Archives of
Transport System
Telematics

Volume 8
Issue 3
September 2015

Some aspects of Intelligent Transport System auditing

M. BAZAN[a], M. BOŻEK[a], P. CISKOWSKI[a], K. HALAWA[a], T. JANICZEK[b], P. KOZACZEWSKI[a], A. RUSIECKI[a]
[a] WROCŁAW UNIVERSITY OF TECHNOLOGY, Faculty of Electronics, Department of Computer Engineering, ul. Janiczewskiego 11/17, 50-372 Wrocław, Poland
[b] WROCŁAW UNIVERSITY OF TECHNOLOGY, Faculty of Electronics, Department of Control Systems and Mechatronics, ul. Janiczewskiego 11/17, 50-372 Wrocław, Poland
EMAIL: marek.bazan@pwr.edu.pl

ABSTRACT
Nowadays, in urbanized areas one of the most important matters is to determine a priori the time of driving from one zone of the city to another at various times of the day. The problem of travel time prediction is crucial in Intelligent Transportation Systems. The solution to this problem is a foundation of any route guidance system that will redirect drivers to their target destination via routes that have a lighter traffic load and thus higher travel velocity.
In this paper is present a concept of a statistical methodology, developed by the ArsNumerica Group, that enables a quantity audit a travel time prediction algorithm. The methodology assumes that we are given database records of vehicles recognized by their unique identifier as well as duration times for which the messages with the predicted travel time are displayed VMS. the second aspect of ITS auditing considered in this paper is a placement of video cameras to measure vehicle stream velocity. Inappropriate camera location results in the fact that the stream velocity measured by them has a low usefulness for travel time prediction.

Keywords: intelligent transportation system auditing, travel time prediction algorithms auditing, fundamental diagram

1. Introduction

In this paper we present two aspects of a detailed assessment of an intelligent transportation system. A review of the aspects that are assessed in the context of intelligent transportation systems, may be found e.g. in [7] and [3]. The travel time predicting algorithms are used for recommending systems that inform drivers of predicted travel times on particular routes to be chosen. While deploying an intelligent transportation system there arises a problem of checking whether such a recommending system works. fine or not, i.e. whether it predicts travel times that correspond to the actual times in the real world.

Of course, to provide a procedure that allows that, one has to have access to two types of data and be able to confront them. The first type of data are just predicted times, the second type is historical data containing real times. Real times are usually aggregated times collected via intelligent transportation system cameras that are able to uniquely identify a vehicle, by recognizing its license plates numbers or other systems that can uniquely recognize signatures of vehicles on particular routes. i.e. via bluetooth.

As may be found in [4] for providing fairly accurate travel time prediction it is sufficient that in the population of all vehicles in the city only 2-3% provide their position. It means that quite a small number of measurements is sufficient to provide an accurate travel time estimation. Based on this fact we consider a method to estimate the average velocity of the traffic stream on separate sections of routes. We use for this purpose a mean estimator and a robust estimator of the average i.e. a median estimator. For both of the above estimators confidence intervals may be calculated even for a small sample size.

The second aspect of the auditing of an intelligent transportation system is checking usefulness of vehicle stream velocity measurements with an intelligent transportation system cameras. The procedure relied on plotting flow-velocity fundamental diagram for three different locations.

This paper is organized as the following: in section 2. a concept of methodology to assess a quality of a travel time prediction algorithm is presented. The application of the incarnation of this concept is shown on the example of the travel time prediction algorithm implemented in the intelligent transportation system in the city of Wrocław. The examples are worked out for data from May 2014 and March 2015. It is known that this algorithm was changed to be improved in the period between May 2014 and March 2015 by the producer (in this case TRAX [11]) and it is seen in the results of the procedure. In the third section we present the location of three types of cameras in the intelligent transportation system in the city of Wrocław. The considerable difference of the corresponding fundamental diagrams of a type flow *vs* velocity is shown.

2. Assessing a time prediction algorithm

2.1. Assumptions on input data

In the concept of the methodology that we present in the following section an assumption is made that one has, on the one hand, the data from the database that contains real travel times. The real travel times are measured by an intelligent transportation system using license plate recognition technology at the beginning, middle, and end points on prescribed routes in the city (see Fig. 1). This means that vehicles are recognized in control points on specified routes using their unique identifier. Please note that the bluetooth technology may be used to identify uniquely moving vehicles, however in such cases independent infrastructure public transport MACs (e.g. trams) have to be filtered out from the measurements, as it would introduce an unwanted bias to travel times. Let us called this dataset a **repository table**. On the other hand, one has data from a recommender system in the form of records containing a start displaying timestamp and a duration of the displayed predicted times (see Fig. 2).

The data within the latter data set are filtered to concern only an analyzed route (see an example 3) whereas the first data set should be filtered to concern only road sections of the route that is analyzed.

On these road sections detection cameras are located. Let us call this dataset a **VMS table**.

2.2. The concept of an auditing methodology

The concept of an audit methodology relies on off-line confronting data containing real travel times and travel times predicted by the travel time prediction algorithm working with the intelligent transportation system in question. Our methodology may be sketched as Procedure 1.

	1 Nr_Rejestracyjny	2 Id_Globalny_Punkt_A	3 Id_Globalny_Punkt_B	4 Czas_Punkt_A	5 Czas_Punkt_B	6 Czas_Przejazdu	7 Czas_Wprowadzenia
1	@M0978	686	695	2014-05-11 15:	2014-05-11 15:	487	2014-05-11 15:43:01.
2	@M0980	680	689	2014-05-11 20:	2014-05-11 20:	1604	2014-05-11 20:12:02.
3	@M0983	680	686	2014-05-11 09:	2014-05-11 09:	836	2014-05-11 09:04:01.
4	@M0984	683	686	2014-05-11 16:	2014-05-11 16:	123	2014-05-11 16:04:02.
5	@M0984	680	695	2014-05-11 17:	2014-05-11 17:	612	2014-05-11 17:07:02.
6	@M0986	686	698	2014-05-11 10:	2014-05-11 10:	102	2014-05-11 10:59:01.
7	@M0986	680	703	2014-05-11 11:	2014-05-11 12:	869	2014-05-11 11:53:02.
8	@M0987	672	683	2014-05-11 15:	2014-05-11 16:	756	2014-05-11 15:52:02.
9	@M0988	689	680	2014-05-11 16:	2014-05-11 17:	503	2014-05-11 16:59:03.
10	@M0991	686	672	2014-05-11 15:	2014-05-11 15:	531	2014-05-11 15:43:01.
11	@M0995	689	680	2014-05-11 06:	2014-05-11 07:	1051	2014-05-11 06:55:01.
12	@M0998	692	674	2014-05-11 07:	2014-05-11 07:	2370	2014-05-11 07:18:01.
13	@M0999	673	683	2014-05-11 13:	2014-05-11 13:	2	2014-05-11 13:02:03.
14	@M0999	680	689	2014-05-11 13:	2014-05-11 13:	117	2014-05-11 13:38:01.
15	@T0109	692	701	2014-05-11 15:	2014-05-11 17:	7034	2014-05-11 15:16:01.
16	@T0113	688	681	2014-05-11 13:	2014-05-11 13:	326	2014-05-11 13:38:01.
17	@T0275	681	695	2014-05-11 01:	2014-05-11 14:	44309	2014-05-11 01:53:01.
18	@T0392	681	688	2014-05-11 19:	2014-05-11 22:	9423	2014-05-11 19:32:02.
19	@T0528	699	670	2014-05-11 01:	2014-05-11 08:	26357	2014-05-11 01:31:02.
20	@T0551	706	695	2014-05-11 19:	2014-05-11 20:	4796	2014-05-11 19:25:03.
21	@T0563	688	699	2014-05-11 05:	2014-05-11 08:	10486	2014-05-11 05:12:01.
22	@T0568	681	695	2014-05-11 19:	2014-05-11 20:	6158	2014-05-11 19:03:01.
23	@T0579	695	700	2014-05-11 15:	2014-05-11 20:	17717	2014-05-11 15:24:01.
24	@T0643	692	699	2014-05-11 14:	2014-05-11 16:	5691	2014-05-11 14:53:01.
25	@T0672	692	681	2014-05-11 11:	2014-05-11 15:	17437	2014-05-11 11:08:01.
26	@T0734	688	695	2014-05-11 18:	2014-05-11 19:	2631	2014-05-11 18:40:02.
27	@T0901	697	681	2014-05-11 11:	2014-05-11 12:	2786	2014-05-11 11:18:01.
28	@T0926	706	695	2014-05-11 19:	2014-05-11 21:	7894	2014-05-11 19:05:03.
29	@T0944	671	699	2014-05-11 15:	2014-05-11 18:	11664	2014-05-11 15:27:02

Fig. 1. An example of a possible structure of the database table containing records of real travel times between any two neighboring points on prescribed routes in a city. In a presented concept of the auditing procedure we call this dataset a repository table [own study]

1. Scan the VMS table (Fig. 2) to establish a **starting time point** and a **time window**.
   (a) Take as a starting time point a timestamp t_0 from the first column.
   (b) Take as a duration of the window a time d_0 that is a difference between t_0 and the timestamp in the first column in the successive record in the VMS table.
2. Launch select to the repository table (Fig. 1) for a starting control point (column 2) and a middle control point (column 3) on the route to calculate a mean travel time d_1 when a trip starts within the current time window.
3. Launch select to the repository table (Fig. 1) for a middle control point (column 2) and an ending control point (column 3) on the routes to calculate a mean travel time $\tilde{d}_2$ when a trip starts between $t_0 + d_0$ and $t_0 + d_0 + \tilde{d}_1$.
4. A real mean travel time is $\tilde{t} = \tilde{d}_1 + \tilde{d}_2$. Compare $\tilde{t}$ with the predicted travel time from the second column of the VMS table.
5. Go to 1 stepping to the next record in a VMS table.

Procedure 1. An auditing procedure for a route with one middle control point

The above procedure may be easily generalized to work for routes with more than one middle control point (see Fig. 3). The generalization should:

1. exchange step 3. with an iteration with a variable *i* that loops over successive *N* middle points on exchange step 3. with an iteration with a variable *i* that loops over successive *N* middle points on the considered route. In the *i*-th iteration we calculate a mean time d_{i+1} of travel times of trips starting from $t_0 + \sum_{n=1}^{i} \tilde{d}_n$ to $t_0 + d_0 + \sum_{n=1}^{i} \tilde{d}_n$.
2. in step 4. calculate $\tilde{t} = \sum_{k=1}^{N+1} \tilde{d}_k$ and then compare $\tilde{t}$ with the predicted travel time from the second column of the VMS table

An additional filter in the above procedure should be added that would enable the omission of trips lasting longer than some prescribed period. Such trips are suspected to have intermediate stops and should not be used to estimate actual travel time.

	1 vstime	2 czas_1
1	2014-05-25 23:25:15.8809600	8
2	2014-05-25 23:25:05.9430140	NULL
3	2014-05-25 23:20:15.6030820	7
4	2014-05-25 23:01:04.3250660	8
5	2014-05-25 06:00:05.5753890	NULL
6	2014-05-25 05:55:15.3057210	7
7	2014-05-25 05:40:15.3033710	7
8	2014-05-25 05:25:14.9290980	8
9	2014-05-25 05:05:14.7130550	8
10	2014-05-25 04:50:14.7889040	8
11	2014-05-25 04:45:15.4070600	8
12	2014-05-25 04:35:14.8139670	9
13	2014-05-25 04:25:15.0339560	8
14	2014-05-25 04:15:14.6936340	8
15	2014-05-25 03:45:15.1803710	10
16	2014-05-25 03:40:15.4441010	12
17	2014-05-25 03:30:15.2637980	12
18	2014-05-25 03:25:15.1823790	11
19	2014-05-25 03:20:14.8217310	11
20	2014-05-25 03:10:14.7871670	10
21	2014-05-25 03:00:15.0970800	9
22	2014-05-25 02:40:15.2570960	10
23	2014-05-25 02:35:15.5620140	8
24	2014-05-25 02:15:15.2425510	9
25	2014-05-25 02:10:15.3145720	8
26	2014-05-25 02:05:45.5041480	8

Fig. 2. A log of the predicted travel times displayed at a single VMS table. In a presented concept of the auditing procedure we call this dataset a VMS table [own study]

2.3. Confidence intervals

In the above concept a mean estimator is used to estimate real travel time on a prescribed route in a prescribed time window. In the examples in the next section also the robust estimator of the travel time, namely a median travel time, is used. Both of these estimators are used when the number of samples in the window is greater than 10. It means that it is sensible to calculate confidence intervals for the localization of the specified estimator of the travel time. This is due to the fact that

- the **mean** sampling distribution in the limit approaches to the normal distribution with the mean μ equals the mean travel time and the real standard deviation divided by a number of samples regardless of its distribution (c.f. [2]),
- the **median** position is approximated by the binomial distribution with parameter p = 0.5, and if $p{\cdot}N > 5$ it can be approximated again by the normal distribution the mean μ equals $\frac{N}{2}$ and the standard deviation equals $\sigma = \frac{\sqrt{N}}{2}$ where N is a number of samples (c.f. [8]).

Therefore a 95% a confidence interval [L,U] is given

$$L = \tilde{\mu} - z_{0.025}\tilde{\sigma},$$
$$U = \tilde{\mu} + z_{0.025}\tilde{\sigma},$$

where

- for the **mean** μ there is $\tilde{\mu} = \frac{1}{N}\sum_{i=1}^{N} t_i$ and $\tilde{\sigma}^2 = \left(\frac{1}{N-1}\sum_{i=1}^{N}(t_i - \tilde{\mu})^2\right)/N$,
- for the position of **median** in the sorted sequence of travel times in a specified window there is $\tilde{\mu} = \frac{N}{2}$ and $\tilde{\sigma} = \frac{\sqrt{N}}{2}$.

In the expressions for L and U $z_{0.025}$ is the z-value corresponding to the 2.5-th percentile of the normal distribution with a mean 0 and standard deviation equals to 1 which approximately equals 1.96. For a small number of observations in the analyzed intervals of course one should instead of the normal distribution the t-Student distribution should be used. Confidence intervals using t-Student distribution were used in the calculations presented in the next paragraph.

Fig. 3. One of the routes analyzed by our procedure in the intelligent transportation system in the city of Wrocław (Poland). A map obtained from Google Maps [own study]

2.4. Examples of representative routes in Wrocław

In Fig. 3 we show the route from the ITS in the city of Wrocław with four subsections that was analyzed using the above procedure. In Fig. 4 the results of the application of the procedure described in subsection 2.2 for the route shown in Fig. 3 for data from May 2014, are shown. In Fig. 5 the results of the application of the same procedure for data from March 2015, are shown. As one can see the trend of the real velocities is recovered very well by the travel time predictor implemented by the system in data from March 2015. The small shift is caused by the lack of data on one of the sections in the time window. Our auditing procedure then takes a nominal travel time i.e. travel time achieved with a maximum allowed speed. In data from May 2014 the prediction is much worse since the trend is not just shifted in real time, but crosses many times the real time what may be seen comparing upper plots on figures 5 and 4. On these plots there are also shown confidence intervals below the blue line – corresponding to measured times of trips.

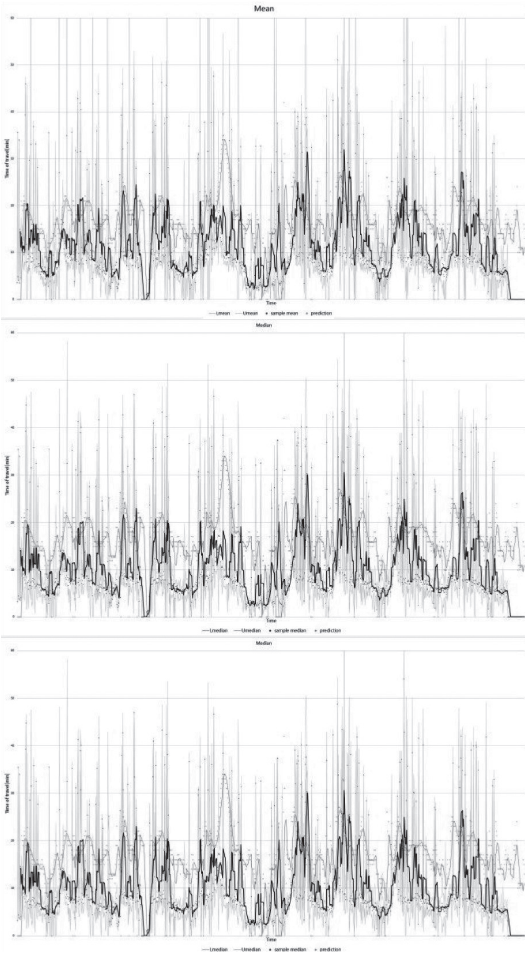


Fig. 4. Results of the analysis for data from May 2014 for the route 3. The upper plot is a mean travel time plot. The middle plot is median travel time plot. The lower plot is an estimation error plot [own study]

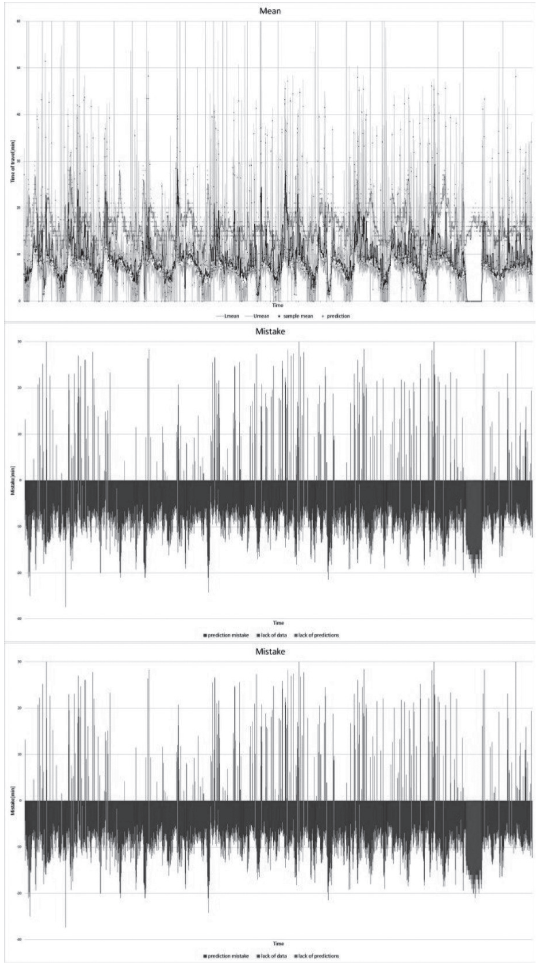


Fig. 5. Results of the analysis for data from March 2015 for route 3. The upper plot is a mean travel time plot. The middle plot is median travel time plot. The lower plot is an estimation error plot. As one can see the trend of real velocities is recovered very well by the predictor. The small shift is caused by the lack of data on one of the sections in the time window. Our auditing procedure then takes a nominal travel time i.e. travel time achieved with a maximum allowed speed [own study]

3. Velocities

The problem of measuring velocity in various locations along a road link between signalized intersections is described in [13], while good sources for fundamental diagrams are [14] or [12].

Location of video cameras to measure vehicles' stream velocity is one of the crucial aspects of an intelligent transportation system.

Intelligent Transportation System in Wroclaw uses three different types of cameras to measure vehicles' stream velocity: ARTR cameras, velocity cameras of type 1 and velocity cameras of type 2. We will shortly describe the way they work, show their locations and present fundamental diagrams – flow rate vs velocity ([12]), based on measurements from these three types of cameras. Two estimators of velocity are used on diagrams: mean value and median value. We will show that the fundamental diagrams diverge a lot for these three locations and camera types. The data used to generate these plots were collected during 2 weeks of May 2014.

3.1. ARTR cameras - location 1

38 ARTR units are used in the city of Wroclaw to measure 62 road sections covering 45 routes. The cameras recognize license plate numbers and record them along with time in database, so that the system is able to compute travel times between two points for individual vehicles. The location of ARTR cameras is shown in Fig. 6, while the fundamental diagrams: Mean Velocity *vs* Flow and Median Velocity *vs* Flow are presented in Fig. 7. Travel times were used to calculate mean speed for individual vehicles, and then aggregated for the periods of 60 minutes, along with the traffic flow rate.

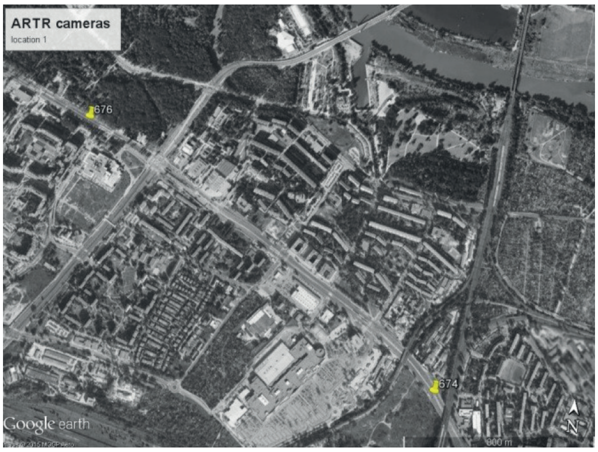


Fig. 6. Location of the rst group (ARTR cameras) of cameras at Legnicka and Lotnicza street in Wrocław. A map obtained from Google Maps [own study]

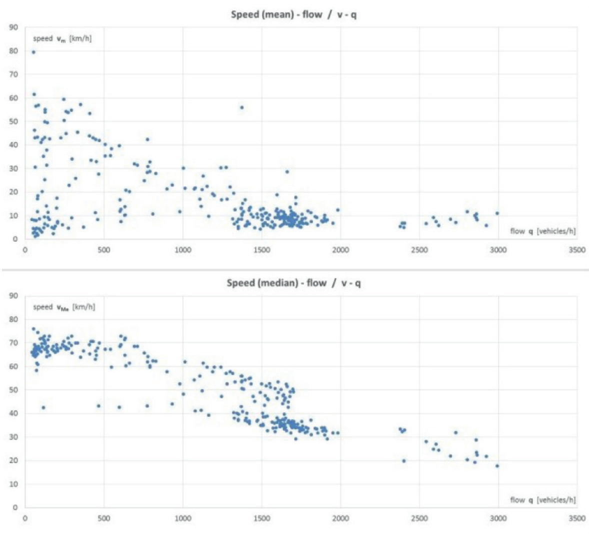


Fig. 7. Fundamental Diagrams for the first cameras location aggregated over 60 minutes. a) Fundamental diagram Mean Velocity *vs* Flow rate. b) Fundamental diagram Median Velocity *vs* Flow rate aggregated [own study]

3.2. Velocity cameras type 1 - location 2

Intelligent Transportation System in Wroclaw uses 355 cameras to measure individual vehicles' velocities and lengths. They also recognize 7 types of vehicles: passenger cars, buses, vans, (motor) cycles etc. Each camera observes one to five lanes and records data for individual vehicles in the database. We aggregated these measurements for periods of 15 and 60 minutes. The locations of velocity cameras of type 1 are shown in Fig. 8, while Fig. 9 presents fundamental diagrams of Mean and Median Velocity *vs* Flow rate, respectively.

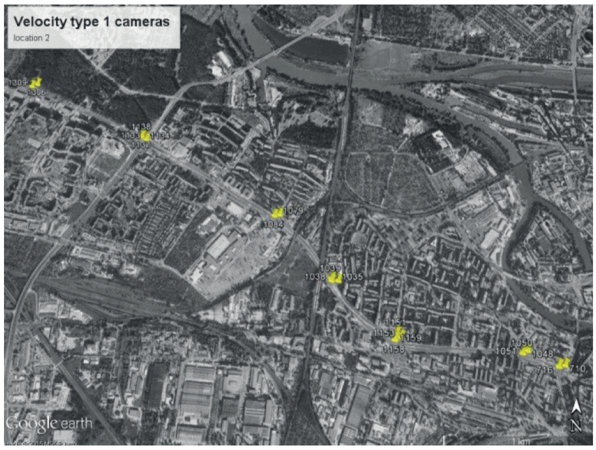
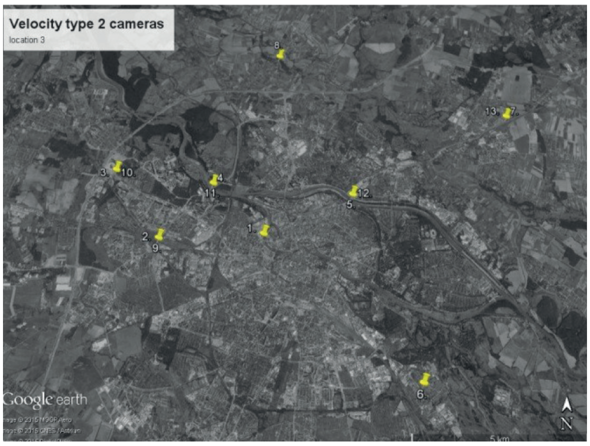


Fig. 8. Location of the second group of cameras. A map obtained from Google Maps [own study]

Fig. 9. Fundamental Diagrams for the second cameras location aggregated over 60 minutes. a) Fundamental diagram Mean Velocity *vs* Flow rate. b) Fundamental diagram Median Velocity *vs* Flow rate aggregated [own study]

3.3. Velocity cameras type 2 - location 3

The intelligent transportation system in Wroclaw uses 13 flow rate measurement points. Their cameras are pointed in different directions (usually opposite, e.g. south-north) and cover 1 or 2 lanes, what results in the total number of 22 measurement locations. These cameras record the number of vehicles and their mean speed in 10-minute intervals. Other accompanying information is also recorded, insignificant in our calculations. We aggregated the number of vehicles and mean speeds to 60-minute periods. The locations of flow rate measurement points is shown in Fig. 10, while Fig. 11 presents the fundamental diagram of Mean Velocity *vs* Flow rate for this type of cameras.



Rys. 10. Location of the third group of cameras. A map obtained from Google Maps [own study]

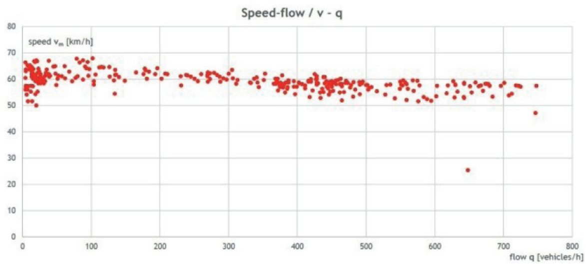


Fig. 11. Fundamental diagram Mean Velocity *vs* Flow rate aggregated over 60 minutes for the third location [own study]

4. Establishing a proper distribution of measurement points

An algorithm for estimation of an optimal location of the sensors for the task of travel time estimation on the highway was described in detail in [5]. Is it still an open problem for urban areas. The approach to solve this problem currently being developed by the ArsNumerica Group is based on an origin destination matrix calculation implementation presented in [10].

5. Conclusion

In this paper we presented the concept of the methodology to assess travel time prediction algorithms in an intelligent transportation system. The methodology was applied to audit the travel time prediction algorithm used in the intelligent transportation system deployed in the city of Wrocław (Poland). It was used to verify that the corrections to the travel time prediction algorithm applied at the end of 2014 were successful, i.e. changes to the algorithm improved the quality of the prediction. The second aspect of the assessment of intelligent transportation systems analyzed in this paper was the location of the cameras measuring velocity and the flow rate.

Acknowledgements

The authors would like to thank Mrs. Agnieszka Hadas - a leader of the Crisis Management Center in Wrocław as well as Mr. Błażej Trzcinowicz - a director from the Department of the President of Wrocław for providing data from the Wrocław Intelligent Transportation System from May 2014 and March 2015.

Bibliography

[1] BAZAN M., et al.: A concept of the methodology to audit travel time prediction algorithms in Intelligent Transportation Systems, Report W04/P-008/15, Wrocław University of Technology, (2015)

[2] BRUNING J.L.: Computational handbook of statistics, Longman, (1997)

[3] FRANCERIERS E., LIVER K.: Centralized traffic management system as response to the effective realization of urban traffic fluency, Archives of Transport System Telematics, Vol. 4, Issue 4, (2011)

[4] HERRERA J. C.: Assessment of GPS-enabled smartphone data and its use in traffic state estimation for highways, PhD Thesis, University of California, Berkeley, (2010)

[5] HERRING R. J.: Real-Time Traffic Modeling and Estimation with Streaming Probe Data using Machine Learning, PhD Thesis, University of California, Berkeley, (2010)

[6] KERNER B.S.: Introduction to Modern Traffic Flow Theory and Control, The Long Road to Three-Phase Traffic Theory, ISBN: 978-3-642-02604-1, Springer, (2009)

[7] MBIYDZENYUY G.: Quantitative Assessment of Intelligent Transport Systems for Road Freight Transport, Blekinge Institute of Technology, BTH, Sweeden, (2013)

[8] PRICE R.M., BONETT D.G.: Estimating the variance of the sample median. Journal of Statistical Computation and Simulation, 68, 295-305, (2001)

[9] SIDDLE D.: Travel time predictability, ISBN 978-0-478-41966-5 (electronic)

[10] SZYMAŃSKI A., et al.: Two methods of calculation of the origination destination matrix of an urban area, Report W04/P-007/15, Wrocław University of Technology, (2015)

[11] http://www.traxelektronik.pl/ [date of access: December 2014]

[12] TREIBER M., KERSTING A.: Traffic Flow Dynamics, Data, Models and Simulation, ISBN: 978-3-642-32459-8, Springer, (2013)

[13] WAGNER P., et al.: Fundamental Diagram of Traffic Flows on Urban Roads Local Versus Whole-Link Approaches, Transportation Research Record (ISSN: 0361-1981), p. 213-221, National Academy of Sciences, (2009)

[14] Greenshield Symposium, 75 Years of the Fundamental Diagram for Tra-c Flow Theory, Transportation Research, E-C149, June (2011)