td>
</tr>
<tr>
<td>Optimal in case of minimal delays [s]</td>
<td>42</td>
<td>44</td>
</tr>
</tbody>
</table>

### Tab. 8. Cost of environmental emission

<table>
<thead>
<tr>
<th>Direction 1: from Petőfi bridge</th>
<th>Direction 2: from Gellert sqr</th>
<th>Direction 3: from Alsorakpart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental emission cost of current signalling [HUF/h]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Car</td>
<td>56.26</td>
<td>61.77</td>
</tr>
<tr>
<td>Goods Vehicle</td>
<td>1.45</td>
<td>1.45</td>
</tr>
<tr>
<td>sum of direction</td>
<td>57.71</td>
<td>63.22</td>
</tr>
<tr>
<td>total sum</td>
<td>183.86</td>
<td></td>
</tr>
<tr>
<td>Environmental emission cost of new signalling [HUF/h]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Car</td>
<td>35.38</td>
<td>37.99</td>
</tr>
<tr>
<td>Goods Vehicle</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td>sum of direction</td>
<td>36.25</td>
<td>38.86</td>
</tr>
<tr>
<td>total sum</td>
<td>171.1</td>
<td></td>
</tr>
<tr>
<td>Change [%]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sum of direction</td>
<td>-36.99%</td>
<td>-38.55%</td>
</tr>
<tr>
<td>total sum</td>
<td>-6.95%</td>
<td></td>
</tr>
</tbody>
</table>

### 3.2 Place 2: Bertalan L. str.

The same methodology was used to calculate the costs and green times related to Place 2: Bertalan L. str (1), (Tab. 5.). For the optimal green times the total cost was determined (Tab. 6.). Authors determined the optimal green time for intersection (place 2: Bertalan Str.) in case of minimising environmental pollution (2), (Tab. 7.). As it can be seen in Tab. 7 the same result was found as in case of delay minimising. It can be easily understandable as there are no buses or goods vehicles in the traffic flow. For the optimal green times the total cost was determined (Tab. 8.).
3.3 Place 3: Egry J. str.

The same methodology was used to calculate the costs and green times related to Place 3: Egry J. str, (1), (Tab. 9.). For the optimal green times the total cost was determined (Tab. 10.). Authors determined the optimal green time for intersection (place 3: Irinyi J. str) in case of minimizing environmental pollution (2), (Tab 11.). For the optimal green times the total cost was determined (Tab. 12.).

4 Analysis

After analyzing the intersections separately the authors have investigated the possibility of synchronizing of basis of delay minimizing or minimizing environmental pollution. Due to the same optimal solution for Place 2: Bertalan L. str and Place 3: Egry J. str the synchronizing can be easily done in both case (See Fig. 2 and Fig. 3).

5 Conclusions

In this article we have introduced the social cost based intersection synchronizing as a form of network controlling. As the single programmed intersections can be grouped to chains and can be synchronized the same algorithm can be derived for more complex social cost based intersections (Fig. 4.). As it has been shown the social interest would lead to different optimum in case of intersection controlling compared to single program (traffic) controlled situation. Further reserved potential can be recovered with synchroning these social cost controlled intersections.
Tab. 12. Cost of delay

<table>
<thead>
<tr>
<th>Direction 1: from Petőfi bridge</th>
<th>Direction 2: from Gellért sqr</th>
<th>Direction 3: from Irinyi J. str</th>
<th>Direction 4: from Egry J. str</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental emission cost of current signalling [HUF/h]</td>
<td>Passenger Car</td>
<td>156.6</td>
<td>136.59</td>
</tr>
<tr>
<td>sum of direction total sum</td>
<td>160.95</td>
<td>153.41</td>
<td>65.25</td>
</tr>
<tr>
<td>Change [%]</td>
<td>-44.86%</td>
<td>-44.21%</td>
<td>44.63%</td>
</tr>
</tbody>
</table>

Fig. 4. Hierarchy structure of intersection controls

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