Research Article

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Testing the way of driving a vehicle in real road conditions

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Abstract: Safety is one of the most important issues in all areas of human life. It is taken into account during the design of motor vehicles, road infrastructure, the implementation of training for drivers, and their education. The main goal is to raise it, which is why it is discussed in many research studies. The research concerns the construction of motor vehicles, systems equipped with them, infrastructure, as well as drivers, their behavior, and the way they are driven. This article presents tests of the method of driving a vehicle in real road conditions. To evaluate the driver, selected vehicle motion parameters were used, which were recorded while driving on a real test section characterised by changing traffic conditions.

Keywords: vehicle driving, road safety, road conditions, driver behavior, vehicle motion parameters

1 Introduction

Driver research is a very frequent topic covered in many publications and articles. This is due to a large number of factors that affect the driver while driving, and the many methods and approaches are used to carry out these tests. Expanding the knowledge of drivers, and especially their behavior, is very important from the point of view of road safety because they have the greatest influence on them. This is all the more important as driving is a very common activity. Therefore, this research topic is still relevant today. More and more different ways of describing and modeling the behavior of drivers are being sought. He tries to implement the results of the tests in the algorithms of operation of safety systems in motor vehicles and in the systems supporting the driver while driving.

The aforementioned large number of factors that affect the driver while driving are directly related to his behavior. On the other hand, the behavior of the driver may have many reasons, including a bad physical condition [1] or mental condition of a person [2], lack of appropriate skills and experience [3], failure to adapt to the current road conditions [4], taking wrong decision [5], failure to comply with road traffic regulations [6,7], or making an incorrect assessment of the situation at the moment [8]. Therefore, to better understand and try to analyse the behavior of drivers, research is carried out taking into account various factors influencing the driver.

One of the directions of research for drivers is the study of the impact of road infrastructure elements and their surroundings on the way a vehicle is driven. An example of such research is described in ref. [8]. The authors analysed the effect of changing the width of the lane and the center marking using a driving simulator on the change of the speed of the vehicle by a given driver. In [9], the change in the operation of traffic lights into the number of stopping vehicles after a specific way of lighting the signaling was analysed. Other studies looked at how information is displayed on VMS (variable message sign) road signs. The authors, by changing the size of the font and its color, checked the speed of drivers' reactions to the information displayed. Wanvik [10] concerned the impact of installing lighting in places where there was no lighting before on the number of registered road accidents.

There are also studies of drivers on the impact of their health on the way they drive. Among the publications these are studies of drivers with Alzheimer's and Parkinson's diseases [11–13], where, due to the visual and cognitive disorders caused by these diseases, e.g. detection of collisions by such persons by comparing the obtained results with healthy persons. People with disabilities were also tested, e.g., knee surgery [14,15] or hip surgery

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[16], and the possibility of determining the time after which such drivers can drive motor vehicles again without increasing the risk on the road was examined.

I another group of studies, the influence of alcohol consumption [17] on the reaction time of drivers is analysed. Under special conditions, drivers carried out a series of car journeys, where they were to stop the vehicle at the light signal. In between the trips, the drivers consumed consecutive portions of alcohol. Similar studies were also carried out in [18,19]. Studies on the effects of drugs on driving by vehicle drivers [20] or the combined effects of alcohol and drugs on drivers [21] have also been reported.

There are also papers where the topic of research is drowsiness and fatigue of drivers. The previous study [1] investigated the effect of long-term driving associated with different drivers' sleep time on their reaction time. The results obtained from driving in real conditions were also compared with the results obtained from driving on the simulator. In this group of studies, due to the danger of carrying out research in real conditions, the creation of questionnaire studies has also become a very frequently used method of obtaining information [22,23].

Research in ref. [2] is about stress. The authors, by selecting four factors influencing the change in driving conditions, studied drivers of different sex and age. Experience is also an important factor influencing drivers' reactions. This issue was analysed inter alia in ref. [3], where learning drivers and driving instructors took part in the research. On the simulator, they covered the designated route for three scenarios during the day, night, and rainfall.

There are also items in the literature where the influence of environmental factors on driving a car is examined. Merkisz et al. [24] measured the driving parameters and the concentration of harmful exhaust components for three adopted driving scenarios, which each driver had to complete in three runs. The level of emission of harmful exhaust components and the level of driving economy were also studied in many other studies [25,26].

Very often, when examining drivers, the parameter that allows them to be compared with each other is the reaction time. The simplest test that enables the determination of such a time is the reflexometer test [27,28]. There are also specially prepared stations, such as those described in ref. [29], where the time was tested while driving. During the test drive, the influence of certain factors on the time achieved by drivers was examined. One of such factors is the phone call or, more generally, the use of a mobile phone. Research in this area is also quite extensive [30–33]. Reaction time tests were also carried out in pre-accident situations, where, in addition to the aforementioned time, the drivers' reactions and their defensive behavior were tested [5,34].

An important area of research for drivers is the attempt to define their driving style. The knowledge of driver behavior can be used in the development of driver assistance systems and vehicle control systems for autonomous driving. In the literature, you can find many articles with specific proposals for the method of evaluating drivers. A vehicle control algorithm was prepared in ref. [35]. It was based on the description of 11 parameters that are related to the control of the vehicle. The publication [36] uses the acceleration and speed values of the vehicle as well as such measurable indicators as TTC (time to collision), THW (time-headway) or MMTC (margin to collision) to assess drivers [37]. The authors in refs [38,39] used to evaluate drivers with the parameters of vehicle motion and engine operation. However, there are also such items where the identification of the driving style was done using data recorded from a smartphone [40–42].

It is also worth mentioning that the cited examples of research on drivers are only a very small excerpt representing a huge number of publications on this topic. And looking also in a broader perspective, road transport and related research have a very wide range of topics, ranging from aspects related to legal regulations concerning transport [43–45], the functioning of transport companies [46], to research related to motor vehicles [47], surroundings and road infrastructure, as well as drivers.

All recorded data and indicators allowing to describe a specific driver can be divided into simple and more complex. The simple ones include the vehicle position, vehicle speed [48], and acceleration [49]. To use them to assess the driving style of a given driver, it is necessary to indicate how various factors affect the variability of the aforementioned parameters. To make it possible, research should be carried out in specific conditions and road situations, and indicate how they determine the behavior of drivers. In addition to factors that directly affect the driver, his driving skills, experience, or the individual driving technique used, the change in the value of traffic parameters is influenced by the type of vehicle used, the type of roads on which the vehicle is traveling, or, for example, weather conditions.

In this article, the aim is to determine the impact of road types on simple vehicle motion parameters. The conducted research was aimed at preliminary verification of the research methodology and determination of the usefulness of the obtained data for the evaluation of the driving style of a given driver using simple parameters.

These studies are preliminary studies that will be carried out in the future for a greater number of journeys, and routes, drivers, and will be used for a broader analysis of how drivers drive vehicles as part of the doctoral dissertation.

2 Measurement methodology

The research was carried out on the route from Chęciny to Kielce and back. The total length of the mapped route was less than 50 km. The route selected for the tests was characterised by the fact that the journey took place on various types of roads. The course of the planned route is presented with the help of Google Maps in Figure 1.

The test route covers several road sections with different traffic conditions. One of such sections is the section running through the built-up area, located in the center of the city of Kielce. It is presented in Figure 2.

A driver driving a Renault vehicle took part in the study. He covered the route twice at two times on the same day characterised by increased traffic. The first time it was in the morning, when most people commute to work, college, or school, and in the afternoon, when the same people return home. For both journeys, the driver followed the route in a natural way without any guidance on how to drive the vehicle. It should also be noted that both journeys were carried out with road safety and compliance with the applicable road traffic regulations.

During the runs, data such as longitudinal acceleration, lateral acceleration, travel velocity, and vehicle position were recorded.

As part of the research in real road conditions, the Renault Captur vehicle shown in Figure 3 was used.

Renault Captur (first generation, five-seater) with a total curb weight of 1,245 kg, powered by a diesel engine with a capacity of 1,461 cm^3, 66 kW, and 220 Nm torque. This vehicle was loaded during the tests with an additional mass of 75 kg.

3 Measuring equipment characteristics

To record data during the actual driving of the vehicle, a measuring system was used, consisting of a tracker that allows you to send and record the exact position of the vehicle and sensors recording both the velocity of the vehicle and its acceleration. This system is powered by 12 V, so it could be connected to the power socket in the car. A characteristic feature of the system is its compactness because it has been mounted in a small, hermetic housing made of plastic. This system allowed for data recording with a frequency of 25 Hz and is shown in Figure 4.

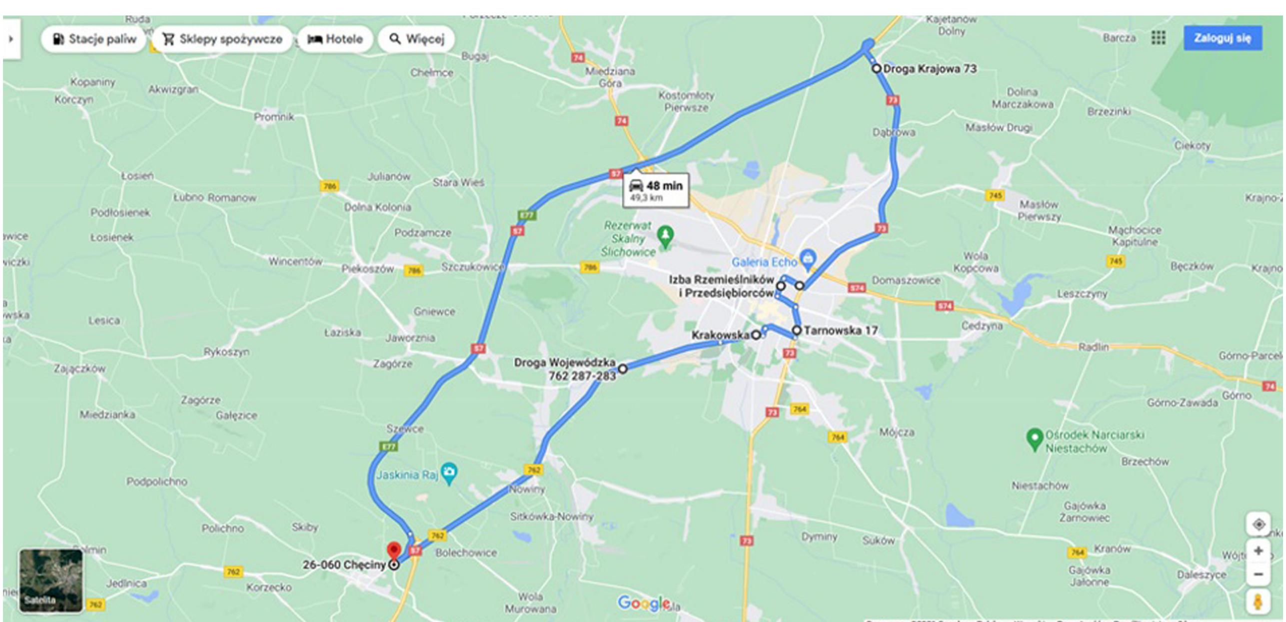

Figure 1: Test route.

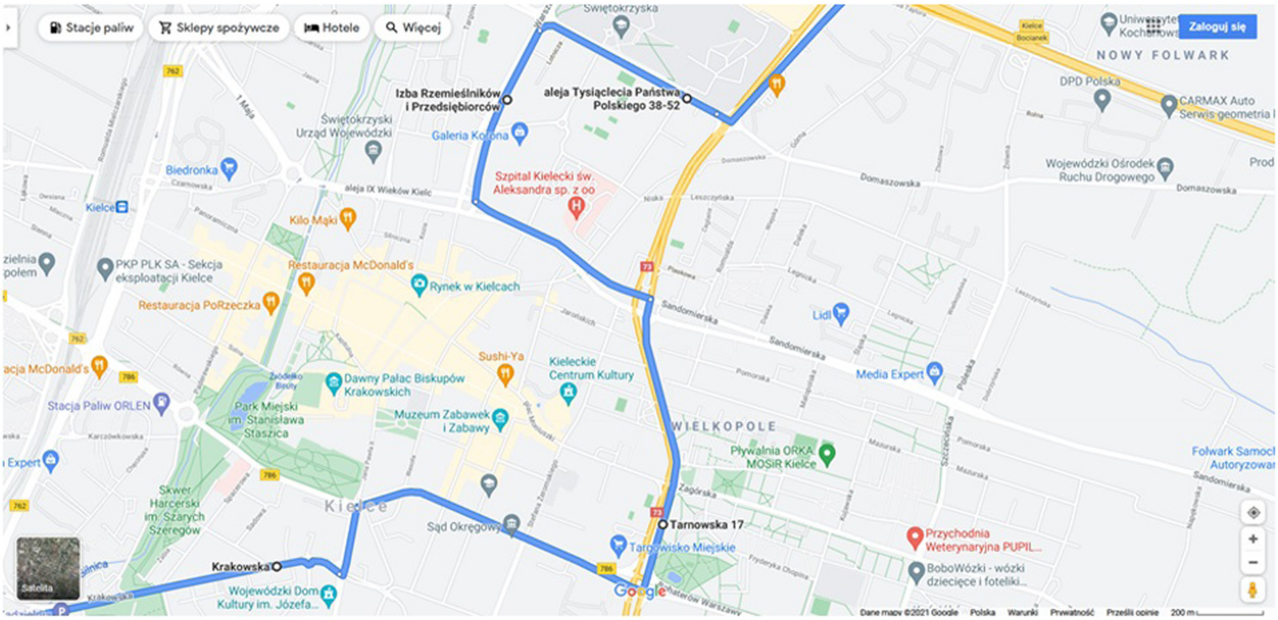

Figure 2: A fragment of the planned research route, taking into account the drive through the city of Kielce.

Figure 3: Renault Captur vehicle used for the tests.

Figure 4: The interior of the measuring system.

4 Measurement results

The result of the tests carried out in real road conditions was obtaining two sets of data stored in the internal memory of the device. Apart from them, the course of the vehicle's route was also recorded. Viewing and accessing it is possible thanks to the use of the Globtrak^{TM} system.

After the initial analysis, the measurement results were divided into several groups in each of the trips. These groups differ in the road conditions in which the tested driver was driving, and the division is as follows:

- Section of the route 1 – driving the road between Chęciny and Kielce (dual carriageway extra-urban road),
- Section of the route 2 – driving in Kielce (city traffic),
- Section of the route 3 – exit from Kielce (non-urban dual carriageway road),
- Section of route 4 – driving the express road to Chęciny (express road – fast dual carriageway road),
- Section of route 5 – access road to Chęciny (single carriageway extra-urban road).

According to the adopted division, velocity diagrams during both runs were determined. Figure 5 shows the course of the vehicle velocity during the morning drive, while Figure 6 shows the velocity profile of the drive made in the afternoon.

Based on the data in Tables 1 and 2, the respective characteristic velocity values and their average values for individual sections of the route for both journeys are compiled.

As a result of the performed measurements, the values of longitudinal and transverse acceleration were also determined. In the case of longitudinal acceleration, its positive values apply to vehicle acceleration, while negative values indicate its braking. Figure 7 shows the values of longitudinal acceleration recorded in the morning, and Figure 8 shows the values recorded in the afternoon.

Table 3 summarises the maximum and minimum longitudinal acceleration values for both journeys, divided into route sections characterised by different road conditions.

Figures 9 and 10 show the values of lateral acceleration for the morning and afternoon travels, respectively.

As in the case of longitudinal accelerations, also in the case of lateral accelerations, Table 4 summarises the maximum and minimum acceleration values for both runs divided into route sections characterised by different road conditions.

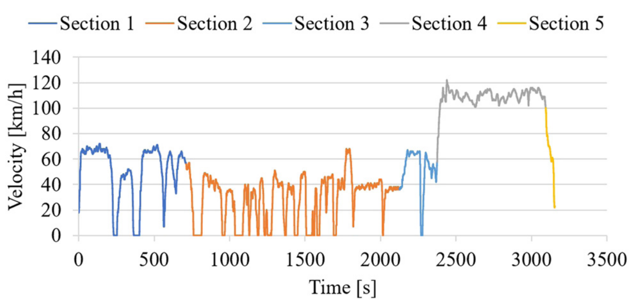

Figure 5: Velocity profile on the Chęciny–Kielce–Chęciny route in the morning.

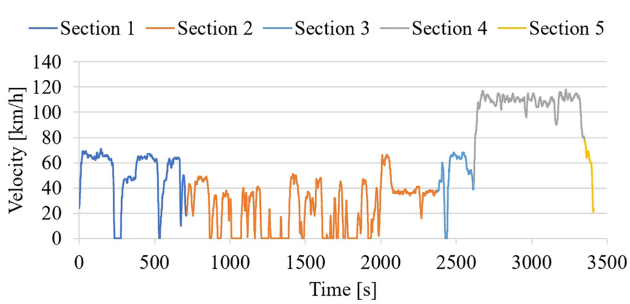

Figure 6: Velocity profile on the Chęciny–Kielce–Chęciny route in the afternoon.

Table 1: Vehicle motion parameters – morning drive

Section	Velocity (km/h)			Time (s)
	Minimum	Maximum	Average	
1	0	72	51	713
2	0	68	29	1,412
3	0	67	52	250
4	58	122	109	719
5	22	100	64	60
Whole route	0	122	55	3,154

Table 2: Vehicle motion parameters – afternoon drive

Section	Velocity (km/h)			Time (s)
	Minimum	Maximum	Average	
1	0	71	52	713
2	0	66	24	1,659
3	0	68	52	243
4	41	118	107	735
5	21	78	58	62
Whole route	0	118	51	3,412

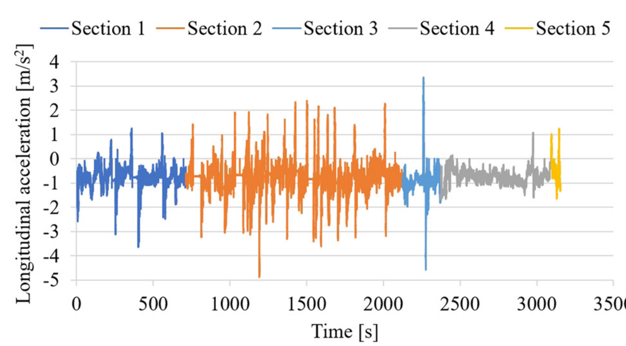

Figure 7: Longitudinal accelerations – morning drive.

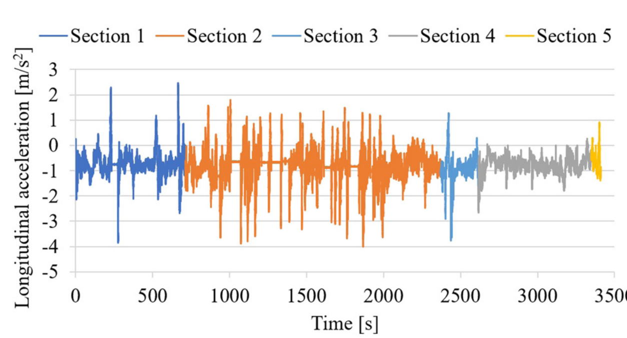

Figure 8: Longitudinal accelerations – afternoon drive.

Table 3: List of extreme longitudinal acceleration values

Section	Minimum (m/s^2)		Maximum (m/s^2)	
	Morning	Afternoon	Morning	Afternoon
1	−3.65	−3.85	1.26	2.47
2	−4.88	−4.00	2.39	1.80
3	−4.57	−3.76	3.36	1.27
4	−1.69	−2.66	1.08	0.27
5	−1.65	−1.39	1.25	0.91
Whole route	−4.88	−4.00	3.36	2.47

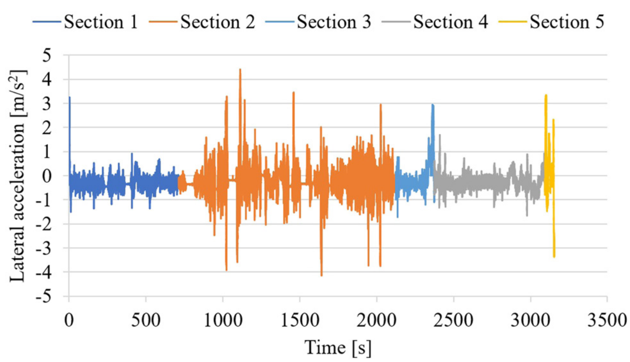

Figure 9: Lateral accelerations – morning drive.

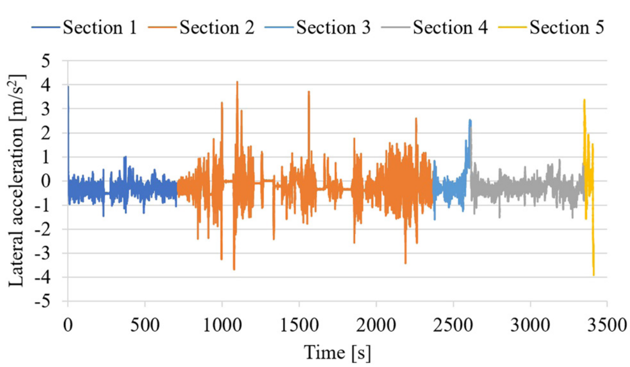

Figure 10: Lateral accelerations – afternoon drive.

Table 4: Summary of extreme lateral acceleration values

Section	Minimum (m/s^2)		Maximum (m/s^2)	
	Morning	Afternoon	Morning	Afternoon
1	−1.51	−1.46	3.25	3.92
2	−4.14	−3.69	4.41	4.12
3	−1.69	−1.59	2.95	2.54
4	−1.66	−1.53	1.70	2.22
5	−3.37	−3.92	3.34	3.38
Whole route	−4.14	−3.92	4.41	4.12

5 Analysis of results

Figure 11 shows the frequency of occurrence of particular values of longitudinal acceleration during the morning drive. It has been noticed that the most acceleration occurs in the range between −0.5 and −1 m/s^2. These are the accelerations that indicate frequent gentle braking and deceleration of the vehicle. Their high number of occurrences compared to the general number (about 56%) provides information about the increased need to slow down, stop the vehicle, and not drive at a constant speed.

In the case of the interval between 0.5 and −0.5 m/s^2, it is only less than 17% of all accelerations. This range includes low acceleration values, which allows it to be conventionally considered driving at a constant speed. The relatively small number of small acceleration values allows us to conclude that there were many sections of the route during the journey, where it was not possible to move at a constant speed, or the driver did not try to keep it while traveling.

In the case of higher acceleration values indicative of more rapid acceleration and braking, above 3 and below −4 m/s^2, respectively, it can be noticed that such large values are almost nonexistent. All this proves the "calm" driving style of the tested driver, who covered the majority of the route without sudden acceleration of the vehicle.

To compare the observations concerning the first and second run, Figure 12 shows a graph with a relative difference in the frequency of specific acceleration values. This difference shows how the frequencies of particular acceleration values from the afternoon drive differ from the morning drive. From the graph, it can be seen that the acceleration distribution is almost the same. The frequency of occurrence in particular intervals differs

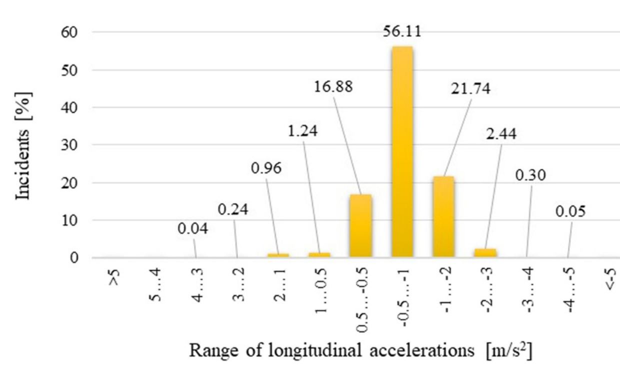

Figure 11: The frequency of occurrence of particular values of longitudinal acceleration – morning drive.

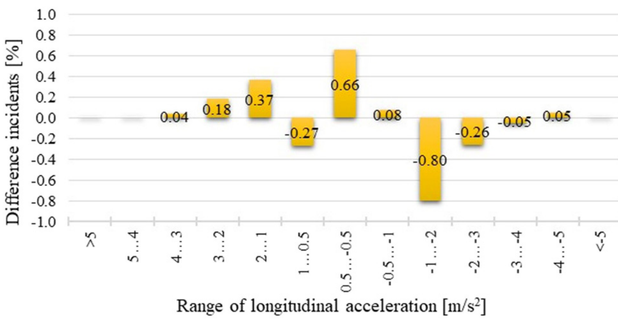

Figure 12: The difference in the frequency of occurrence of particular values of longitudinal acceleration of the afternoon drive in relation to the morning drive.

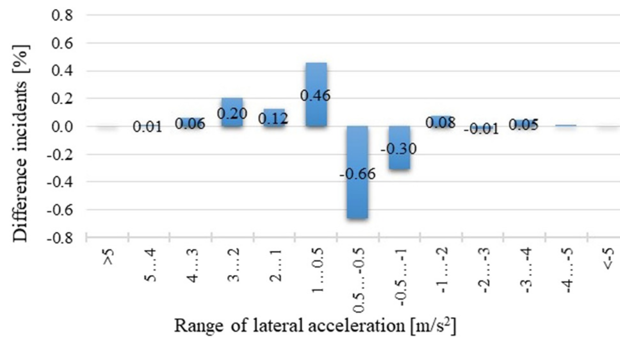

Figure 14: The difference in the frequency of occurrence of particular values of lateral acceleration of the afternoon drive in relation to the morning drive.

between journeys by no more than 0.8%. This proves that the conditions in which the route was driven were very similar and that the driver covered the route in a manner similar to his style.

Figure 13 shows the second type of acceleration recorded during the tests. The diagram shows the frequency of occurrence of lateral acceleration values, with positive and negative values illustrating the direction of their action. The prevailing acceleration values in the first run range from 0.5 to −0.5 m/s^2, which constitute over 81%.

Figure 14 shows a comparison of the lateral acceleration values obtained in the afternoon drive for the value from the morning drive. Also in this case, the acceleration distributions are very similar to each other. The frequency of occurrence in particular intervals differs between journeys by no more than 0.66%. The driver, while covering the re-marked route, steered the car in a manner characteristic of his driving style.

The presented frequencies of the occurrence of particular accelerations refer to entire routes without division into individual sections. However, taking into account the diversity of road conditions caused by various road sections that are driven during the journey, the question arises whether the frequency of occurrence of individual acceleration values for particular types of roads differs from each other. To answer this question, Figure 15 shows the frequency distribution of longitudinal accelerations for individual route sections.

As shown in Figure 15, for the morning drive, the distribution of the frequency of longitudinal acceleration for individual sections differs from each other. In Sections 1–4, the greatest acceleration ranges from −0.5 to −1 m/s^2. It is different only for Section 5, and here, the most values range from 0.5 to −0.5 m/s^2. In the case of the distribution of the remaining values, it is worth noting that there is a noticeable tendency for a greater share of braking while traveling the route than acceleration. It is most visible for route Sections 2 (city) and 3 (leaving the city). The distribution of these values allows confirming that we are dealing with a “calm” style of driving the vehicle by the driver, without noticeable more rapid acceleration and braking of the vehicle.

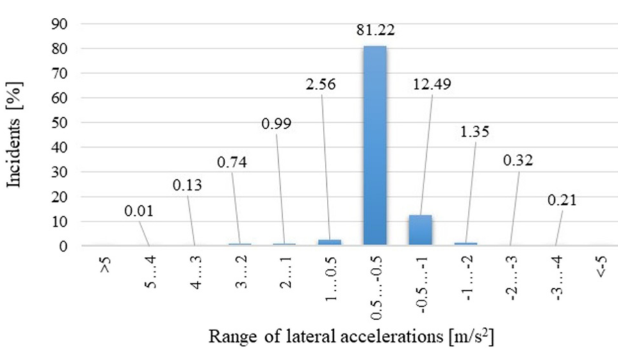

Figure 13: The frequency of occurrence of particular values of lateral acceleration – morning drive.

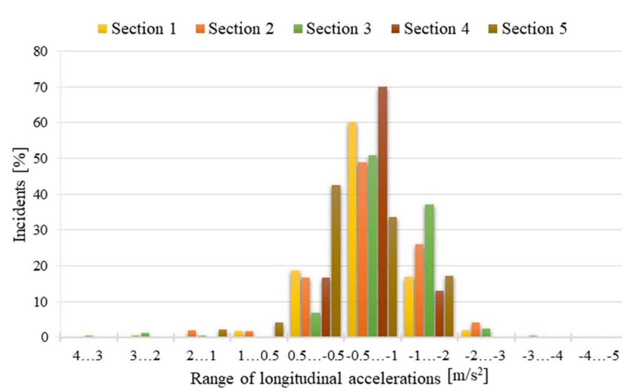

Figure 15: The frequency of occurrence of particular values of longitudinal acceleration for selected sections of the route – morning drive.

Table 5 presents the differences in the frequency of individual longitudinal accelerations for the designated sections of the afternoon drive versus the morning drive.

The data presented in Table 5 confirm a similar distribution of longitudinal acceleration values for the afternoon drive compared to the morning drive. For the majority of sections, this difference does not exceed 5%. It is slightly different only for Section 5, where the values differ more. However, this is due to the fact that in the case of Section 5, we are dealing with a fragment of the route that is characterised by a very short length, and thus a very short data registration time (Tables 1 and 2). This may cause that even a small variation of accelerations over such a section may have a significant impact on their distribution.

Figure 16 and Table 6 present the data on the lateral acceleration.

Table 5: Percentage differences in the frequency of individual longitudinal accelerations

Section	Range of longitudinal accelerations (m/s^2)				
	4 … 3	**3 … 2**	**2 … 1**	**1 … 0.5**	**0.5 … − 0.5**
1	0.00	−0.28	−0.59	−0.30	3.64
2	0.00	0.35	1.04	−0.31	0.16
3	0.53	1.07	−0.03	−1.46	−1.83
4	0.00	0.00	0.01	0.17	−0.98
5	0.00	0.00	2.25	2.11	10.33
	−0.5 … − 1	**−1 … − 2**	**−2 … − 3**	**−3 … − 4**	**−4 … − 5**
1	−0.07	−3.47	0.93	0.13	0.00
2	−2.56	1.51	−0.23	−0.04	0.08
3	0.03	3.40	−1.15	−0.77	0.19
4	4.76	−3.22	−0.74	0.00	0.00
5	−8.23	−6.46	0.00	0.00	0.00

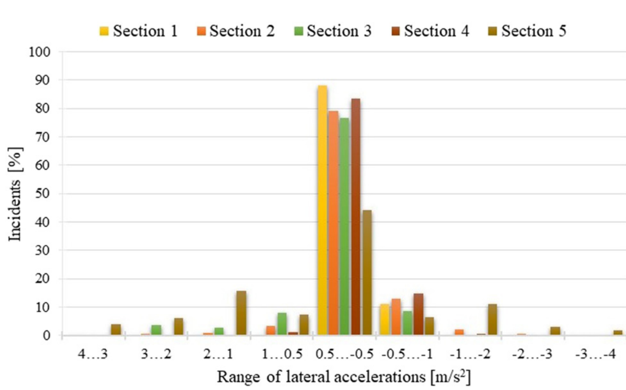

Figure 16: The frequency of occurrence of particular values of lateral acceleration for selected sections of the route – morning drive.

Table 6: Percentage differences in the frequency of occurrence of particular lateral accelerations

Section	Range of lateral accelerations (m/s^2)				
	4 … 3	**3 … 2**	**2 … 1**	**1 … 0.5**	**0.5 … − 0.5**
1	−0.04	0.29	0.05	0.21	5.30
2	0.03	0.14	0.22	0.88	−3.44
3	0.00	1.32	−0.18	−0.82	0.28
4	0.00	−0.03	−0.05	0.52	−1.23
5	3.01	−1.91	1.44	−1.55	0.17
	−0.5 … − 1	**−1 … − 2**	**−2 … − 3**	**−3 … − 4**	
1	−5.92	0.12	0.00	0.00	
2	1.71	0.21	0.06	0.18	
3	0.20	−0.80	0.00	0.00	
4	0.91	−0.12	0.00	0.00	
5	−3.13	4.87	−1.40	−1.50	

Based on Figure 16 and Table 6, assuming that the lateral acceleration ranging from −0.5 to 0.5 m/s^2 is considered a “smooth and normal drive,” it can be concluded that the driver covered the test route in exactly this way.

The frequency of individual accelerations in each section has a similar distribution with respect to each other, in relation to the distribution made for the entire route and for the afternoon trip in relation to the morning drive.

6 Conclusion and summary

This article presents data from two journeys by a passenger car. These journeys took place on the same day at two of its times characterised by increased traffic on the road. Both trips were made by the same driver who used the vehicle in a natural way. The covered route was less than 50 km long and consisted of sections with different traffic conditions and different types of roads. During the runs, basic traffic parameters such as vehicle position, velocity, longitudinal, and lateral accelerations were recorded.

The obtained data, presented in the form of charts and tables, were used to analyse the usefulness of these data for the assessment of the driving style of a driver in various traffic conditions, on various types of roads.

The first parameter that was presented is volocity. Based on Figures 7 and 8 and Tables 1 and 2, it can be concluded that this parameter allows to identify very well not so much the driving style, but the type of route on which the vehicle was traveling. Several sections of the route can be listed. This is possible by analysing the course of the speed profile. Such a possibility of division was confirmed thanks to the simultaneous analysis of the car position.

The values of the measured accelerations show a great variety. Depending on the type of road, their scope and variability change. These parameters are slightly less sensitive to changes in the type of road and road conditions, but thanks to the implementation of more tests for different drivers and reference to the already completed tests [50], it will be possible to determine, e.g., acceleration ranges allowing for the classification of drivers.

In this study, the authors used some conventionally accepted ranges of acceleration [51]. For longitudinal accelerations, accelerations between −0.5 and 0.5 m/s^2 are considered to be the range where the driver makes very slight corrections to the vehicle speed. Therefore, this way of driving was considered to be driving at a constant speed, and the driving style in this case was conventionally called "calm, gentle style." Similarly, also in the case of lateral acceleration, exactly the same range characterises the correction of the vehicle position carried out in a "calm, gentle" manner.

When analysing the acceleration distributions of the tested driver along the entire route, it is worth noting that the most frequently achieved values were usually within narrow ranges. High values, significantly different from the others, occurred in individual cases. Based on the current research, such results do not yet provide grounds for calling the driving style "daring," but when analysing a larger group of drivers in similar road conditions, it may turn out that it will be possible to parameterise such situations.

Testing the driving style of drivers on the basis of basic traffic parameters has its practical application. Based on the recorded data, the impact of changing the road type on the obtained values was indicated, as well as the usefulness and the possibility of using individual parameters to assess the driving style. This shows an area of scientific activity that can and should be developed. The presented research can be treated as a pilot study. On the basis of the obtained results, further, broader studies have been planned, in which the basic parameters of vehicle traffic will be recorded at different times of the day, for different drivers, and while driving different types of vehicles.

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