PRELIMINARY DRIVING STYLE CLASSIFICATION OF THE PROFESSIONAL DRIVERS

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Abstract

Driving style and driver behaviour are important in evaluating city bus drivers. Buses are one of the means of public transportation in cities, used by millions of people. The purpose of this study was to present a model for preliminary classification of driving style of the professional drivers based on averaged maximum values of lateral and longitudinal acceleration recorded during regular work. First, the recorded acceleration values of 69 city bus drivers were analysed. Then, the correlation between the acceleration values and the age and experience of the city bus drivers was examined. Based on the results of the preliminary classification of drivers, extreme values for both lateral acceleration and longitudinal acceleration (deceleration and acceleration) were obtained by 3 drivers out of the 69 tested. The study also examined the relationship between averaged values of maximum lateral and longitudinal acceleration and driver age and experience. Based on the correlation results, showed that age and the number of years of holding a driver's license are not significantly related to acceleration. Therefore, the method can be used to analyse drivers regardless of their age and experience.

Keywords: driver behaviour; urban bus; acceleration; professional driver; driving style

1. Introduction

Behaviour and driving style is individual for each driver. Although the process of driving vehicles is currently extensively supported by advanced driver assistance systems (ADAS), the attention and behaviour of the driver are critical for road safety. While driving a vehicle, the driver has also an impact on other road users. The dynamically changing road situation forces the driver to quickly assess events and make precise decisions. Professional city bus drivers spend much more time driving a vehicle each day than other professional drivers. A professional driver is a person hired or paid to drive or operate a vehicle, whether for private use or public hire. A professional driver transports people or goods and has the appropriate qualifications to perform this work. Due to the specific character of the profession, city bus drivers

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work for a long time in complex and demanding driving conditions. Behaviour and driving style is individual for each driver. Although the process of driving vehicles is currently extensively supported by ADAS, the attention and behaviour of the driver are critical for road safety.

Buses are one of the most important means of public transport in cities. The driver's job is to drive the bus on specific routes according to timetables and obey traffic regulations, to ensure a smooth and safe ride for passengers. Bus drivers perform their work at different times of day, under different traffic or weather conditions. The drivers are expected to be able to remain calm and ride safely under various conditions and circumstances.

The bus driver's job specification requires constant concentration while driving, although the work can often seem monotonous. However, unexpected traffic situations require the driver to react appropriately, maintain self-control and make quick decisions. The driver must drive according to the timetable, strive not to cause delays and reach the right stop at the right time. Bus drivers often work at night, on weekends and public holidays. Based on the research presented in [33], it was found that fatigue and the need for the recuperation of the body mediate the relationship between work tension and risky driving behaviour [21, 34]. The driver's fatigue is caused by many personal factors, such as stress and the need for organizational support, as well as factors related to the working environment [4, 18, 35]. The results presented in [16] showed that professional bus drivers often working overtime are the most vulnerable to accidents. It was confirmed in [10] that the level of stress increases significantly in extreme weather conditions.

The behaviour of city bus drivers translates directly into road traffic safety. A lot of research on drivers' behaviour has been carried out and presented in many academic publications. Professional drivers spend many hours driving a vehicle in various traffic conditions. The research results presented in [29] show that erroneous reactions, inattention errors, violations of road regulations while driving and the risk of accidents are positively correlated with each other. This allows for the conclusion that any such behaviour may result in a high risk of a road accident. The correlation analysis presented in [33] allowed for the determination of indexes of a positive and significant relationship between the errors of reaction while driving a vehicle and general fatigue of the driver and the fatigue caused by driving. Fatigue results (both general and work-induced) translated into the higher rates of risky driving behaviour. The results of the analysis of the drivers' binary personality traits presented in [39] show that the average annual mileage is significantly positively correlated with aggression. Bus drivers can be bored and apathetic due to the fixed routes, as well as long hours, long-distance and repetitive work. This may lead to greater aggression, a symptom of which is e.g. frequent use of the horn. The work [9] presents the results of multivariate analyses determining the factors related to the participation of professional drivers in accidents. They showed that increased pressure at work, as well as erroneous reactions while driving, were the causes of accidents.

Recognizing drivers' driving styles can isolate unsafe behaviour and improve traffic safety by monitoring high-risk activities. Methods for collecting data on driving behaviour are questionnaire surveys and experimental studies in road conditions or with the use of simulators.

In questionnaire surveys, drivers are asked to answer questions related to their daily behaviour while driving. The questionnaire is a list of questions, designed and arranged in a specific way. The value of a well-constructed questionnaire as an assessment tool is the accuracy and reliability of individual questions or sets of questions. In the case of the driver's behaviour questionnaires, the reasons for a specific action while driving and how the respondent perceives and assesses their skills and behaviour are determined. The anonymity of the source of information provided by the respondent is ensured and appropriate answer times are provided. The most frequently used questionnaires in the studies of driver behaviour are Manchester Driver Behaviour Questionnaire (DBQ), Driver Attitude Questionnaire (DAQ) and Safety Climate Questionnaire (SCQ). Examples of this approach can be found in many works, including [10, 28, 37].

Experimental driving behaviour studies can be carried out in road conditions or using driving simulators. In studies with the use of a simulator, it is possible to collect information on the behaviour of drivers in various road situations and various traffic conditions. Simulators make it possible to map driving in various weather conditions and times of the day. With the use of simulators, it is possible to simulate dangerous situations, which would be problematic and dangerous to simulate in real traffic conditions [19]. Despite the many advantages of using simulators, they also have limitations. During the tests with the use of the simulator, the participant is aware of participating in an experiment, which means the perception of risk is limited since the driver is not afraid of the consequences of a road accident. Moreover, simulators do not fully reflect the real sound and image, and thus significantly reduce the visual and motor stimuli perceived by the driver [5, 13].

Experimental tests conducted in road conditions consist in assessing the behaviour of drivers during actual driving. Data can be collected using sensors equipped with a Global Positioning System (GPS) module, On-Board Diagnostics (OBD) connectors or collected through the Controller Area Network (CAN) bus. With these measures, it is possible to study the driver's driving dynamics.

The method of collecting data using GPS sensors is quite straightforward as driving information is collected automatically, without the need to modify the vehicle structure or special arrangements for the experiment. Sensors with GPS modules pro-vide information about the current location of the vehicle, its current speed, current acceleration values, distance travelled and travel time [20, 25]. The number of available parameters recorded by the GPS modules can easily be used to analyse driving style and driver behaviour. Examples of the use of this driver behaviour data collection method are shown, among others, in works [7, 15, 32].

Data on vehicle dynamic parameters from the CAN bus can be used to assess the driver's behaviour in real conditions [12, 36, 38]. Many scientists believe that they provide a more complete picture of the driver's behaviour pattern than information from GPS sensors. The data obtained from the CAN bus include longitudinal and lateral acceleration, brake pedal use, accelerator pedal use, or engine speed.

Another popular method of collecting driving parameters to evaluate driver's behaviour is the use of an OBD connector that is connected to a dedicated port on the vehicle. With the use of OBD, it is possible to record longitudinal and lateral acceleration, engine speed, accelerator position, brake pedal position and fuel consumption. The method of collecting data with the use of the OBD connector in the research on the driving behaviour was used in the research presented in [3, 23, 26].

Many studies use the methods described above simultaneously to analyse the driving behaviour of the driver in more detail [6, 18]. The behaviour of the driver can be studied using motion sensors and cameras focused on the driver, for example the driver's head position, facial pose, eyes' behaviour (e.g. opening/closing times and blinking frequency) and the position of the mouth [22, 30].

Longitudinal acceleration is directly related to acceleration and braking manoeuvres, while the lateral acceleration is related to trajectory change manoeuvres (e.g. turning, changing lanes, avoiding obstacles). The legitimacy of determining the driver's behaviour based on the acceleration values is confirmed in the literature. The acceleration profile characteristics may exhibit different driver-specific behaviour [8, 11]. The test results presented in works [27, 35] confirmed that each driver has an individual perception of the environment and reacts to changing traffic conditions, which is reflected in the acceleration values. Many works include the results of experimental research aimed at establishing the relationship between the increase in acceleration and speed [24, 29]. Speed has been proven to have a significant influence on the driver's acceleration behaviour. To investigate the driver's behaviour, one can find in many works examples of investigating the relationship between the acceleration values and other variables, e.g. using statistical, stochastic or optimization methods [31, 33].

Based on the literature study, it can be concluded that many factors influence driver behaviour. In the works cited above, researchers analyse many parameters simultaneously to classify drivers. This requires many observations and complex research methods. In companies where many drivers are employed, conducting an analysis of their driving style can be challenging. The authors believe that a preliminary classification of drivers would make it possible to isolate drivers whose driving behaviour can be considered aggressive and significantly different from others.

According to the authors, a preliminary classification of professional drivers can be carried out on the basis of analysis of acceleration values recorded during regular driving. The purpose of this paper is to present a method for preliminary classification of the driving style of professional city bus drivers on the basis of longitudinal and lateral acceleration values. The proposed method includes analysis of the maximum values of deceleration, acceleration and lateral acceleration recorded during each hour of driving. The proposed method of preliminary driver classification makes it possible to isolate drivers with extreme acceleration values and can draw attention to those whose driving behaviour requires deeper analysis.

The present study presents the driver's behaviour evaluation model based on the values of longitudinal and lateral acceleration. In the first part of the study, the acceleration values recorded for 69 bus city drivers during regular driving were analysed. Then, the correlation between the acceleration values and the age and seniority of the city bus drivers was examined.

2. Methodology

2.1. Data collection

In this study, longitudinal and lateral acceleration values recorded during the operation of real city buses were analysed. The research was conducted in a medium-sized city, according to European criteria (200,000 inhabitants). Data was collected on regular timetable routes. During the tests, the vehicles were driven on routes of various lengths, in various traffic conditions and in various areas (urban, suburban), as well as under various weather conditions (rain, sun, cloud cover, etc.). In this work, the impact of traffic and weather conditions on the acceleration values was not investigated. Due to the specificity of work, city bus drivers must drive regardless of weather and traffic conditions. Acceleration values were collected with the use of recorders using GPS technology. The research conducted as part of the project included measurements of longitudinal accelerations, lateral accelerations, speed and instantaneous position of the vehicle. The project developed a system and a measuring device enabling the simultaneous measurement of the previously mentioned parameters during regular operation of vehicles. The system included both a GPS sensor that recorded and exported vehicle location data and an accelerometer that stored data on a memory card at a frequency of 25 Hz. The measuring apparatus was verified. The sensors were installed in 25 vehicles.

2.2. Parameters used for preliminary drivers classification

In presented study acceleration and deceleration are the key parameters for describing driving behaviour. These parameters are the basis for the preliminary classification of drivers. A driver who reacts to changing driving conditions is not always able to adjust his driving style to ensure the highest possible sense of safety and comfort for passengers. The longitudinal and lateral acceleration values define how the driver accelerates, brakes, and performs lane changes and turning manoeuvres. The data were recorded during the regular work of drivers, according to the timetable runs and routes. While driving, the sensors recorded the values of longitudinal and lateral accelerations, as well as the current position of the vehicle. The collected acceleration values were selected for each driver (A_{ij}). Of the longitudinal acceleration profiles ($A_{(xij)}$) for each driver, the following maximum values of acceleration and deceleration for each driving hour were estimated:

· acceleration

$$A_{a_{ij}} = fmax(A_{x_{ij}}) \tag{1}$$

· deceleration

$$A_{d_{ij}} = fmin(A_{x_{ij}}) \tag{2}$$

where i – driver, j – driving hour.

Collected lateral acceleration profiles ($Ayij$) were allocated to each driver and the maximum and minimum values for each driving hour were estimated:

$$A_{y_{ij}} = fmax(|A_{y_{ij}}|) \tag{3}$$

where i – driver, j – driving hour.

For the purpose of evaluation of drivers and further research, average values of the previously determined variables for each driver were determined. The following values of longitudinal acceleration were adopted for the analysis:

acceleration

$$a_{a_i} = \frac{1}{n}\Sigma_j^n A_{a_{ij}} \tag{4}$$

deceleration

$$a_{d_i} = \frac{1}{n}\Sigma_j^n A_{d_{ij}} \tag{5}$$

and the values of lateral acceleration:

$$a_{y_i} = \frac{1}{n}\Sigma_j^n A_y \tag{6}$$

The values of averaged maximum longitudinal and lateral accelerations were used for assessing the driver's driving style. Based on the above parameters, it is possible to distinguish drivers whose recorded values are significantly different from the average. In the present study, it is assumed that values of lateral and longitudinal acceleration above the third quartile recorded simultaneously by the driver give grounds for defining his driving behaviour as alarming.

2.3. Correlation study

In the next part of the study, it was decided to investigate the influence of selected driver characteristics on the average maximum values of longitudinal and lateral accelerations.

The correlation between the averaged maximum values of longitudinal acceleration and lateral acceleration and the age of drivers, the seniority and the number of years of holding driving license were investigated. Studies of the relationship of the above-mentioned parameters will reveal whether the averaged maximum acceleration values used in the method affect driver characteristics. Statistica (StatSoft) software was used in the correlation study.

3. Results

3.1. Characteristics of drivers participated in the study

69 city bus drivers took part in the research – 67 men and 2 women. The average age of the drivers – 46 years. The youngest driver was 23 years old and the oldest 65. The age distribution of the analysed group of drivers is shown in Figure 1. The distribution of experience in driving a city bus in years of the analysed group of drivers is shown in Figure 2.
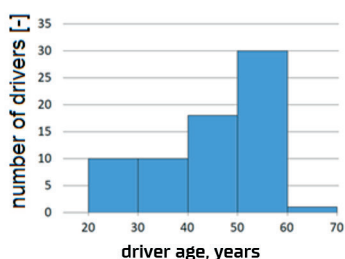
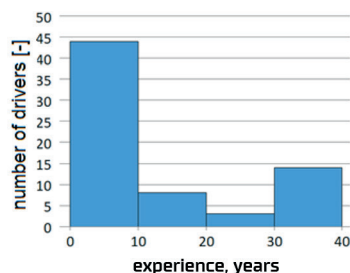Fig. 1. The age distribution of the city bus drivers participating in the research

Fig. 2. Distribution of experience as a professional city bus driver for all drivers

Work experience as a professional city bus driver in the analysed group of respondents varied. As many as 14 drivers had less than one year of experience. It is 20% of all researched drivers. The longest period of work as a professional bus driver was 34 years.
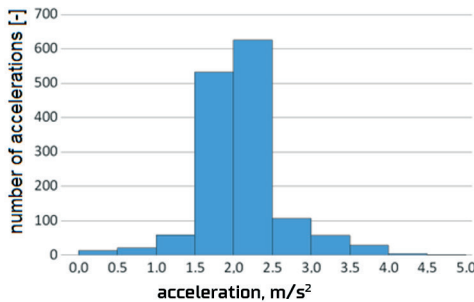
3.2. Acceleration values recorded during the study

Longitudinal and lateral acceleration values were recorded during actual city bus trips. Using the collected acceleration profiles, the maximum acceleration values of each driver for each driving hour were calculated. Figure 3 presents the distribution of longitudinal acceleration values during braking.
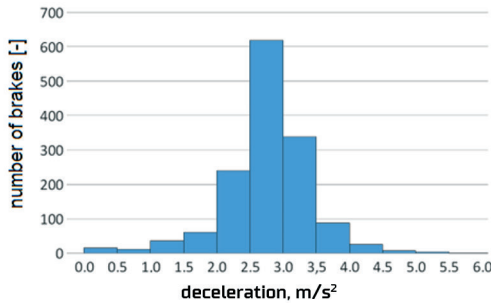
Fig. 3. Distribution of the maximum deceleration values (A_{dij}) during braking from each measured hour for each driver

The deceleration scatter was 6.0 m/s². The average deceleration value was 2.8 m/s². The standard deviation was 0.6 m/s². The range (2.4–3.4) m/s² includes 75% of all the recorded deceleration values. Harsh braking occurred during the measurements. The highest deceleration value recorded during the measurements was 6.0 m/s². Of all the recorded values of longitudinal acceleration values during braking, 6 deceleration values above 5.0 m/s² were recorded. Figure 4 shows the values of longitudinal acceleration during gathering speed recorded for the researched drivers in each hour of driving.

Fig. 4. The distribution of the maximum acceleration values (A_{aij}) during gathering speed from each measuring hour for each driver

The range of (1.7–2.5) m/s² contains 75% all recorded acceleration values. The aver-age acceleration value during gathering speed was 2.1 m/s². The standard deviation was 0.5 m/s². The highest recorded acceleration value achieved by the researched drivers was 4.9 m/s². Figure 5 shows the distribution of lateral acceleration values recorded for the tested drivers in each driving hour.
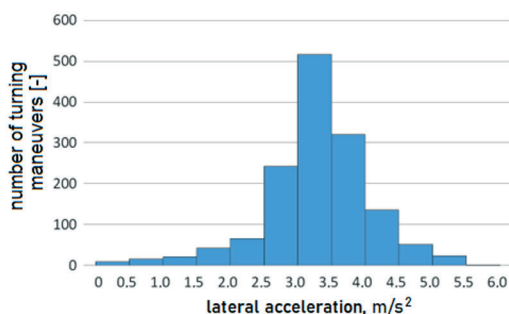
Fig. 5. Distribution of maximum lateral acceleration from each measurement hour for each driver

The scatter of lateral acceleration values was 5.9 m/s². The range of (2.6–4.3) m/s² contains 75% of the lateral acceleration values. The average lateral acceleration was 3.3 m/s². The standard deviation was 0.8 m/s².

3.3. Drivers' preliminary classification

Distribution of the averaged maximum longitudinal acceleration values (aai, adi) recorded for each of the researched drivers is given in Figure 6 and Figure 7.

The scatter of the averaged maximum deceleration values for the drivers taking part in the research was 2.2 m/s². The average deceleration recorded for the drivers is 2.8 m/s². The standard deviation was 0.4 m/s². The research showed that 75% of the averaged maximum deceleration values were recorded within the range of (2.4–3.0) m/s². The scatter of the averaged values of the maximum acceleration values was 2.0 m/s². The range (1.7–2.2) m/s² includes 75% of the acceleration values. The average acceleration value of all drivers was 2.1 m/s². The standard deviation was 0.4 m/s².
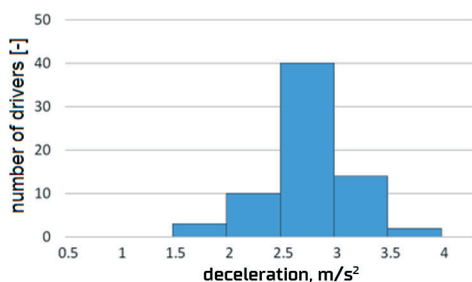

Fig. 6. Distribution of the averaged maximum deceleration values (a_{di}) during braking recorded for each driver
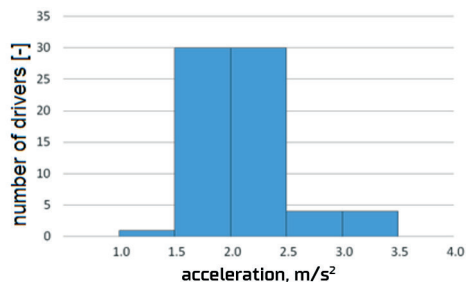
Fig. 7. Distribution of the averaged maximum acceleration values (a_{ai}) while gathering speed

Figure 8 shows the distributions of the average values of the maximum lateral acceleration (a_{li}) for each of the researched drivers.
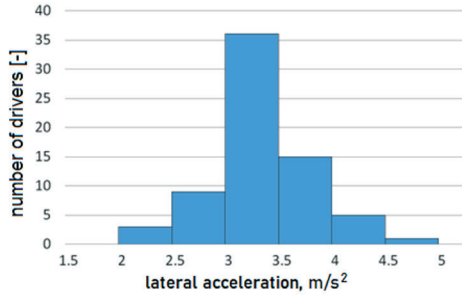

Fig. 8. Distribution of the averaged maximum values of lateral acceleration (a_{li})

Among the analysed averaged values of lateral acceleration, 75% falls in the range [2.9–3.6] m/s^2. The average lateral acceleration was 3.3 m/s^2. The standard deviation of the analysed values is 0.5 m/s^2.

Based on the parameters analysed above, it was observed that 11 drivers obtained both lateral (a_{li}) and longitudinal (deceleration (a_{di}) and acceleration values (a_{ai})) above the average of these populations. Of these, 3 drivers simultaneously recorded values of lateral and longitudinal accelerations above the third quartile of the population of these parameters. Values of both transverse and longitudinal accelerations below their average were recorded for 9 drivers. Figure 9 shows box plots of longitudinal and lateral acceleration values obtained for one driver who achieved acceleration values above the 3rd quartile.
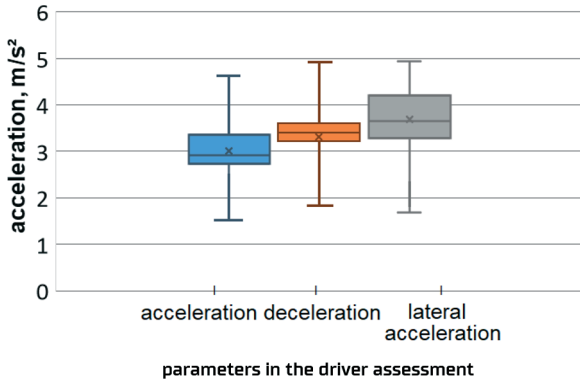

Fig. 9. Distribution of longitudinal and lateral acceleration recorded for the one of the drivers (the averaged maximum acceleration value is expressed by the symbol X)

3.4. Correlation analysis

For the maximum acceleration values (acceleration (a_{ai}), deceleration (a_{di}), and lateral acceleration (a_{li})) recorded for each driver, a study of the correlations of the following variables was performed: driver's age, work experience as a city bus driver (experience in driving a city bus), the number of years of holding a driving license. The values of the correlation coefficients are presented in Table 1.

Tab. 1. Person's (r) correlation coefficients of the analysed variables

	correlation coefficient		
	age	work experience as a bus driver	number of years of holding a driving license
deceleration (a_{d_i})	−0.03	−0.18	−0.01
acceleration (a_{a_i})	−0.19	−0.12	−0.15
lateral acceleration (a_{y_i})	−0.05	−0.15	−0.02

In the presented analyses, the correlation assessment according to Guilford [14] was implemented. The performed calculations prove that the deceleration values do not show any relation to the age of the driver and the number of years of holding the driving license. There was a weak negative correlation between the deceleration value and the years of experience as a city bus driver (−0.2, p<0.05). The acceleration values are minimally correlated with the age of the driver (−0.2, p<0.05) and the number of years of holding a driving license (−0.2, p<0.05). The lateral acceleration is minimally negatively correlated with the driver's seniority. There was no correlation between the lateral acceleration and the age of the driver and the number of years of holding a driving license.

4. Discussion

The study presents the city bus drivers' evaluation methodology with the use of longitudinal and lateral acceleration values. The driver rating is the average value of the maximum and minimum acceleration values recorded in each measuring hour. By analysing the drivers' ratings in accordance with the adopted methodology it was found that the range of acceleration values recorded for drivers was (1.4–3.4) m/s². The average acceleration value of all drivers was 2.1 m/s². The deceleration values fell within the range of (1.7–3.9) m/s² and the average deceleration was 2.8 m/s². The values of lateral acceleration recorded in the research fell within the range of (2.1–4.5) m/s². The mean lateral acceleration was 3.3 m/s².

In the next part of the work, the relationship between the acceleration values and the drivers' age, seniority (years of experience) and the number of years of holding a driving license was investigated. The correlation analyses performed show that the driver's age does not significantly affect the values of longitudinal and lateral accelerations. The age correlation coefficient and the acceleration values range from −0.2 to 0 (p<0.05). Therefore, it can be

concluded that the acceleration values decrease with age. The results of the analyses carried out confirm the results obtained in the previous research in this area. The research results presented in [36] confirmed that the driver's age is negatively correlated with the longitudinal acceleration. The correlation coefficient obtained was -0.27 ($p<0.05$). The authors found no relationship between the driver's age and lateral acceleration. Similar results are presented in [2].

In the present work, seniority is understood as the driver's professional experience in driving city buses in years. The results of the correlation carried out showed a weak relationship between the driver's seniority and the values of longitudinal and lateral accelerations. The correlation coefficient ranges from -0.18 to -0.12 ($p<0.05$). The results of the research presented in work [1] confirm the weak correlation between the driver's experience and the values of acceleration. The correlation studies presented in [1, 16, 39] show that the experience of a city bus driver does not significantly influence the number of traffic violations, accidents and dangerous situations on the road.

The analysis of the correlation between the number of years of holding a driving license and the values of longitudinal and lateral acceleration showed a weak relationship between these variables. The correlation coefficient falls within the range of -0.15 to 0 ($p<0.05$).The analysis of the correlation between the number of years of holding a driving license and the values of longitudinal and lateral acceleration showed a weak relationship between these variables. The correlation coefficient falls within the range of -0.15 to 0.

5. Conclusions

In the present study, the behaviour of city bus drivers was assessed based on the maximum values of lateral and longitudinal acceleration recorded during regular work. Based on the analyses of the acceleration values, it was observed that the average value of the longitudinal acceleration during gathering speed was 2.1 m/s^2. The average deceleration for the researched drivers was -2.8 m/s^2. The average lateral acceleration when turning left was 3.3 m/s^2.

The paper presents a method for preliminary classification of drivers' driving styles using acceleration values. The presented method is carried out using the average of the maximum values of longitudinal and lateral accelerations recorded by drivers during each hour of driving. This method facilitates the identification of drivers who drive more aggressively than other drivers.

The method was verified during an analysis of the driving style of 69 professional city bus drivers. Based on the values of longitudinal and lateral accelerations recorded during the drivers' regular work, an evaluation of the drivers' driving style was carried out. As a result, it was noted that 3 drivers showed simultaneous values of lateral and longitudinal accelerations (acceleration and deceleration) above the third quartile of the population of these accelerations. These results allow to consider the driving style of these drivers as aggressive and significantly different from others.

The previous section of the paper presents an analysis of the correlation of average maximum longitudinal and lateral acceleration values with driver age and experience. The correlation analysis showed that the age and the number of years of holding a driving license are not significant determinants of the driver's behaviour. Based on the results of the correlation, a relationship was observed between the values of lateral and longitudinal acceleration and the driver's experience. Therefore, it can be concluded that the averaged maximum acceleration values used in the method are not significantly affected by the age and experience of the driver. Thus, the method can be suitable for evaluating a driver regardless of his number of years of service and age.

The results of the research may be important from the point of view of the human resource departments in passenger transport companies. The proposed method for the initial classification of drivers is relatively simple and does not require sophisticated measurement equipment. The method can be easily used in practice, such as in applications and modules for evaluating drivers in fleet software. The presented research results are part of the project Innovative system research project supporting the motor vehicle insurance risk assessment dedicated to UBI (Usage Based Insurance). Further work is planned to analyse longitudinal accelerations and lateral accelerations recorded by drivers of different types of vehicles.

6. Acknowledgement

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