A study of some cars dynamic parameters in urban traffic flow

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Abstract. In this paper different methods for determining some dynamic parameters like longitudinal accelerations of cars are presented. The studies were conducted at different road intersections in Ruse, Bulgaria. Data of accelerating cars in real traffic flow with non-contact equipment, VBOX GPS Data Logger measurement system has been acquired. This study can be used by the experts in forensic accident investigation of vehicles. The data presented in this article can improve the calculations accuracy and the quality of expertise during the accident investigation.

1. Introduction
The significant increase in cars over the past years has led to a positive impact on the economy and people's comfort. But at the same time to many problems (pollutions [1], noise [2] etc.), including heavy road accidents. The number of deaths in road accidents in Bulgaria is about three times bigger than some countries in the European Union [3]. In order to clarify the reasons for the occurrence, and the mechanism of the occurrence of these heavy accidents, the police and the court appoint technical expertise investigation to third party independent professionals. Those experts need broad spectrum of knowledge within the transport engineering, mechanics, vehicle dynamics, etc. The main task of the expertise is to determine the pre-collision velocity. And for road accidents occurring at intersections, the velocity can be determined if the vehicle acceleration and the distance traveled to the point of impact are known.

There are various models, methods and studies of vehicles acceleration and traffic flow in safety area (also vehicle fuel consumption and emissions etc.) [4, 5, 6, 7, 8]. However, some vehicle accelerations studies are for specific locations, cities and countries, or specific roads and driving situations [9, 10, 11, 12, 13, 14]. Unfortunately, there are no suitable studies for Bulgaria, tailored to the needs of the expert practice.

The aim of this study is to compare different methods for determining the vehicles accelerations and choose relevant method for accelerations in urban traffic flow.

2. Mathematical model
The vehicle distance in motion at constant acceleration without initial speed can be calculated

\[ D = \frac{at^2}{2} \cdot m \]  

where \( a \) is the vehicle acceleration, \( m.s^{-2} \); \( t \) – the acceleration time, s.

Using (1) it can be determine the acceleration in such a movement by
Some of the Bulgarian experts in vehicle accident investigation use dependence (2) to determine the acceleration of the vehicle and then the pre-collision velocity.

The pre-collision velocity can be calculated by

\[ V = (2Da)^{1/2}, \text{ms}^{-1}. \] (3)

3. Experimental study

In this paper three different methods to determine the vehicle acceleration are used. The objects of the study are randomly selected cars.

3.1. First method

In this method non-contact equipment, VBOX GPS Data Logger measurement system (Racelogic, Ltd) was used [15, 16]. GPS has now become a popular way of measuring due to the very high accuracy. VBOX is a powerful instrument used for non-contact measuring of a moving vehicle and can measure speed, distance, acceleration, lap times, position and much more. The logged data is stored directly onto a compact flash card for easy transfer to a PC.

The test vehicle, equipped with the VBOX Data Logger (Figure 1, position 1), stops in parallel to a vehicle, that stops in front of the intersections stop line (Figure 1, position 2). The test vehicle starts and moves in parallel with the other vehicle (Figure 1, position 3). The VBOX system has a video camera that monitors whether the vehicles’ movement is parallel. The acceleration is determined only for vehicles that have moved in parallel for the distance of the study.

![Figure 1](image)

Figure 1. The testing scheme for the first method.

In this way a study of 200 vehicles was carried out. The study was conducted in April in clear and dry weather at intersections of different streets in Ruse. The results of the study were processed with VBOX Tools software [17]. Figure 2 shows the main window of the software and the specified acceleration for a distance of 30 meters, for one of the tests.
Figure 2. The main window of VBOX Tools software.

The average values of acceleration were determined for the travelled distance (from 10 to 70 meters for each test) with this software.

Figure 3 shows the results for the average values for the acceleration in real traffic flow depending on the travelled distance.

![Graph showing acceleration vs distance](image)

**Figure 3.** The acceleration versus the travelled distance – average values.

The variation of acceleration according to travelled distance (Figure 3) is

\[ a = 0.0134D^2 - 0.1884D + 1.798, \text{ms}^{-2} \]  

where \( a \) is the vehicle acceleration, \( \text{ms}^{-2} \); \( D \) – the travelled distance, \( \text{m} \).

The determination coefficient of equation \( R^2=0.96 \), which indicates that a variance in the acceleration is insignificant. This satisfies the accuracy required by the expert practice.

The Figure 4 shows minimum values of acceleration in real transport traffic flow depending on the travelled distance.

![Graph showing minimum values of acceleration](image)
For the minimum values, the variation equation describing the acceleration according to the distance is

\[ a = 0.0223D^2 - 0.2482D + 1.5093, \text{ms}^{-2} \] \hspace{1cm} (5)

The determination coefficient of equation \( R^2 = 0.99 \), which indicates that 99% of the acceleration variance in the response variable can be explained by the explanatory variables.

The Figure 5 shows the results for maximum values of acceleration, depending on the distance.

In these results (Figure 5) the equation describing the variation of the acceleration according to the distance is

\[ a = 0.0098D^2 - 0.199D + 2.2325, \text{ms}^{-2} \] \hspace{1cm} (6)

The determination coefficient of equation \( R^2 = 0.97 \).

The extent \( R \) of the statistical scattering is determined by

\[ R = a_{\text{max}} - a_{\text{min}} \] \hspace{1cm} (7)

The Figure 6 presents the extent \( R \) of the statistical scattering depending on the distance.
The Figure 6 shows a tendency to decrease $R$ by increasing the distance. At a distance of 70 meters, scattering decreases by 46% compared to a distance of 10 meters. As a result, in the investigation, it is necessary to carefully analyze the evidence on how to accelerate the vehicles involved in the accident.

3.2. Second method
Where there is no possibility to apply expert methods to determine the speed, some Bulgarian experts use the following method. Time measurement carried out with a stopwatch for which the vehicle travels a certain distance. Once the time and distance is known by (1), (2) and (3), the speed of the vehicle can be determined.

Sometimes the same acceleration values are used for different traffic situations, without taking into account the distance traveled by the vehicle. Of the results obtained so far shows that this type of modeling is inaccurate, and leads to poor quality of the expertise.

Further, this method raises certain questions about its accuracy and applicability. In order to answer these questions, a study was conducted to determine the vehicle acceleration. The study was conducted at 20 intersections on different streets in Ruse. And the data was collected from 100 vehicles.

The travel time was measured with a stopwatch at the 20th meter, 30th meter and 40th meter from the stop line. The speed of the vehicles at the beginning of the measurement is zero, i.e. the vehicles have stopped and the drivers are waiting for green light at the traffic signals (Figure 7, position 1).

The travel time results are obtained at each station (20 m, 30 m and 40 m) and filed in the work sheets (Figure 7, position 2).

Once the time is determined using (2), the vehicle acceleration is calculated. The results of the calculations are presented in Figure 8.
The minimum, average and maximum values of the study are presented. The results are for acceleration distances of 20, 30 and 40 meters (Figure 8).

3.3. Third method
The experiment was implemented at a vehicle training ground, i.e. the studies were not conducted within real traffic flow. For the purpose of the study different vehicles were used, with drivers from 20 to 50 years old. Each driver accelerates with the vehicle in three ways – normal, fast and very fast (with acceleration marks on the road). The VBOX Data Logger registration system [15, 16, 17] was used to determine the accelerations. The results of the study were processed with VBOX Tools software.

From results on Figure 9 it can be concluded that the normal acceleration judged by the drivers differs from the average acceleration values in real traffic flow (Figure 3).

This is very important and these differences need to be carefully analyzed and taken into account by the experts in the investigation of accidents.

4. Conclusions
The data from all the studies presented in this article can be used in expert practice in the investigation of vehicle accident. Using the data can improve the accuracy of the calculations and the quality of the expertise in the investigation of accidents.
For first method longitudinal accelerations are: minimum values from 1.28 to 0.87 $\text{ms}^{-2}$; maximum values from 2.08 to 1.30 $\text{ms}^{-2}$; average values from 1.67 to 1.12 $\text{ms}^{-2}$ obtained from predetermined distances from 10 m to 70 m.

Experts using second method must be careful because the mathematical model is for constant acceleration motion. In fact, vehicle does not pass the distances at constant acceleration. This was confirmed by the first method.

As for the third method in real traffic flow the normal acceleration is higher than the normal acceleration on a vehicle training ground. For example in 30 meters distance the average acceleration in real transport flow is 25.7% higher than normal acceleration measured on the vehicle training ground.

References

[1] Hristov R and Stefanov S 2019 Study of the potential for reducing CO2 emissions from road transport in Bulgaria *IOP Conference Series: Materials Science and Engineering* vol 614.

[2] Li Q and Qiao F and Yu L 2015 Testing of in-vehicle noises when driving on freeways with different pavement types *Proceedings of the 108th Air and Waste Management Association (AWMA)* Raleigh North Carolina USA.

[3] European Commission. Transport. Statistical pocketbook 2017. Available at: https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2017_en

[4] Goñi-Ros B and Knoop V and Takahashi T and Sakata I 2016 Optimization of traffic flow at freeway sags by controlling the acceleration of vehicles equipped with in-car systems *Transportation Research Part C* vol 71 pp 1–18

[5] Jin W and Laval J 2018 Bounded acceleration traffic flow models: A unified approach *Transportation Research Part B* vol 111 pp 1–18

[6] Leclercq L 2007 Bounded acceleration close to fixed and moving bottlenecks *Transportation Research Part B* vol 41(3) pp 309–319

[7] Wang Y and Bin Y and Keqiang L 2008 Longitudinal Acceleration Tracking Control of Low Speed Heavy-Duty Vehicles *Tsinghua Science & Technology* vol 13 pp 636–643

[8] Zhao H and Liu X and Chen X and Lu J 2018 Cellular automata model for traffic flow at intersections in internet of vehicles *Physica A: Statistical Mechanics and its Applications* vol 494 pp 40–51

[9] Bokare P and Maurya A 2017 Acceleration-Deceleration Behaviour of Various Vehicle Types *Transportation Research Procedia* vol 25 pp 4733–4749

[10] Bokare P and Maurya A 2016 Study of Acceleration Behaviour of Motorized Three Wheeler in India *Transportation Research Procedia* vol 17 pp 244–252

[11] Dey P and Biswas P 2011 Acceleration of queue leaders at signalized intersections *Indian Highways* No 3(1) pp 49–54

[12] Gattis J and Bryant M and Duncan L 2010 Truck acceleration speeds and distances at weigh stations *Journal of the Transportation Research Board* National Academies, Washington

[13] Haas R and Inman V and Dixson A and Warren D 2004 Use of intelligent transportation system data to determine driver deceleration and acceleration behavior *Transportation Research Record* pp 3–10

[14] Wang J and Dixon and Li H and Ogle J 2004 Normal acceleration behavior of passenger vehicles starting from rest at all-way stop-controlled intersections *Transportation Research Record* 1883 pp 158–166

[15] Racelogic Company Profile. Available at: http://www.racelogic.co.uk/index.php/en/

[16] Vehicle testing (Video) VBOX data logger. Available at: https://vboxautomotive.co.uk/index.php/en/products/data-loggers

[17] VBOX Tools software. Available at: https://vboxautomotive.co.uk/index.php/en/products/software/vbox-tools