



Evaluation of a vehicle detection system for city traffic control

T. PAMUŁA

SILESIAN UNIVERSITY OF TECHNOLOGY, Faculty of Transport, Krasińskiego 8, 40-019 Katowice, Poland,
EMAIL: teresa.pamula@polsl.pl

ABSTRACT

The paper presents an evaluation of the properties of the vehicle detection system comprising the source of data of traffic flow for road traffic control in a city. The quality of traffic data determines the ability to reach optimal traffic control decisions. Errors of measuring traffic stream balancing locally at junctions and in the whole of the road traffic control system are chosen as evaluation criteria. The city traffic is modelled using a directed graph, with vertices being the measurement sites and with edges linking vertices having weights representing traffic flow values. The analysis of the results enables the determination of measurement sites inadequately mapping the road situation and allows proposing new sites to improve the system. The analysis is performed using real traffic data acquired from the Traffic Control Centre in Gliwice.

KEYWORDS: traffic flow, traffic control, vehicle detection

1. Introduction

The construction of city road traffic control systems is determined by the selection of traffic control policies, the complexity of the road network, the number of road connections with other municipalities and most significantly by available resources for construction [1]. Different municipal traffic policies determine the most important criteria of appraisal of optimisation tasks in traffic control. The aim is to diminish the costs of urban travel for all participants, reduce environmental damages and improve the economy of functioning of the transport infrastructure. The economy is at first perceived as costs of construction, which leads to traffic control and management systems with the minimum number of controlled junctions aiming to attain the best performance at least costs. The choice of junctions controlling the most of traffic is of paramount importance.

In order to achieve, set optimisation goals on this scale, it is necessary to coordinate the functioning of traffic controllers. It is envisaged that traffic controllers work on common traffic data. The traffic controllers should also operate together in order to carry out elaborate control strategies on different levels of managing urban traffic systems.

Traditionally UTC (Urban Traffic Control) systems are classified into generations. The first adaptive systems, which widely used vehicle detectors emerged in late 60's. SCOOT, SCATS and TUC are the most widely deployed systems of this generation [2, 3, 4]. Improved systems were introduced when reliable vehicle detectors were constructed for use in traffic control. Systems such as OPAC, PRODYN, RHODES, UTOPIA/SPOT utilize also greatly enhanced processing capabilities of new hardware and communication means – WANs [5, 6, 7, 8].

With each generation of UTC systems the significance of traffic measurements rises and ways of increasing the robustness of data acquisition gain on importance. A minimised UTC structure may lose its control properties if the vehicle detectors in the system do not adequately cover the whole of the city traffic. Investigation of the balance of traffic flows on the bounds of the city will indicate the overall traffic flow leaks, which are not accounted for by the system. Further analysis will enable the designation of traffic network areas, which require special extra vehicle detection points and presumably additional traffic controllers.

The paper is organized as follows. Section 2 presents the digraph model of city road traffic, which is used to organise traffic

data for analysis. In the following section the traffic data is analysed to determine the properties of the current traffic measurement system. This is the main contribution of the paper and allows for a discussion of required improvements of the system, which is done in section 4. The last section lists the conclusions of the investigation of city road traffic balancing.

2. Traffic stream balancing

UTC (Urban Traffic Control) systems cover usually only a part of the city area. The main roads are included and other are chosen on the basis of earlier traffic measurements or more often according to the knowledge and experience of the system designer. This may leave a range of unaccounted vehicles, which disrupt the functioning of the city traffic control system. The selection of correct junctions, which carry the missing traffic is a difficult problem especially when the city lies in a conurbation, that is it is surrounded by places with many common roads.

Earlier research indicates also that traffic flows are highly correlated with week days [9, 10]. The character of daily traffic changes is distinctly marked with – morning and evening peaks of flow during work days. At weekends and during holidays the course of the changes is gentle and the peak hours are shifted by 2 hours. It becomes important to carry out the traffic stream balancing not only globally but also split into week days.

2.1 Assumptions for traffic modelling

The flow of road traffic is measured using a vehicle detector-based infrastructure comprising of video detectors, induction loop detectors and magnetic detectors. It is assumed that vehicle detectors are the fundamental building blocks of the measuring setup and thus the significant constituents of the traffic network. Detectors provide data in the form of vehicle counts acquired in predefined periods of time. The elementary period is 5 min, all other count data is derived by aggregating data from the elementary count periods. The second general assumption is that data for modelling is filtered in order to remove gross count errors, which occur when detectors fail. All data counts are registered by local traffic controllers and transferred to a central data base at the Traffic Control Centre.

2.2 Graph model of the city road network

The traffic model of the city includes traffic junctions, which are equipped with traffic controllers operating in tandem with vehicle detectors. Uncontrolled junctions are omitted. A traffic junction is denoted by J_i and is considered a graph node (vertex). There is a set of N nodes constituting the city junctions $W = \{J_1, J_2, \dots, J_N\}$. Graph nodes i, k are linked with pairs of directed arcs q_{ik} , $q_{ki} \in Q$ representing traffic flows between junctions – upstream, downstream. The city network is the set $S = (W, Q)$.

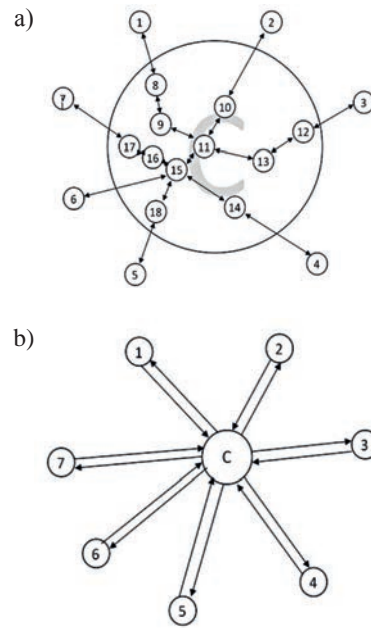


Fig. 1. a) The graph of the road traffic network of Gliwice, b) reduced graph – tree [own study]

Fig. 1.a) shows the traffic network of Gliwice being investigated in this paper. This graph is reduced to the tree in Fig.1.b) to facilitate the global, in the domain of the whole city, analysis of traffic flows. The arcs of the tree represent outbound and inbound traffic flow of the whole city.

Table 1. contains vehicle counts collected during the investigation, these are the arc values of the tree in Fig 1.b. Nodes represent measurement sites of traffic flow from different directions. The daily values are averaged over the period of data collection.

The largest number of vehicles is registered at nodes P4 and P3. These nodes are placed on trunk roads connecting the city with motorways A4 and A2 respectively, which indicates that many drivers leave Gliwice to travel considerable distances to work and study.

Table 1. Daily mean values of vehicle counts in the traffic network of Gliwice [own study]

Number of node N	Inbounds Outbounds	Mon	Tue	Wed	Thu	Fri	Sat	Sun
		1	In	8285	8485	8637	8573	8776
	Out	8781	9137	9109	9216	9547	7417	6343
2	In	8135	8248	7914	7667	8171	5959	4668
	Out	6968	7064	6962	6865	7434	5274	4054
3	In	9683	9644	9928	9741	10047	6396	4786
	Out	7397	7426	7508	7455	7717	4859	3738
4	In	11310	11198	11180	11553	11689	9057	8628
	Out	9321	9523	9618	9620	10439	7360	7897
5	In	8728	8695	8798	8945	9160	7197	5551
	Out	9100	9090	8918	9375	9591	7860	5950
6	In	5533	5737	5439	5494	5718	3580	2889
	Out	4808	4999	4891	5060	5067	3491	2767
7	In	7192	7924	6555	5876	6488	4442	4623
	Out	6682	6936	6965	6837	6956	5649	4478

3. Analysis of road traffic flows

Road traffic data was collected in the period from the 1st of June till the end of November of 2013. Due to malfunctioning of some of the vehicle detectors a considerable number of measurements were rejected. In the result a set of data from 8 full weeks was selected, which had no gross errors. In all more than 225 thousand traffic counts were used in the analysis (8 weeks×7days×255 5min counts×7 vehicle detection sites for inbound and outbound traffic). Traffic balancing was performed for each week day, for whole weeks, for each of the measuring sites and for the whole city.

Fig. 2 presents total mean counts of vehicles from all of the 7 measurement sites split into week day bins. For each week day the total traffic count is:

- inbound traffic Q_{wdin}

$$Q_{wdin} = \sum_{i=1}^N q_{ic} \quad (1)$$

- outbound traffic Q_{wdout}

$$Q_{wdout} = \sum_{i=1}^N q_{ci} \quad (2)$$

where: N is the number of measuring sites (vertices).

The traffic data was collected in 5 min intervals so the daily traffic counts are obtained:

$$q_{ic} = \sum_{t=1}^M q_{it} \quad q_{ci} = \sum_{t=1}^M q_{ti} \quad (3)$$

Where:

q_{ic} – is the inbound traffic count (into the city c from i node),

q_{ci} – is the outbound traffic count,

M – is the number of measuring intervals per day (24×12).

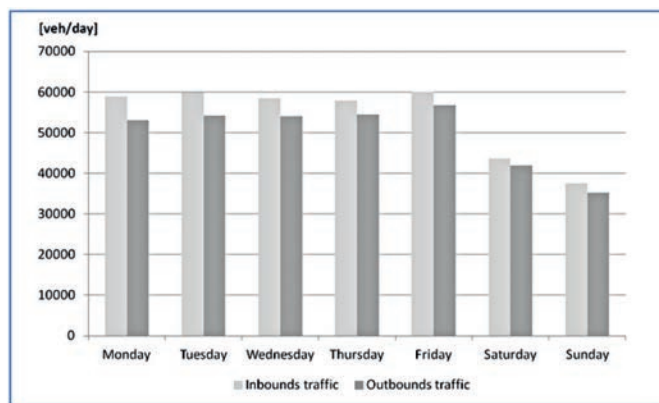


Fig. 2. The number of vehicles travelling in and out of the city split into week day totals [own study]

The vehicle counts range between 35 thousand and 60 thousand per day. Significant differences are observed between inbound and outbound traffic values especially on work days.

3.1 Intra-week traffic flow discrepancies

Intra-week discrepancies between inbound and outbound traffic indicate that a significant number of drivers arrive in Gliwice using the roads controlled by the municipal traffic control system but leave the city using other roads. Fig. 3. presents the percentage of total inbound and outbound traffic attributed to investigated measuring sites. The fraction of inbound traffic and outbound traffic from different directions, corresponding to the measurement sites, is constant on work days. This indicates that drivers exhibit constant travel behaviour, which means that travel destinations such as, work places, schools, offices function on a stable time basis 5 days a week.

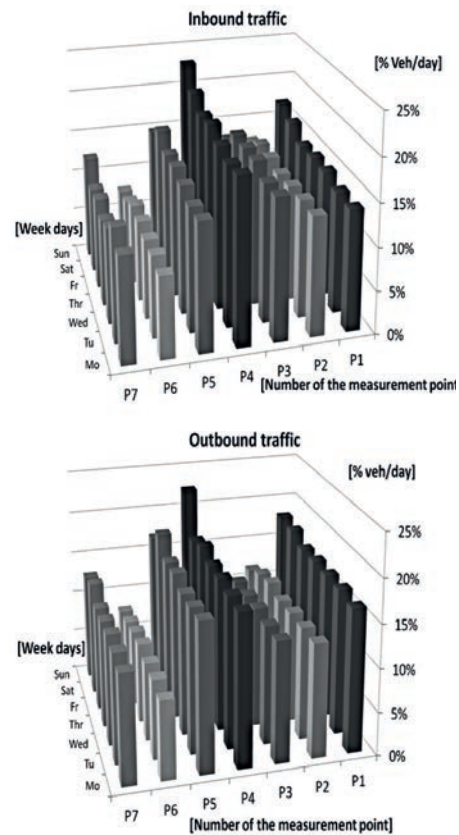


Fig. 3. Percentage of total inbound and outbound traffic attributed to measuring sites on week days [own study]

During the weekends the sites P1, P6 and P5, P4 to a lesser extent, show higher traffic counts than usual but also smaller differences between in and out traffic. This may be accounted for visits to shopping centres outside Gliwice.

A more detailed picture is revealed on Fig. 4 using D_{av} values. D_{av} , that is average percentage differences of traffic count values, are calculated:

$$D_{av} = \frac{q_{ic} - q_{ci}}{(q_{ci} + q_{ic})/2} * 100\% \quad (4)$$

Where:

q_{ic} – is the inbound traffic count (into the city c from i node),

q_{ci} – is the outbound traffic count,

i – measurement site number.

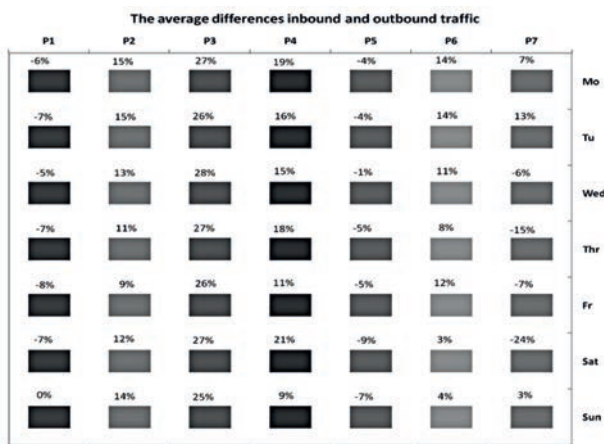


Fig. 4. The average differences in inbound and outbound traffic in Gliwice [own study]

Direction P3 and P4 prevails as an outbound site, while P1 and P5 prevail as inbound sites and show little fluctuations in the whole week. P3 and P4 traffic shows a flow of drivers who leave Gliwice to stay (work, study) elsewhere on work days. The largest fluctuations of traffic is noted at site P7. The differences in vehicle counts per measurement site and per week day are much higher than total differences for the whole city traffic (Fig. 2). Traffic routes in different parts of the city, which are not noted by the traffic control system, cancel out some of the differences.

3.2 Intra-day traffic flow discrepancies

In order to analyse the intra-day traffic flow discrepancies the traffic counts from the measurement sites are smoothed by aggregating the elementary 5 min counts to 15 min counts. This smoothing eliminates the variability of flow caused by traffic lights and enables a more consistent analysis. The difference of inbound and outbound traffic is calculated and representative intra-day graphs are presented in Fig. 5 and 6.

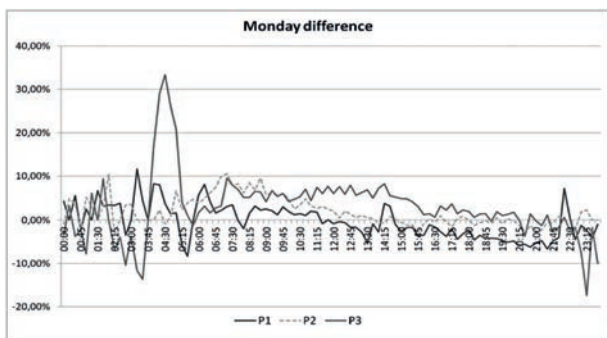


Fig. 5. The average differences in inbound and outbound traffic in Gliwice for Mondays [own study]

A Monday graph, representative of work days, has characteristic paired extrema indicating neighbouring periods of high in- and out-traffic for site P1, P3 and a slowly fluctuating course for P2 which reaches a gentle hump between 6 and 9 a.m. The morning

period differences hump indicate that many drivers come to Gliwice from neighbouring places. Paired extrema indicate that a numbers of drivers leave Gliwice to reach destinations for time to work and a much larger number arrive a little later at the borders in time to work in Gliwice. Sunday traffic differences exhibit significant peaks early in the morning for direction P1 it is an outbound peak while for direction P3 it is an inbound peak. P2 graph has a rather gentle outbound hump in the morning and in the afternoon. These outbound excess is related to weekend shoppings or mass events.

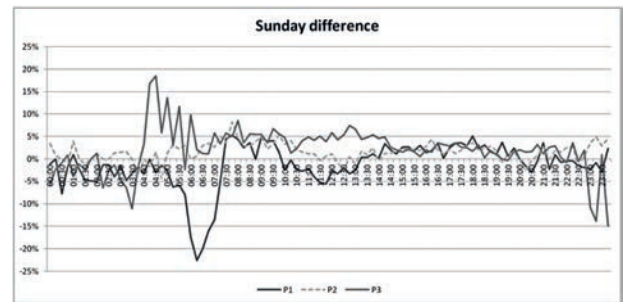


Fig. 6. The average differences in inbound and outbound traffic in Gliwice for Sundays [own study]

4. City traffic

The analysis uses a digraph to represent the structure and traffic flows of the city road network. The digraph is reduced to a tree with the city centre as the root. The merit of this approach is an easier observation of global behaviour of the traffic system, but the drawback is omission of local traffic properties, which may lead to stalls in traffic and in consequence far from optimal traffic control decisions. Fig 2. shows clearly that the vehicle counts in Gliwice are larger for outbound traffic and thus indicate an embedded imbalance of the control system. The traffic stream equilibrium rule is not preserved [10].

Further investigation was performed for measurement sites which demonstrated the largest differences in total daily traffic flows. For the site P3 the differences are as high as 26% of the mean daily traffic. This site is potentially a weak point in the system and requires supplementation with some other detection sites. Similar behaviour is observed for site P2.

5. Conclusion

Balancing of the traffic flows in the city is the first step in evaluating the performance of the municipal traffic control system. This analysis shows that the current system in Gliwice requires additional traffic controllers to cover traffic from the directions between sites P2 and P3. Analysis of the original traffic graph (Fig. 1a) is required to establish the exact positions of these controllers.

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