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Research into the effects of changes in drivers' driving style on vehicle movement parameters

Michał Gruszczyński[1]✉, Rafał S. Jurecki[2]

[1] https://orcid.org/0000-0002-4489-4486
[2] https://orcid.org/0000-0003-0105-1283

Kielce University of Technology, Faculty of Mechatronics and Mechanical Engineering
Department of Automotive Engineering and Transport
7 Tysiąclecia Państwa Polskiego Ave., 25-314 Kielce, Poland
e-mail: [1]mgruszczynski@tu.kielce.pl, [2]rjurecki@tu.kielce.pl
✉ corresponding author

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Abstract
Investigations into driver's behavior are a very important and frequently addressed topic by researchers. They allow us to understand drivers better and characterize their behavior. However, this can be difficult due to the many factors that affect the driver while driving. Therefore, many efforts are being made to improve the safety of both drivers and other road users. In this study, in order to better understand and describe the driver's driving behavior, the results of a pilot study conducted under real traffic conditions are presented. The test route includes different road types and is characterized by varying traffic conditions. Modifications in simple vehicle movement parameters are analyzed in relation to changes in the way drivers drive test routes.

Introduction

Nowadays, it is very difficult to imagine a reality without motor vehicles. Vehicles make it possible to transport people and cargo, which promotes the development of economies and is one of their main driving forces. Just as important as the self-realization of transport tasks is maintaining an appropriate level of safety in the process. This is all the more important in the case of Poland, as the road transport system is the most common mode of transport here compared to the others, accounting for approximately 87% of travel methods (Jurecki & Jaśkiewicz, 2012; Łukasik, Bril & Bril, 2013).

Such a large share of the road transport system encourages incidents and dangerous situations on the roads, resulting in reduced safety levels. Not insignificant in this respect is the number of cars, which reached 682 per 1,000 people in 2021 (GUS, 2023). Thus, a number of solutions are being applied to counteract this phenomenon. Some of these relate to improving and adapting road infrastructure. In practice, this means using appropriate signaling and information systems or building modern road systems. Other solutions, on the other hand, focus on drivers. These include stricter traffic rules, training, and education to improve drivers' skills and raise their awareness of irresponsible driving. Still other solutions concern motor vehicles and the use of modern safety and driver assistance systems in them (Jurecki & Jaśkiewicz, 2012; Łukasik, Bril & Bril, 2013; Liščák, Moravčík & Jaśkiewicz, 2014).

Each of the solutions mentioned requires the collection of a range of information, the vast majority of which is supported by a series of studies. Analyzing the research results makes it possible to identify specific problems that need to be addressed (Pędziwiatr & Sosik-Filipiak, 2021). The effect of these measures could be to improve road safety. In the very large group of studies that are carried out all the time, it is noticeable that the topic of drivers is frequently mentioned. This is due to the numerous factors that affect the driver while driving and is justified since human behavior is considered by far the greatest influence on safety during driving situations. Consequently, increasingly improved ways of modeling driver behavior are being sought. These models are used in algorithms responsible for the operation of vehicle safety systems or systems that support the driver while driving. They can also be employed in frameworks used to reconstruct traffic accidents.

One important direction of driver research is to attempt to determine the style in which drivers drive. Having this knowledge allows the development of in-vehicle safety systems, driver assistance systems, or vehicle control systems used for autonomous driving. Determining driving style can be done in a number of ways. One of them can be the development of an algorithm that is based on the identified parameters (Wang, Lu & Li, 2010). Through these parameters, it becomes possible to describe drivers according to their driving style. Another approach (Li et al., 2017) is to rely not on the duration or frequency of maneuvers, but on the relationships that characterize the transitions between them. An attempt to describe the style can also be made on the basis of vehicle movement parameters or, for example, engine operating parameters. In a previous publication (Suzdaleva & Nagy, 2018), the values of vehicle speed, throttle position, fuel consumption, and gearbox ratios were employed to assess drivers. An earlier paper (Rygula, 2009) used tachograph discs in its research, where speed and acceleration profile analyses were used to assess the driver. In other works (Varthelyi et al., 2004; Wakita et al., 2006), such examinations were complemented by an analysis of the position of vehicle controls.

The cited papers on driver research are only examples of the considerable amount of material that can be found in the literature. Indeed, studies are being carried out on the effects of driver health (Vaux et al., 2010; Qurashi et al., 2017), the effects of alcohol (Christoforou, Karlaftis & Yannis, 2013; Vrabel, Sarkan & Vashisth, 2020), drugs (Hindmarch, 2004), sleep medication (Verster, Veldhuijzen & Volkerts, 2004), and sleepiness and fatigue (Pizza et al., 2010; Di Milia & Kecklund, 2013; Gottlieb et al., 2018) on driving. This confirms how complex the process of driving is and how many factors can influence it. At this point, for many of these studies, it is also noteworthy that both speed and acceleration values, as well as measurable indicators (Gruszczyński & Jurecki, 2020), were used to characterize drivers.

In the case of parameters such as vehicle position, speed, and acceleration, in order to use them to assess a driver's driving style, it is necessary to indicate how various factors cause them to change. One method to make such an assessment is to carry out road tests. These tests need to be performed in specific weather conditions and driving situations to indicate how they affect a particular driver. In addition, during such tests, attention should be paid to the type of vehicle used and the type of roads the vehicle drives on. All this makes it possible to check the influence of specific factors on the variation of the vehicle's performance, accounting for elements that characterize the driver, their driving skills, the driving technique used, and their experience.

The present study is concerned with determining the influence of one of the mentioned factors, i.e., the type of road, on simple vehicle movement parameters. This analysis is aimed at verifying the research methodology and determining the usefulness of the data obtained for assessing the driver's driving style. The research presented here is preliminary but will later be extended to include more routes, drivers, and the number of journeys made. In turn, the obtained results will be used for a broader analysis of drivers' driving styles.

Measurement methodology

The tests were carried out while driving a route of around 50 km under real road conditions. The route was composed of sections with significantly different road conditions, including non-urban, urban, and express roads. It ran from Chęciny to Kielce and back. The course of the planned route and a fragment with a specified urban section are shown in Figure 1.

The tests consisted of one driver driving the route in real traffic conditions in the same vehicle on three days in the morning. Each day, the way in which the driver covered the route was, by design, different. On the first day, the driver was tasked to drive the designated route in a way that was natural to him (hereafter referred to as 'normal' driving), so no recommendations were given on how to drive. On the next day, the driver drove the designated route with the recommendation to take care to use as little fuel as possible. In this case, the driver was to drive as smoothly as possible, minimizing the use of the brake pedal, anticipating traffic situations, and accelerating the vehicle in a gentle

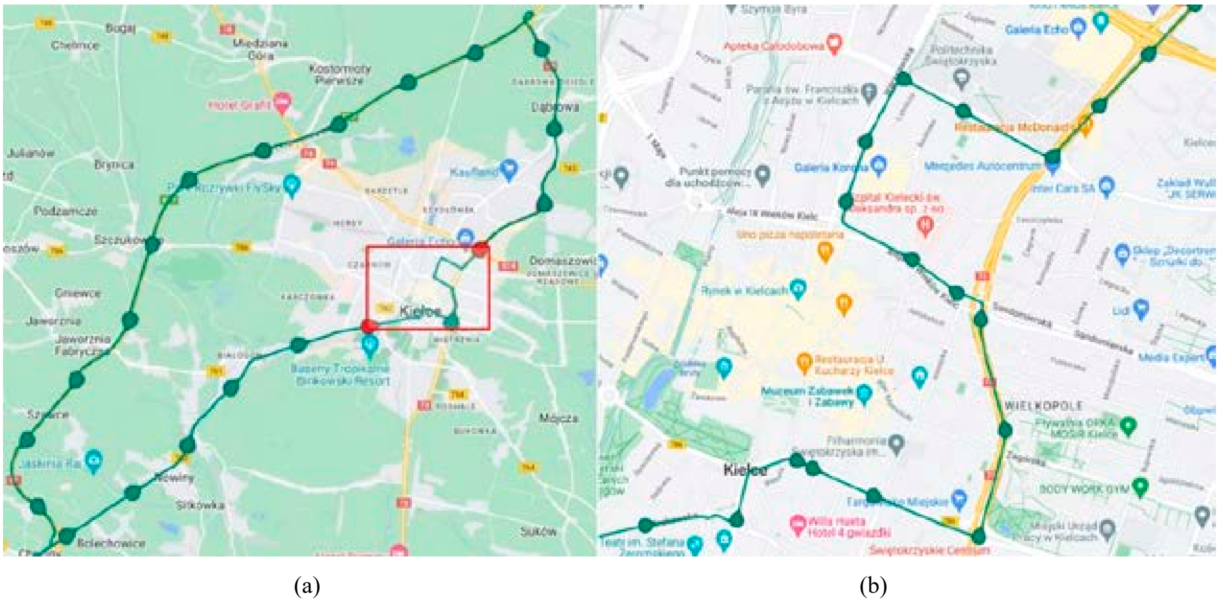

Figure 1. Measurement route: (a) view of the entire test route and (b) section of the route passing through the city of Kielce – the start and end of the route are marked with a red point

manner. This drive is referred to as the 'economic' drive. On the third day, the route was to be completed as quickly as possible. The driver did not have to concern himself with fuel consumption, the number of brakes, or the way in which the vehicle accelerated, only account for traffic regulations and the safe completion of the test route. This method of completing the route is referred to hereafter as 'dynamic' driving.

Data such as vehicle position, speed, and longitudinal acceleration were recorded during all drives. The vehicle used for the tests was a third-generation Renault Megane, equipped with a 1598 cc petrol engine with 81 kW of power and 151 Nm of torque. It has an unladen weight of 1215 kg and was loaded with the driver's weight of 75 kg during the tests.

For data recording, the Corrsys-Datron™ road car test equipment kit was used. The kit consisted of a Corssys-Datron S-350™ optoelectronic sensor for measuring the components of motion, i.e., longitudinal velocity, transverse velocity, and drift angle; a Corssys TAA™ linear acceleration sensor for measuring acceleration in the X, Y, and Z axis directions; a Corssys uEEP-12™ data acquisition station with a control tablet and ARMS software.

Measurement results

Three datasets were obtained following the road tests. Additionally, it was also possible to access the actual path data of the test vehicle. All results were checked for completeness and divided according to the type of roads the vehicle traveled on. This division specified five route sections:

1) the section of a dual carriageway, a non-urban road running between the town of Chęciny and the border of the city of Kielce;
2) the section running through the city of Kielce;
3) a fragment when exiting the city of Kielce, which is a dual carriageway extra-urban road section;
4) the section of the dual carriageway leading to the town of Chęciny;

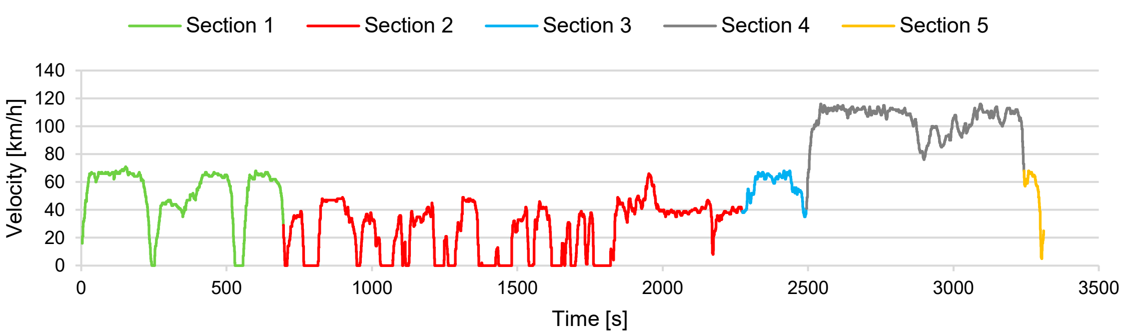

Figure 2. Velocity profile for a 'normal' drive

5) the shortest section that constitutes an exit from the expressway to the starting point of the survey, which is a fragment of an extra-urban single carriageway road.

Diagrams of the speed courses were prepared for each test journey with the adopted divisions. An example diagram of the speed course on the analyzed route is presented in Figure 2. For all three crossings, Table 1 summarizes the traffic parameter values for the whole route and individual sections.

Table 1. Vehicle movement parameters for the three test drives

Type of journey	Road Section	Velocity [km/h]			Time [s]
		Min.	Max.	Average	
'normal'	1	0	71	52	695
	2	0	66	26	1578
	3	35	68	57	221
	4	41	116	104	748
	5	5	68	52	68
	Whole route	0	116	52	3311
'economic'	1	0	69	47	772
	2	0	61	22	1807
	3	0	65	46	274
	4	35	110	94	827
	5	14	80	52	71
	Whole route	0	110	46	3751
'dynamic'	1	0	70	51	704
	2	0	65	26	1532
	3	16	69	54	227
	4	39	120	100	783
	5	27	79	60	60
	Whole route	0	120	52	3307

Longitudinal acceleration values were also recorded during the tests. Positive values indicate vehicle acceleration, while negative values signify braking. Figure 3 shows an example of one of the determined acceleration curves (for a 'normal' drive), accounting for the adopted route division into sections. Table 2 summarizes the minimum and maximum longitudinal acceleration values for each of the crossings, accounting for the breakdown of the route by road type.

Table 2. Minimum and maximum values of the longitudinal accelerations for completed journeys

Road Section	Minimum values [m/s^2]		
	'normal'	'economic'	'dynamic'
1	−2.49	−2.35	−3.98
2	−4.00	−2.52	−4.51
3	−1.51	−1.33	−2.27
4	−1.35	−1.07	−1.32
5	−3.11	−0.77	−0.91
Whole route	−4.00	−2.52	−4.51
Road Section	**Maximum values [m/s^2]**		
	'normal'	'economic'	'dynamic'
1	1.69	1.69	2.60
2	3.52	3.32	2.76
3	1.38	1.28	2.30
4	2.30	1.21	1.46
5	2.38	1.35	1.66
Whole route	3.52	3.32	2.76

Analysis of results

Figure 4 presents the frequency of occurrence of individual values of longitudinal acceleration during a 'normal' drive. The greatest number of accelerations were recorded between the values of 0.5 m/s^2 and −0.5 m/s^2. This represents approximately 79% of the values recorded over the entire drive. These are low acceleration values that allow driving with such vehicle accelerations to be termed as approximately 'constant speed' driving. The next ranges with the highest share of individual acceleration values

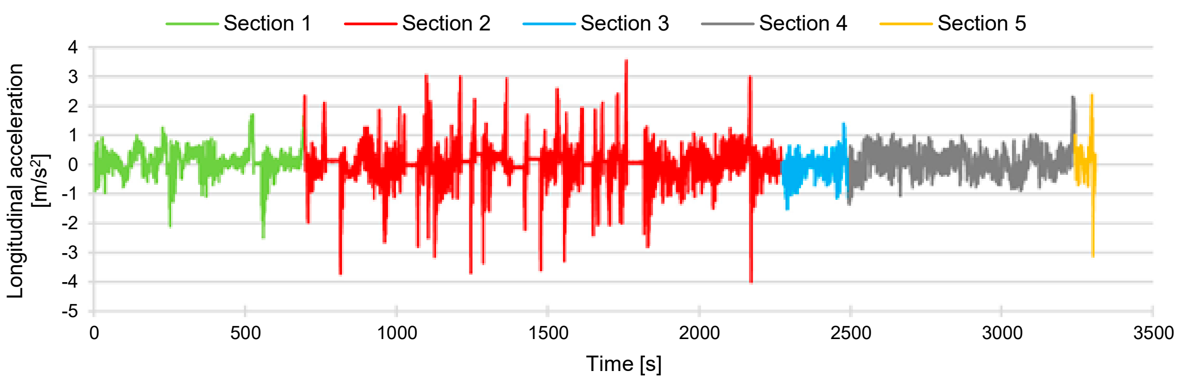

Figure 3. Longitudinal accelerations for a 'normal' drive

are, respectively, the range from 1 m/s^2 to 0.5 m/s^2, representing just under 8% of the share of accelerations, and the range from −0.5 m/s^2 to −1 m/s^2 signifying about 6.5% of the share. The first range is due to the vehicle's gentle acceleration, while the second range is due to the vehicle's gentle deceleration (braking). For higher acceleration values, i.e., above 1 m/s^2 and below −1 m/s^2, it can be seen that the share of occurrences of each value decreases significantly. Referring to the entire distribution of longitudinal accelerations from a 'normal' drive, it can be concluded that the vast majority of the route was traveled without sudden accelerations and decelerations. This is evidenced by the absence of values above 4 m/s^2 and below −4 m/s^2.

Figure 5 shows the difference in frequency of occurrence of individual longitudinal acceleration values of an 'economic' drive relative to a 'normal' drive. It can be seen from this figure that there has been a decrease in the frequency of occurrence of individual acceleration values for almost all ranges of the longitudinal acceleration. There was a clear increase in the number of occurrences of accelerations in the range of 0.5 m/s^2 to −0.5 m/s^2 and a slight growth in the range of −0.5 m/s^2 to −1 m/s^2, which are respectively indicative of constant speed driving and associated with soft braking. This means that the driver, accounting for the driving recommendations, reduced the number of more intense accelerations and braking, making the way he drove smoother and calmer than his 'normal' driving.

Figure 6 presents the difference in the frequency of occurrence of individual acceleration values from a 'dynamic' drive compared to a 'normal' drive. The resulting distributions of the occurrence of individual acceleration values differ. There is a slight decrease in the intervals above 1 m/s^2 and in the interval characterizing 'constant speed' driving, i.e., between 0.5 m/s^2 and −0.5 m/s^2. In contrast, some increase is seen in the intervals below −0.5 m/s^2 and between 1 m/s^2 and 0.5 m/s^2. However, all the differences between these drives are small since they do not exceed 1%. This means that the driver had a very similar drive during a 'dynamic' drive relative to a 'normal' drive.

The distributions of the frequency of occurrence of individual acceleration values, together with the differences in these distributions between individual journeys, are presented for the entire route. In order to better analyze the results obtained, it is possible to check if and how the obtained distributions differ depending on the type of road

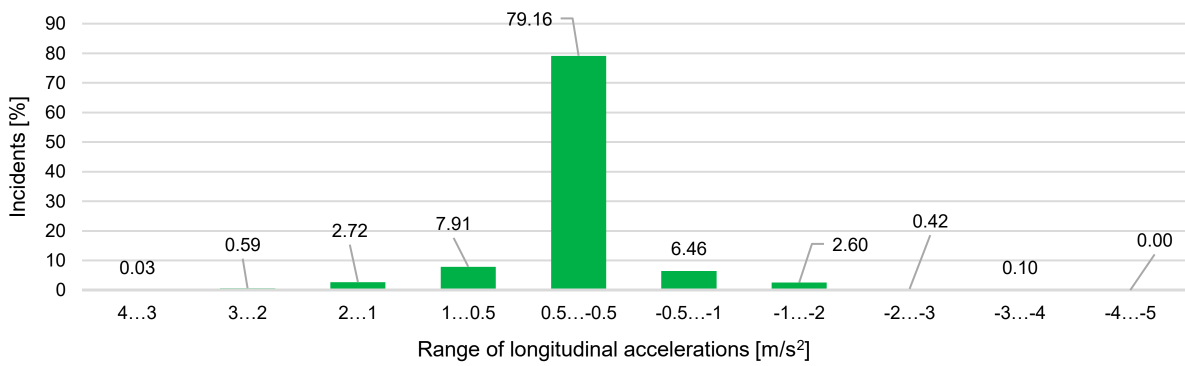

Figure 4. Frequency of occurrence of individual longitudinal acceleration values for a 'normal' drive

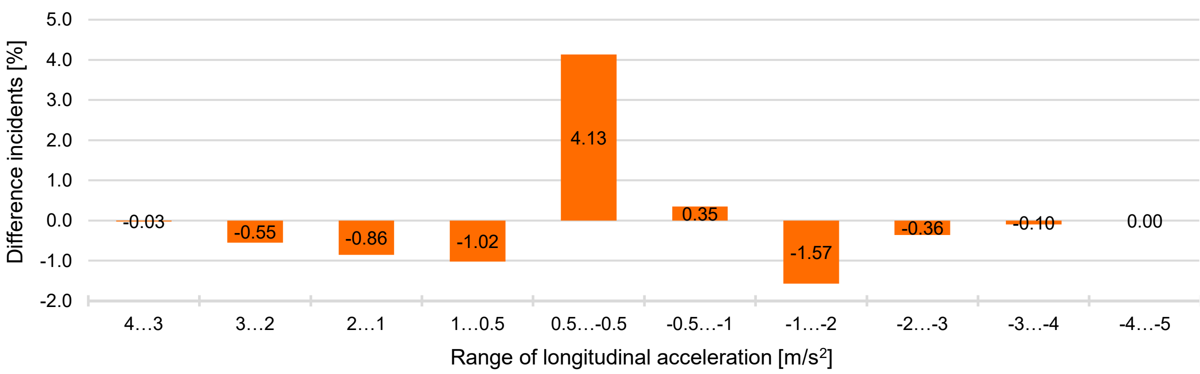

Figure 5. Difference in the frequency of occurrence of individual longitudinal acceleration values of an 'economic' drive relative to a 'normal' drive

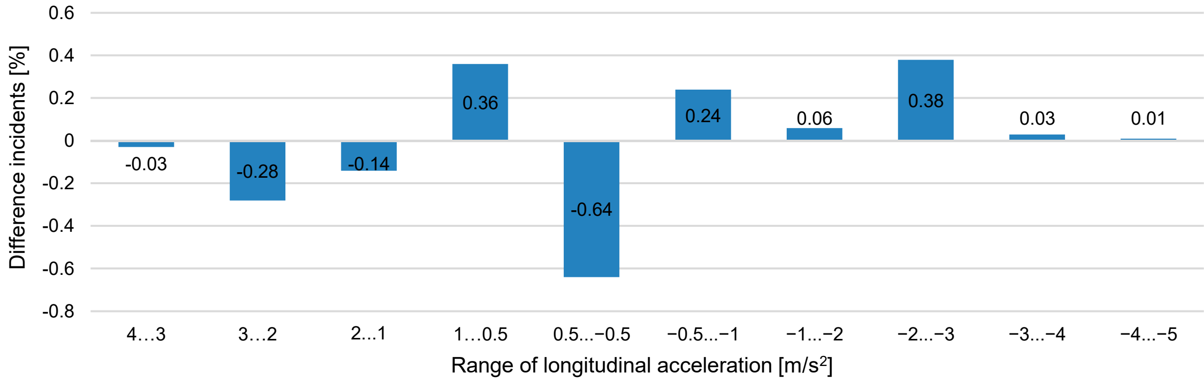

Figure 6. Difference in the frequency of occurrence of individual longitudinal acceleration values of a 'dynamic' drive relative to a 'normal' drive

the vehicle was traveling on. Before such an analysis is carried out, however, it is worth pointing out that one of the specified sections stands out for its very short length; this is section 5. Its short length means that the values obtained are characterized by a high degree of randomness. Therefore, the analysis in this case seems to have little validity – this section of the route will be omitted from further investigation. For sections 1 to 4, Figure 7 presents the frequency of occurrence of individual values of longitudinal acceleration from a 'normal' drive.

In Figure 7, it can be observed that, for each of the designated road sections, the frequency distributions of individual acceleration values differ. This is particularly evident for the extreme acceleration values. Due to the significantly higher number of accelerations falling within the range from 0.5 m/s^2 to −0.5 m/s^2, values for this and the other acceleration value ranges are given separately. From the presented results, it can be seen that the frequency distribution of individual acceleration values varies depending on the road type in question. For section 2 of the route, which runs through the city of Kielce, the greatest variation in the achieved acceleration values is visible. Values ranging from 3 m/s^2 to −4 m/s^2 have been recorded for this section. The proportions of the occurrence of accelerations with high positive as well as negative values are much higher than in the case of the other sections of the route, where the speeds along them are higher. It can also be observed that as the average speed reached on a section increases (Table 1), the shares of values approaching zero increase.

For a more complete analysis of the results obtained from each drive, Table 3 compares the frequencies of occurrence of individual acceleration values for each of the designated route sections. Analyzing the data of Table 3, it can be seen that the comparisons of values presented in Figures 5 and 6, without a subdividing of the type of roads on which the vehicle is traveling, effectively show the trend of changes in the occurrence of individual acceleration values. This is most easily seen in the case of the comparison between 'normal' and 'economic' driving. Both Figure 5 and Table 3 show an increase in the number of occurrences of values from intervals closer to zero, and a decrease for intervals with more positive or negative values.

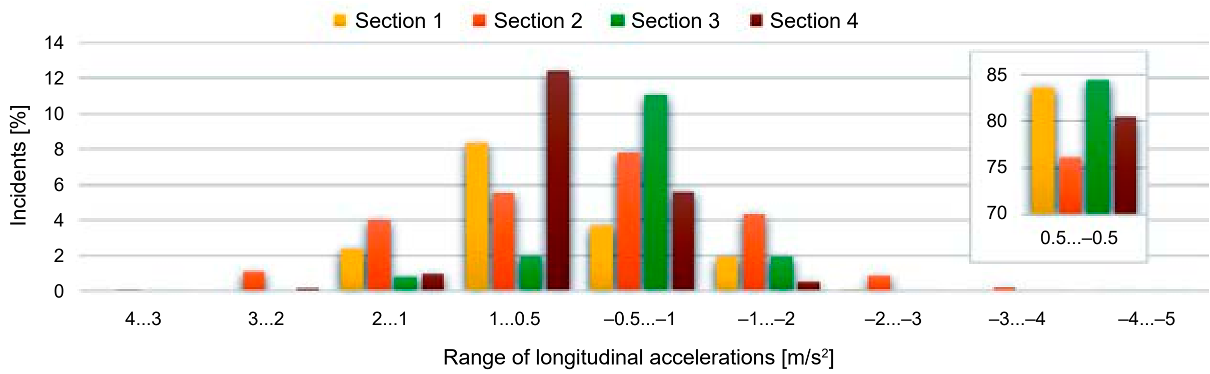

Figure 7. Frequency of occurrence of individual longitudinal acceleration values for designated route sections and a 'normal' drive

Table 3. Percentage differences in the frequency of occurrence of individual longitudinal acceleration values between a 'normal' and an 'economic' drive or a 'dynamic' drive

Section	Differences between a 'normal' and an 'economic' drive [%]									
	Range of accelerations [m/s^2]									
	4…3	3…2	2…1	1…0.5	0.5…−0.5	−0.5…−1	−1…−2	−2…−3	−3…−4	−4…−5
1	0.00	0.00	−1.05	−0.23	1.32	1.31	−1.30	−0.04	0.00	0.00
2	−0.07	−0.97	−1.14	0.97	3.36	1.35	−2.58	−0.73	−0.19	0.00
3	0.00	0.00	0.13	3.07	−4.12	2.17	−1.26	0.00	0.00	0.00
4	0.00	−0.13	−0.90	−5.36	10.81	−3.90	−0.52	0.00	0.00	0.00
Section	Differences between a 'normal' and a 'dynamic' drive [%]									
	Range of accelerations [m/s^2]									
	4…3	3…2	2…1	1…0.5	0.5…−0.5	−0.5…−1	−1…−2	−2…−3	−3…−4	−4…−5
1	0.00	0.18	−0.85	−1.83	−0.22	1.32	0.79	0.47	0.14	0.00
2	−0.08	−0.48	0.25	1.45	−0.23	−0.72	−0.78	0.55	0.03	0.02
3	0.00	0.14	0.58	2.77	−6.88	0.35	2.56	0.49	0.00	0.00
4	0.00	−0.13	−0.56	0.71	−0.66	0.64	−0.01	0.00	0.00	0.00

Conclusion and summary

Research on drivers often involves trying to obtain information to improve safety and comfort while driving. There are a vast number of works that deal directly with drivers, their driving behavior due to their psycho-physical state (Guzek, 2014; Choudhary & Velaga, 2017; Ogata et al., 2019), skills, or experience (Konstantopoulos, Chapman & Crundall, 2010), but one can also find works where the influence of the environment (Lai, 2008; 2010) and road infrastructure (Ben-Bassat & Shinar, 2011) on the driver is analyzed. On the other hand, the impact of drivers (the way they drive) on, for example, harmful exhaust emissions (Merkisz, Andrzejewski & Pielecha, 2013), fuel consumption (Lee & Son, 2011), or energy consumption (Felipe et al., 2015; Skuza & Jurecki, 2022) is analyzed.

The focus of this work is to analyze the suitability of simple vehicle movement parameters recorded while driving under real road conditions for assessing drivers' driving styles. For this purpose, a certain methodology for recording parameters was proposed and tested during journeys carried out on a specific route. This route was characterized by different types of roads with varying traffic conditions. The driver drove this route three times, each time changing the driving style. The driving styles used to complete the route were characterized in advance, and the driver was familiarized with them. During the tests, parameters such as vehicle speed and longitudinal acceleration were recorded and analyzed.

When comparing all three drives with each other, it can be seen that vehicle speed is a parameter that is less sensitive to changes in the driver's driving. This is especially evident in the presented results since the driver had to comply with the traffic rules during all drives and, therefore, could not exceed the speed limits. One can only presume, that if there was no obligation to do so, this parameter could provide more information about the driving behavior. The situation is different for the longitudinal acceleration of the vehicle. From the collected data, one can see the differences that occurred depending on the driving style of the vehicle. From a comparison between 'economic' and 'normal' driving, it is apparent that there is an increase in the occurrence of acceleration values in the range of so-called 'constant speed driving' and in the range indicating soft braking. However, there is a decrease in the other ranges, including those with values indicating more violent maneuvers. When comparing a 'dynamic' drive with a 'normal' drive, the differences in the distribution of acceleration values are no longer so apparent. Only a slight decrease in the acceleration values indicating 'constant speed driving' and an increase in all values relating to vehicle braking and soft acceleration can be observed. On the other hand, the shares of values relating to accelerating the vehicle slightly decreased. This means that, when comparing the two journeys, the driver traveled a fairly similar route.

The research presented here is a case study; its main objective was to test the measurement methodology and refine the final method of analyzing the results. Similar research has already been carried out by the authors and described previously (Gruszczyński & Jurecki, 2023), where they checked the repeatability and sensitivity of the recorded vehicle traffic parameters by comparing journeys made by the same driver and vehicle along an identical route in similar traffic conditions. The presented work was intended to provide information on how to analyze the results. It allowed for the verification of the measurement methodology. From the obtained results, it can be concluded that, depending on the imposed driving behavior, the recorded simple vehicle movement parameters reflect this and are a source of information for assessing the driver.

Similar studies will be conducted on a larger group of drivers, routes, and vehicles to fully analyze driver behavior. The final results of this work will be used for further analyses that enable the classification of driving styles based on larger amounts of data and, ultimately, to develop solutions to improve the safety of drivers, passengers, and other road users.

Acknowledgments

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