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Analysis of the Structure of Driver Maneuvers in Different Road Conditions

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Abstract: The safety of road users is one of the priority issues taken into account in both the operation and design of vehicles. The presented work is part of a study that aims to develop a method for parametric assessment of driver behavior. The driving style of a driver depends on their skills and psychophysical characteristics, the type and performance of the vehicle used by the driver, and the type of road. This method involves the continuous measurement of the longitudinal and lateral acceleration values of a vehicle body. The paper analyzes how the type of road influences the structure of the maneuvers undertaken by the driver. The paper formulates criteria for distinguishing basic maneuvers (acceleration, braking, and turning). The structure of maneuvers was analyzed for two parameters: the extreme value of acceleration occurring during the execution of a given maneuver and the frequency of maneuvers during the passage of a given route. The analysis presented in this paper confirms that the type of road has a significant influence on the structure of the maneuvers undertaken by the driver.

Keywords: safety; driving exploitation condition; driving behavior; maneuvers; acceleration

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1. Introduction

Research on how drivers behave in different traffic situations is carried out in many research centers. One of the main objectives of this type of research is to improve road safety in its broadest sense. Due to the very large number of factors that can influence the way drivers to behave, the variety of studies undertaken is vast. There are many publications in the literature that describe different research methods to analyze the driving process. Some of them aim to qualitatively determine the method of driving, and others quantitatively determine the driver's behavior by means of the different indicators.

Many publications refer to the physical fitness, mental fitness, knowledge, skills, and attitude of the driver. One or a combination of parameters characterizing the driver may also be determined. Due to its high practical usefulness (especially for accident analysis), a very frequently chosen parameter is reaction time, both in the braking process and in the obstacle avoidance process [1–3]. In order to characterize the driver's operating style, research is being carried out to determine how defensive maneuvers, i.e., braking or avoidance maneuvers, are undertaken [4]. The driver's hand–eye coordination, depending on various factors, e.g., lighting, time of day, thinking performance, and working time, also significantly affects steering [4,5] or exploitation conditions [6,7].

In [8], Marzoug et al. described a study of driver behavior at the entrance of the merging part of two roads and the probability of car accidents occurring. For some time now, there have been plenty of publications describing research aimed at identifying the driver's mode (style) of behavior. As a result of this research, simple or more sophisticated tools are being developed to determine (and also classify) the "driver type", which is also called "driver's style", "driving style", and more recently, increasingly referred to in publications as "driver profile" or "driver behavior profile". In the latter case, the acronym DBP is used as an acronym for **D**river **B**ehavior **P**rofile. They are developed on the basis of certain indicators which, either quantitatively or qualitatively, can determine the driver's operating style. This may enable an objective assessment of their mental inclination towards certain positively or negatively evaluated driving behaviors [9].

Publication [10] describes the identification of as many as eleven parameters related to vehicle control. They were used to identify and distinguish different types of driver behavior depending on driving characteristics. In Ref. [11], measured driving speed, maximum speed values obtained, and longitudinal and lateral acceleration were used to determine the driver's style. The latter parameter, lateral acceleration, is quite commonly used to determine the driver profile, as studies conducted so far in many research institutes confirm that it is one of the best parameters for steering analysis [12–15]. References [16,17] describe studies using three-axis acceleration sensors to determine the driver profile. The acceleration results obtained can then be spectrally analyzed to define "aggressive" and "safe" drivers using a developed algorithm. In publication [18], the authors described the concept of a system, used to identify "typical" (non-aggressive) and "aggressive" drivers. The analysis is based on data from typical smartphone sensors. A similar method for evaluating the vehicle control process based on measurements made with an acceleration sensor was described in publication [19]. The method used was based on smartphone sensors with software installed. The quantitative driving assessment was carried out according to an algorithm in which, while driving, the driver received a certain number of points for their actions. This way of evaluation made it possible to quantitatively assign an appropriate score to individual drivers, enabling them to be categorized.

A slightly different way of assessing how a driver controls the vehicle is described in article [20]. In this case, the distribution of velocity and acceleration over specific time intervals was assessed. The driving style analysis carried out in this way was used to identify the driver in psychophysiological terms, e.g., to detect states of drowsiness and fatigue in the driver. The driver's performance can also be assessed by taking into account the controllers' signals, e.g., the accelerator or the service brake pedals [21,22]. A very interesting and promising stream of ongoing research involves analyses aimed at profiling the driver and recognizing their intentions [20,23,24]. The data obtained, characterizing the driver's operating behavior style, can be used to profile the driver's behavior. Due to the diversity of the data, simple or more sophisticated profiles may be used.

Publication [25] describes the use of the inertial sensors of a motorcoach, connected to a CAN bus, to profile the driver and detect risky maneuvers undertaken while driving. A smartphone was used to collect data. The system classifies drivers from a safety point of view and provides appropriate feedback to reduce the number of risky maneuvers performed. The authors showed that evaluating braking and turning maneuvers provides better driving method identification than analyzing only the acceleration process. It has also been shown that these sensors can be used to segment and classify traffic incidents quite accurately. Personalized feedback to the driver is a very important element of the system, which is based on the analysis of behavioral profiles [26]. This system was used to reduce the accident risks associated with driving. The results showed that it is beneficial to provide ongoing feedback on possible aggressive behavior, e.g., speeding, in combination with a financial reward system including, for example, a reduction in insurance premiums. Another example of the use of a smartphone to implement this type of research is presented, where a method of driver profiling based on measurements using a smartphone and the Sense Fleet platform that detects risky driving events is described [27]. Such profiling can, according to the authors, be useful for fleet management, adjusting insurance premiums, optimizing fuel consumption, or reducing harmful gas emissions. Due to the variety of technical capabilities of smartphones, the paper analyzes the usefulness of the sensors installed in them in the measurement of vehicle motion parameters. A similar issue is described by Castignani et al. [28]. Research with different smartphone sensors and driver classification algorithms are presented in publication. The main goal of the analysis is to assess which sensor/method gives the highest performance. Different combinations of sensors used to detect seven typical traffic events were tested. The analyses indicated that the best sensors for detecting typical driving events are the gyroscope and accelerometer. Publication [29] presents a method for identifying drivers using variability of values vehicle acceleration data. The presented method is based on using vehicle acceleration data from smartphone sensors. The authors point out that this provides much easier access to data. The results of the analysis showed that the proposed method allows the identification of the driver and distinguishing the driving habits of various driver. The driver's driving style plays an important role in vehicle energy management and driving safety [30–32], and in the development of driver assistance systems to increase the level of vehicle automation [33]. Ref. [34] reviews various driving style identification and classification algorithms with a focus on machine learning methods based on current and future trends. Applications of driving style recognition in intelligent vehicle control systems are also discussed.

An interesting publication [35] presents three different approaches to driving style recognition based on a hierarchical model, which the authors believe is particularly predisposed for use in a system (ADAS—Advanced Driving Assistance System). The proposed model for car driving style recognition considers three aspects: the driver's emotions, driver's state, and driving style. The hierarchical pattern consists of three levels of descriptors, which recognizes emotional states, the driver's state, and driving style. The paper also presents three driving style recognition algorithms based on different paradigms: on fuzzy logic, on temporal logic, and on a recursive pattern-recognition algorithm. A comparison of these approaches was conducted using real data sets. These initial results are regarded by the authors as encouraging. Driving styles are often created that enable simulation tests in various road conditions [9,36–38]. The article [39] addressed the analysis of the correlation of selected measures characterizing driving style with a driver's predictability and reaction time. Individual drivers behave and react in different ways under different conditions, and many driver assistance systems would benefit from certain measures of likely driver behavior under specific conditions. The paper presents several measures of driving style and shows how they correlate with driver predictability and responsiveness under several experimental conditions, in a simulator, and in real traffic conditions. Differences were shown in predictability, but also in susceptibility to feedback from driver assistance systems with different driver personalities.

In the publication [40], the authors do not identify driver profiles but only identify risky driving behavior. For this purpose, they use only a time series analysis of vehicle speed. First, a pattern of positively evaluated speed changes in time is used for various drivers in various speed ranges. Drivers prone to risky driving are then identified, based on different driver patterns. Research exists on the effectiveness of the proposed method, because the speed measurement on newly built vehicles is available, so this solution can be used in various applications, e.g., driver training and insurance.

Although many anti-theft technologies are being implemented, the number of car thefts continues to rise. Criminal groups are increasingly adept at using modern electronics and know the vulnerabilities of in-car security. The idea, therefore, emerged to make driver profile recognition the basis of theft recognition. Study [41] describes a driver profiling approach to detect vehicle theft. The method proposed by the authors compares the recorded driving patterns of the driver-owner and the driving pattern of an unauthorized person, a probable thief, measured by a sensor installed in the vehicle. The method minimizes the effect of fluctuations in the values of driver characteristics through the appropriate use of statistical parameters of the distributions of these characteristics (such as mean, median, and standard deviation). This ultimately generates a reliable driver model.

Mori et al. propose a continuous identification schemes that monitors driver behavior and imposter detection [42]. The developed scheme uses long-term memory (LSTM) to create a driver behavior classifier based on acceleration values and classifies the driver. Results of the realized test show that an acceleration sensor in a real vehicle is enough to classify 15 drivers according to driving behavior in real traffic condition. Since driver behavior cannot be repeated or copied, the authors of the article [43] proposed the use of driver identification as a security system against car theft. In the paper, they present a method to identify a single driver and classify a group of drivers using only car acceleration values and machine learning techniques. To identify an individual driver parameters, the acceleration values is converted into a histogram, and a neural network model is then used. Research on motorcoach drivers, carried out under real operating conditions, showed very high accuracy of the developed method of driver identification and classification. The study used data collected from acceleration sensors installed in vehicles. Driver Behavior Profiles (DBPs) are presented in the publication [44] as an approach to assessing driver behavior affecting accident risk. Driver behavior is a major cause of road accidents, so identifying drivers who are engaged in unsafe driving events has significant benefits. Data obtained from positioning system (GPS), supplemented by spatial and temporal information, is used for this purpose. These profiles consist of typical risk assessments that can be used to compare factors. In this paper, the authors describe the development DBPs and present their use as input data for modeling factors affecting driver behavior. According to the authors, the results show that even taking into account the influence of the road environment, these factors remain the strongest predictors of driver behavior, suggesting that different spatial and temporal environments elicit different psychological responses in drivers. Telemetry devices are generating and transmitting more and more data, which has significant potential for decision makers.

The brief literature review presented above shows that driver behavior recognition is now a fairly widely used research topic. This is because the driver behavior profiles developed can have many potential applications, such as improving fleet management, planning car insurance policies, securing vehicles against theft, or in driver training. Recently, the possibility of using knowledge of driver behavior to create advanced driver assistance systems has been increasingly exposed. Research indicates that each of these applications contributes to improving road safety.

The present publication is part of a study that aims to develop a method for parametric assessment of driver behavior [9,45,46]. This method involves the continuous measurement of a number of parameters, including longitudinal and lateral acceleration values. A driver's driving style (driving technique) depends mostly on the driver themselves: skills, experience, psychophysical characteristics, ability to anticipate risky situations, acquired habits, character traits, etc. However, preliminary studies have already shown that there are other factors that strongly influence a driver's driving style. One such factor is the type and performance of the car used by the driver. The intensity of braking or the performance of curvilinear motion will be markedly different if the same driver is driving a high-performance car and a truck. The publication is located in the current of works carried out in other research centers, which aim to assess drivers' behavior to improve driving technique and traffic safety. A fragment of the work is presented in this publication, which was carried out in a project, in which the purpose was to determine the driving style of the driver (Safe, Unsafe), in order to use them to determine insurance premiums and take into account any personal activities by company managers.

Another factor that can significantly affect driving technique is the type and quality of the road and the road traffic organization. If one were to isolate such elementary maneuvers as accelerating the car, driving at a set speed, braking, or executing a left or right turn in the process of driving, even a cursory observation of car traffic confirms that the characteristics of the road influence the way these maneuvers are executed and the frequency of their occurrence. It is this issue, i.e., the analysis of the structure of the maneuvers undertaken by the driver in different road conditions, which is the subject of this study.

2. Test Methodology and Characteristics of Measuring System

Tests were carried out in real traffic conditions on a 650 km-long Kielce–Szczecin (cities in Poland) route. This particular route was chosen because four distinctly different types of the road could be distinguished on it. These included city roads (built-up areas), suburban, expressway, and highway roads. The research confirmed that the different features of the construction of these roads and the traffic organization result in distinct differences in motion parameters.

The test vehicle used was a VI-generation Ford Transit 9-seater with a curb weight of 2070 kg (engine parameters: 2198 cm^3 capacity, maximum power of 92 kW), loaded with a mass of approximately 320 kg.

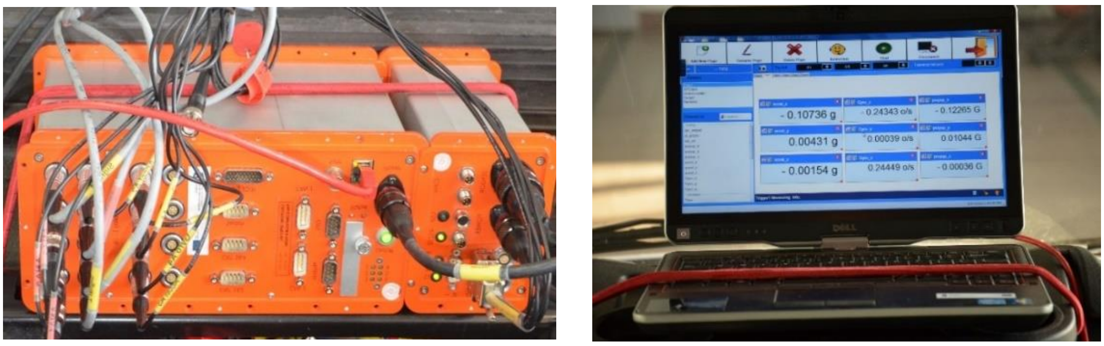
Along the entire route, several vehicle motion parameters were measured continuously, while the vehicle's path was recorded by the Globtrak™ system, which makes it possible, e.g., to record its GPS track.

Measuring equipment was used to determine the parameters of vehicle motion in the research, such as:

1. Datron® s-350 from Corrsys® Kistler Holding AG Germany optoelectronic sensor used to determine, e.g., longitudinal and lateral vehicle velocity (Figure 1a);
2. TAA (TANS) 3-axis linear acceleration sensor from Kistler Holding AG Germany (Figure 1b), which was used to determine longitudinal and lateral acceleration of the vehicle body;
3. Datron® uEEP 12 Data Acquisition Station from Kistler Holding AG Germany (Figure 2a) and installed on the tablet dedicated ARMS® software V.1.2 (Figure 2b) [9].

(**a**) (**b**)

Figure 1. Testing equipment used in the tests: (**a**) Datron® S-350 optoelectronic sensor, (**b**) 3-axis TAA™ and TANS™ sensors.



(**a**) (**b**)

Figure 2. Data acquisition system: (**a**) uEEP 12 Data Acquisition Station Datron®, (**b**) control tablet with ARMS® software.

The data necessary to assess the driving behavior of the vehicle were recorded at 10 Hz.

During the tests, changes in the vehicle's motion parameters were recorded. As a result of the analysis, four routes were selected, characterized by a great variety of vehicle control techniques to ride on them and very different traffic conditions. Four road sections with similar driving times were thus designated, covering the motion of the vehicle on:

(a) City road (built-up area);
(b) Suburban road;
(c) Expressway, dual carriageway;
(d) Highway.

3. Results

The average speed of the vehicle in each road section varied considerably, ranging from nearly 22 km/h to 132 km/h. An example of a speed profile is presented in Figure 3.

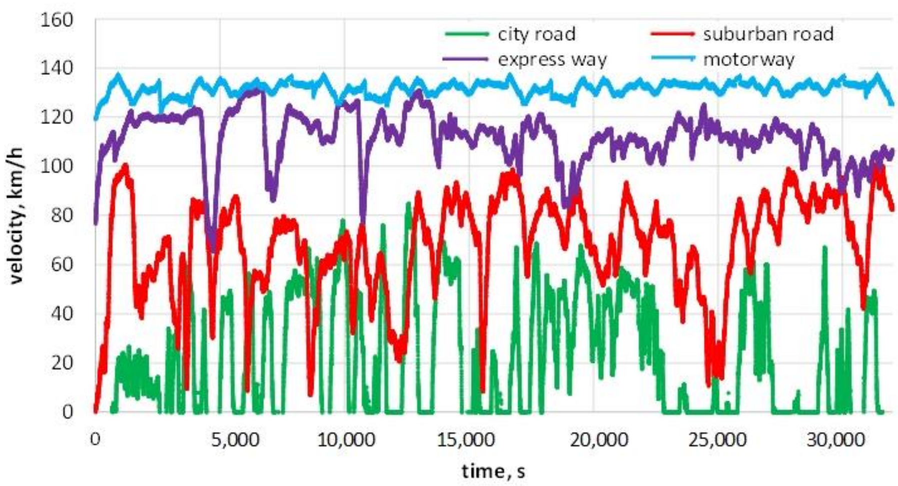


Figure 3. Speed course on the Kielce–Szczecin route at different road sections.

Figure 4a shows an example of recorded values of longitudinal accelerations on the city road. Positive values relate to increasing driving speed, and negative values (decelerations) to the braking [9].

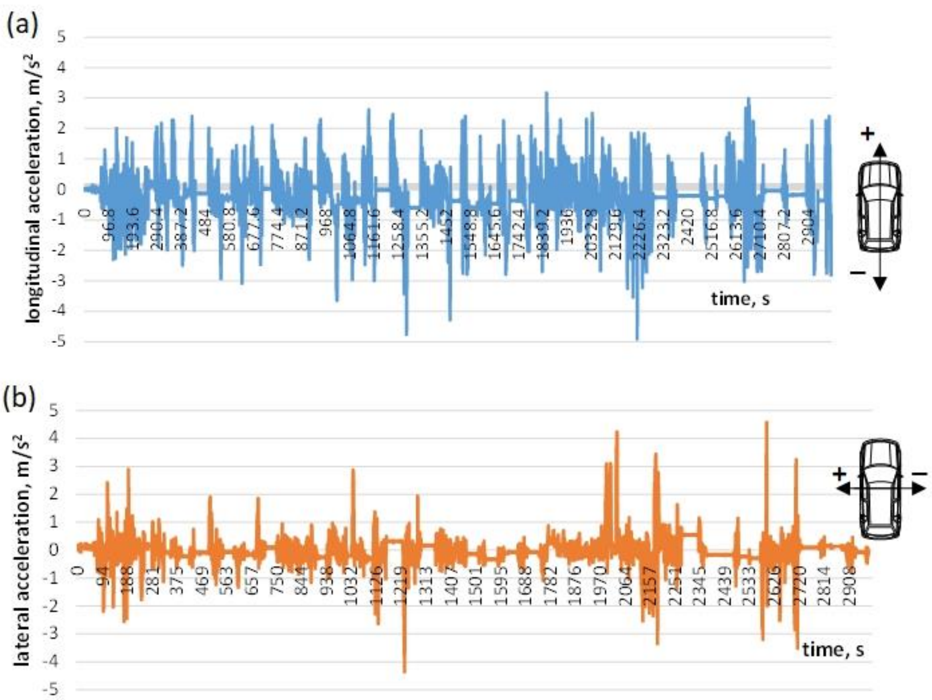


Figure 4. The examples of recorded values of the vehicle acceleration: (**a**) longitudinal; (**b**) lateral.

Figure 4b shows the recorded values of lateral accelerations on the same road [9]. In this case, positive or negative values of acceleration depend on the turning direction (left, right).

4. Discussion

A simple statistical analysis of the sets of values recorded during the travel along the analyzed routes can already give a lot of information showing the nature of motion on particular sections of the route. While driving, even when cruise control is engaged, confirming the desire to drive at a set speed, motion parameters such as speed components or acceleration components are constantly changing. This is due to the fact that even a theoretically horizontal road has a slight positive or negative gradient in many places. Additionally, there may be stronger or weaker winds of varying directions locally, or the quality of the road surface, which changes in many places, may cause a change in the rolling resistance coefficient of the wheels. These and many other factors cause the recorded motion parameters to undergo constant small oscillations.

However, by observing the way the vehicle is driven, it is possible to clearly distinguish, in terms of longitudinal motion, intentional types of motion (maneuvers) by the driver, such as driving at a set speed, increasing the speed of motion (acceleration), and decreasing the speed gently or intensively with the use of brakes. Additionally, with regard to the implementation of curvilinear motion, it is possible to distinguish certain deliberate driver operations, such as the execution of driving straight ahead, and right and left turns. The last two actions can be implemented when cornering, or when performing bypassing, overtaking, or lane-changing maneuvers.

It was decided to examine what regularities characterizing driving on four selected types of the road can be observed by analyzing the driver's elementary actions (elementary types of motion) mentioned in the previous paragraph. However, as far as the study of the longitudinal motion components is concerned, it was decided to base them only on the analysis of the identified acceleration and braking processes. Various preliminary analyses have shown that analyzing the characteristics of these very processes should provide the most interesting information. The values that characterized driving at a fixed speed were "cutted" from the data clouds. These preliminary analyses have shown that this can be performed by removing accelerations between -0.5 and $0.5\ m/s^2$.

In the data clouds prepared in this way, the identification of acceleration processes and braking processes (deliberate maneuvers executed by the driver) was carried out. The maximum value of acceleration should be preceded by an increase in the value of accelerations lasting no less than 0.5 to 0.6 s and followed by stabilization or a decrease in the value of accelerations for at least 0.2 s—the diagram shown in Figure 5a. An analogous procedure has followed the identification of the braking process. In this publication, these values of acceleration for analyzed maneuvers are referred to by the authors as extreme values.

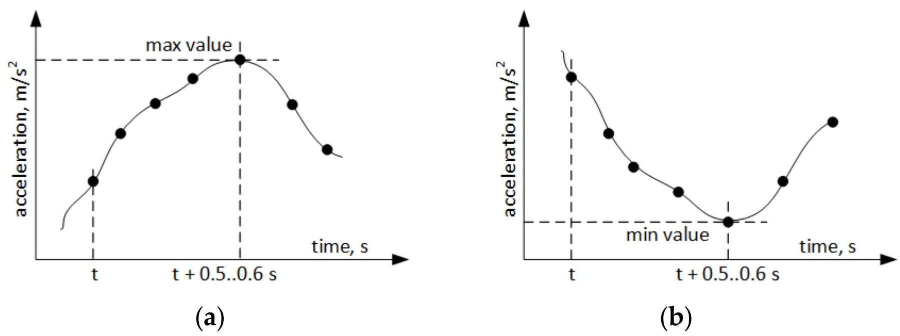


Figure 5. Diagrams of the method adopted to identify maneuvers and their extreme values: (**a**) acceleration, (**b**) braking.

It has been assumed (according to the diagram shown in Figure 5b) that in order to treat the decrease in negative acceleration (increase in deceleration) as a deliberate braking maneuver, it should last no less than 0.5–0.6 s, before reaching the minimum value, followed by stabilization or increase in acceleration values, for at least about 0.2.

Once all acceleration and deceleration maneuvers were identified in the recorded data sets, further analysis was based on extreme values–maximum values (acceleration) and minimum values (braking), presented in Figure 6.

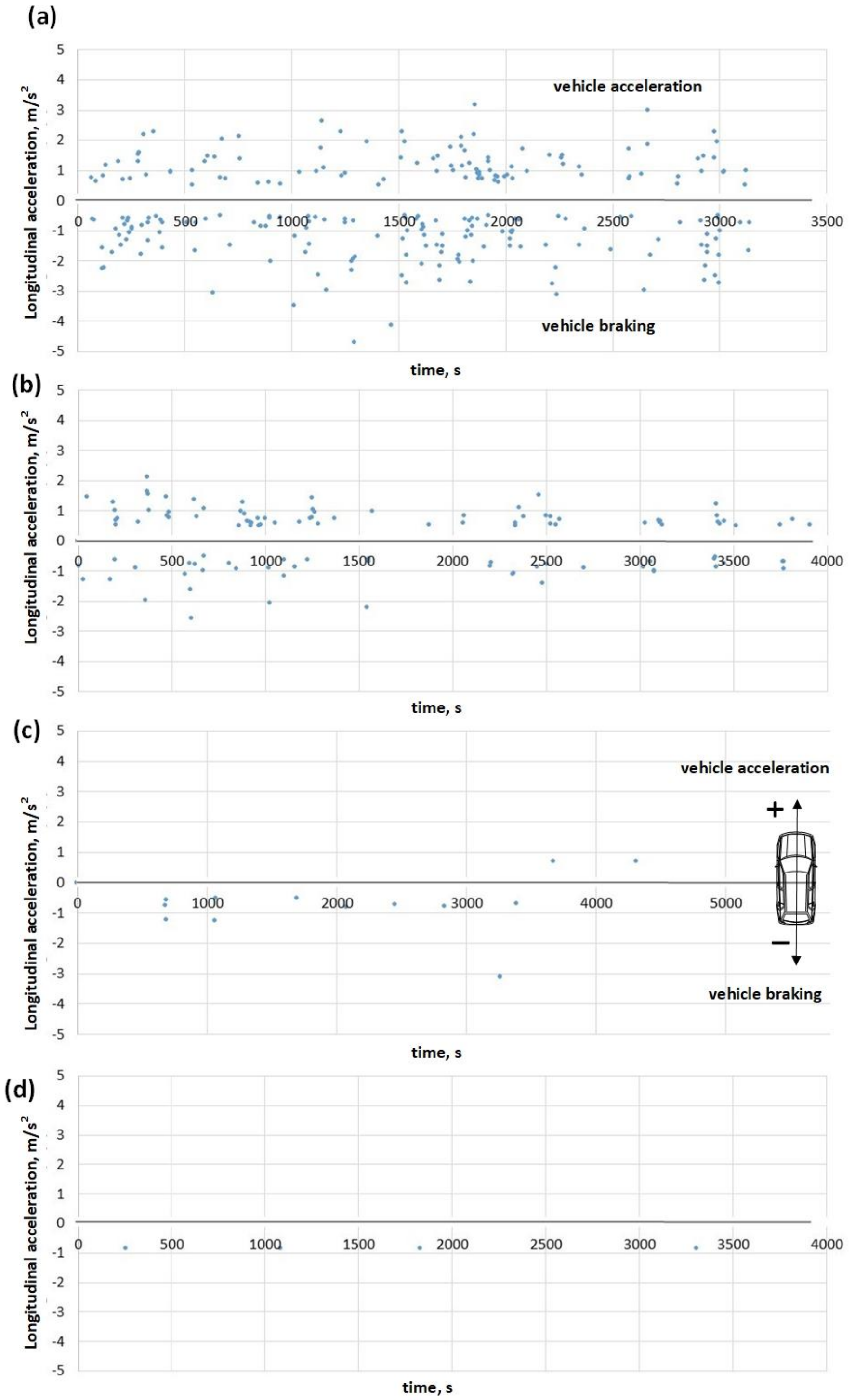


Figure 6. Longitudinal acceleration extreme values in the acceleration and braking maneuvers in the various sections of the route: (**a**) city road; (**b**) suburban road; (**c**) expressway (dual carriageway); (**d**) highway.

As can be seen, urban driving is characterized by many alternating or successive processes of acceleration and deceleration, both of which are characterized by high values of acceleration or deceleration, respectively. The variable nature of the motion means that the number of extremes of the acceleration and deceleration processes determined in this type of road (in the form of points on a diagram) is considerable. Taking into account the time of the recorded trips over individual routes, it can be said that successive processes of acceleration or braking occurred on average every 13.1 s on the city road, every 35.9 s outside the city, every 6.9 min on the expressway, and every 14.4 min on the highway.

The analysis of lateral accelerations was carried out in the same way as for longitudinal accelerations. Here, too, it was decided to look at what regularities characterizing driving on four separate types of the road can be observed by analyzing the driver's elementary actions indicated earlier. For the study of the lateral traffic components, it was decided to rely only on the analysis of the identified turning (right or left) processes. Such actions may be performed when cornering, or when performing bypassing, overtaking, or lane-changing maneuvers. Preliminary analyses showed that studying the characteristics of these very processes should provide the most interesting information. The values that characterized straight-ahead driving, or more precisely, driving within a given road lane when traveling on a straight road, were therefore "cutted" from the data cloud. Drivers then make gentle drive direction corrections within a given road lane, approaching the center of the lane if for any reason (operating the radio, air conditioning, navigation, etc.) they have approached the left or right edge of the lane. This can also be caused by variable crosswinds affecting the car. There are more other reasons which can enforce a correction in the driving path. Preliminary analyses have shown that "cutting out the driving straight ahead data" can be performed by removing lateral accelerations between -0.5 and $0.5\ m/s^2$ from the data set [9].

In the dataset prepared in this way, the identification of right or left turning processes (deliberate maneuvers executed by the driver) was carried out. The procedure for identifying the turning processes was carried out according to the diagrams shown in Figure 5, adopting the same time criteria, i.e., at least 0.5–0.6 s before and at least about 0.2 s after the extreme value was reached.

Once all turning processes (in both directions) were identified in the recorded data sets, further analysis was based on extreme values. Figure 7 shows the values of the extremes of the right and left turning processes determined in this way (minimum and maximum lateral acceleration values).

Driving under different road conditions results in markedly different variations in lateral acceleration values. In urban and non-urban driving, the designated maximum lateral acceleration values reach 3–4 m/s^2. Driving on an expressway means acceleration values of up to 2 m/s^2 and 1 m/s^2 on a highway.

In contrast to the processes of acceleration and braking, for which a very strong dependence of the frequency of their occurrence on the type of road was observed, in the case of lateral accelerations, for all four types of the road the frequency of occurrence of the processes of turning (implementation of curvilinear motion) is very similar, and for three road types, it can even be described as almost identical. It is 26.8 s for a city road, 25.3 s for a suburban road, and 25.4 s for a highway, respectively. Only the frequency of these maneuvers on the expressway differs from these values, as maneuvers occur every 11.3 s. This is more than twice as often as on the remaining three types of roads, but it should be remembered that in the case of acceleration and braking maneuvers, the variation was many times greater, because it amounted to 65 times between the lowest and highest frequencies. However, the second regularity is preserved, showing that the higher the driving speed on a given road, the lower the lateral accelerations during curved motion maneuvers.

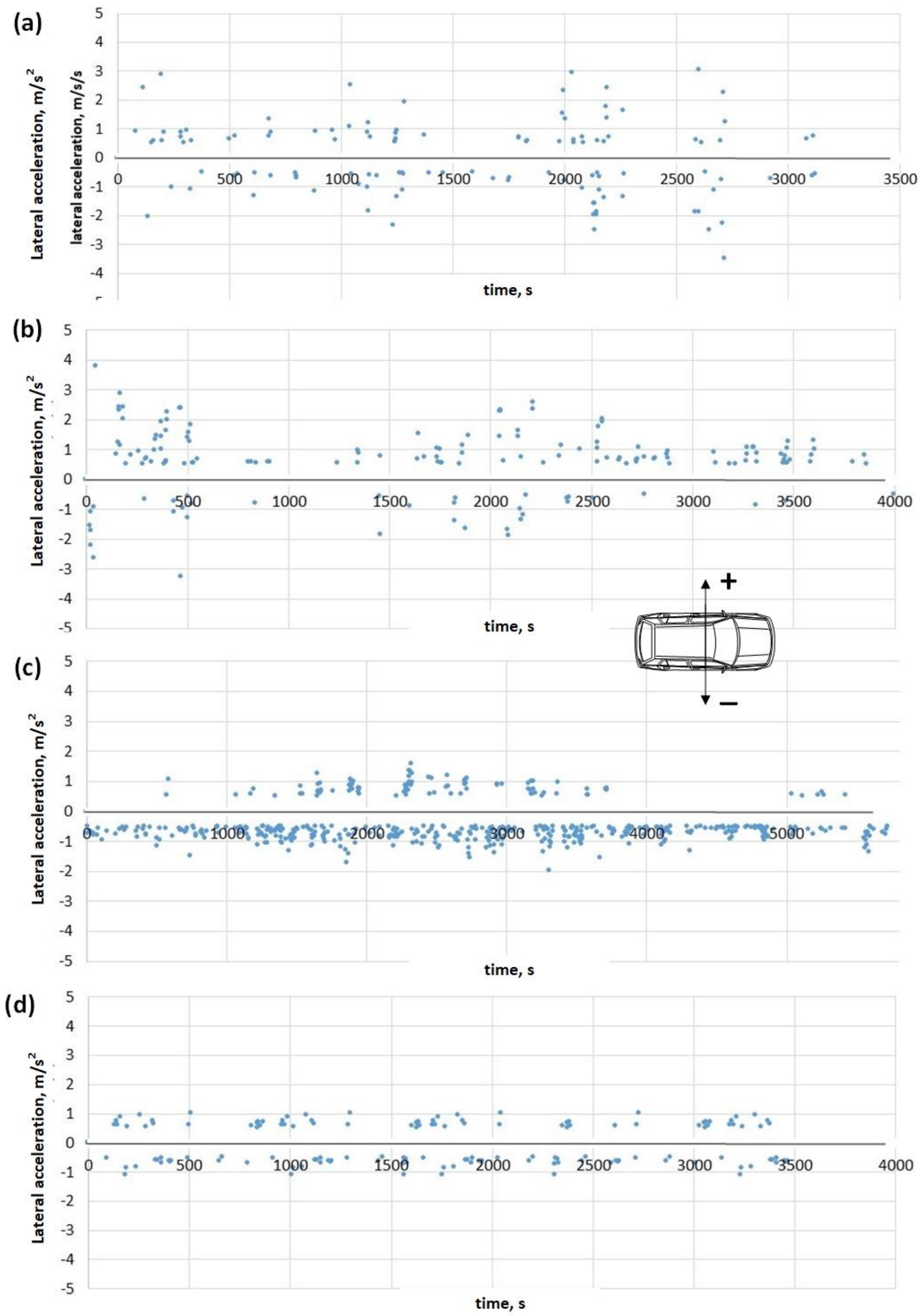


Figure 7. Lateral acceleration extreme values in the right and left turning maneuvers on the different sections of the route: (**a**) city road; (**b**) suburban road; (**c**) expressway (dual carriageway); (**d**) highway.

The two previous figures (Figures 6 and 7) show the characteristics of the processes of acceleration, deceleration, and turning maneuvers, presented as a set of points that are the extreme values of these processes. Since, as stated above, a strong variation in the values of the extremes of these processes is apparent, the following figures will therefore present the distribution of these values for the different road types. Figure 8 shows the distribution of the determined extreme values (Table 1) of the acceleration and deceleration processes.

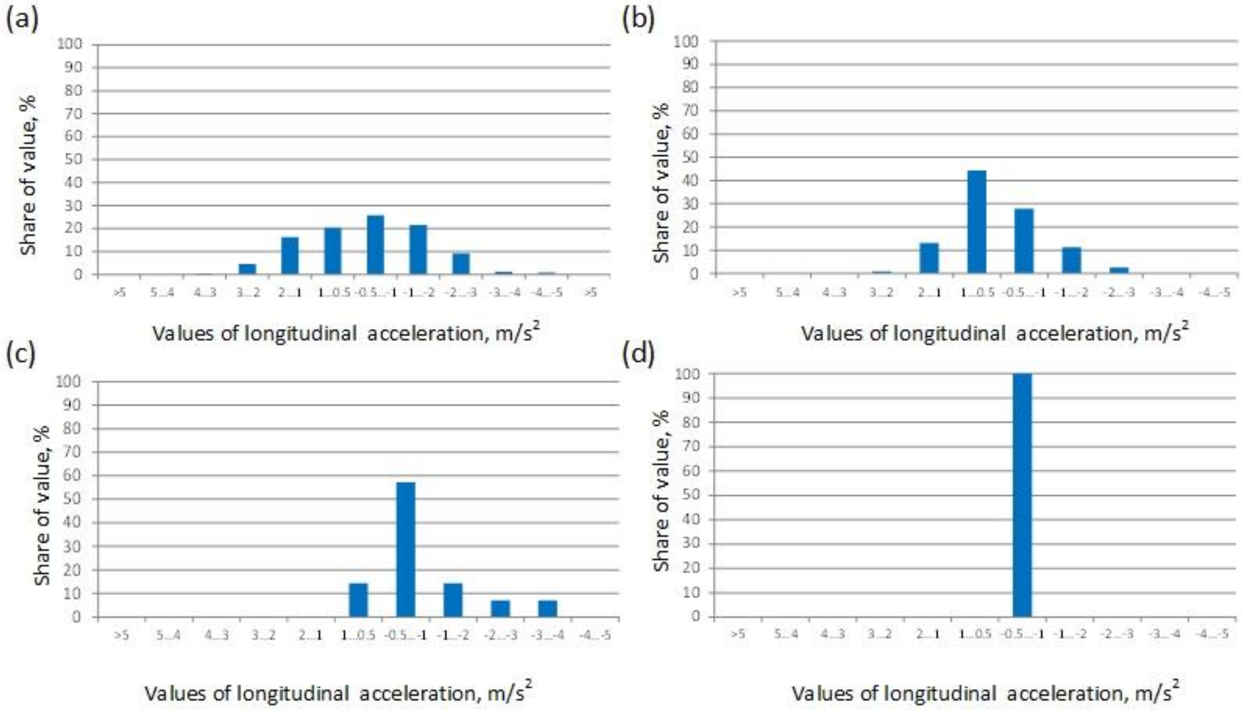


Figure 8. Distribution of the extreme values of longitudinal acceleration and deceleration maneuvers for various route sections: (**a**) city road; (**b**) suburban road; (**c**) expressway (dual carriageway); (**d**) highway.

Table 1. Distribution of the extreme values of acceleration and deceleration maneuvers for various route sections: (a) city road; (b) suburban road; (c) expressway (dual carriageway); (d) highway.

	Acceleration Distribution, %									
Section \ Acceleration	**5 … 4**	**4 … 3**	**3 … 2**	**2 … 1**	**1 … 0.5**	**−0.5 … −1**	**−1 … −2**	**−2 … −3**	**−3 … −4**	**−4 … −5**
a	0	0.41	4.56	16.18	20.33	25.73	21.58	9.13	1.24	0.83
b	0	0	0.87	13.04	44.35	27.83	11.30	2.61	0	0
c	0	0	0	0	14.29	57.14	14.29	0	0	0
d	0	0	0	0	0	100	0	0	0	0

It can be said that the higher the driving speed on a given road type (see Figure 3), the more concentrated the distributions of the extreme values of the acceleration and braking processes are shown in Figure 8. An interesting "disturbance" to the regularity present in the graphs is that for the roads 1, 3, and 4, the modal value of the distributions (maximum in the graphs) occurs for a range of accelerations from -0.5 to -1.0 m/s^2, i.e., for low-intensity braking. However, for road number 2, the modal value of the distributions occurs for the acceleration range of 1.0 to 0.5 m/s^2, i.e., for low-intensity acceleration.

The distributions of the extreme values of the right and left turning processes are shown in Figure 9. In this figure, positive and negative values (Table 2) indicate the direction of the turn (left–right).

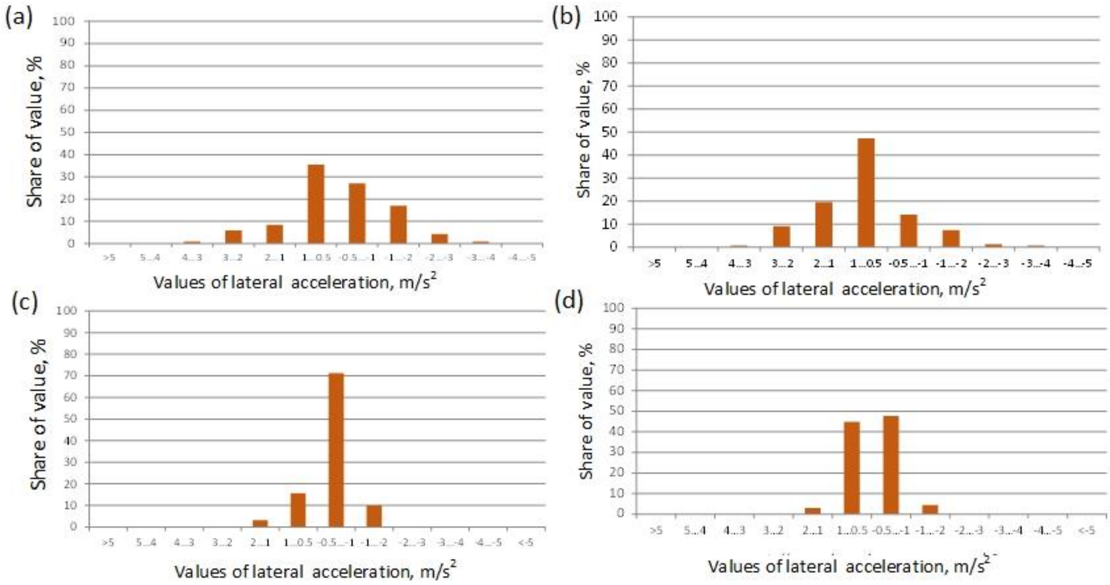


Figure 9. Distributions of the extreme values of lateral acceleration during turning maneuvers for various route sections; route sections: (**a**) city road; (**b**) suburban road; (**c**) expressway (dual carriageway); (**d**) highway.

Table 2. Distribution of the extreme values of lateral acceleration for various route sections: (a) city road; (b) suburban road; (c) expressway (dual carriageway); (d) highway.

	Acceleration Distribution, %									
Section \ Acceleration	**5…4**	**4…3**	**3…2**	**2…1**	**1…0.5**	**−0.5…−1**	**−1…−2**	**−2…−3**	**−3…−4**	**−4…−5**
a	0.00	0.85	5.93	8.47	35.59	27.12	16.95	4.24	0.85	0.00
b	0.00	0.61	9.20	19.63	47.24	14.11	7.36	1.23	0.61	0.00
c	0.00	0.00	0.00	3.13	15.63	71.29	9.96	0.00	0.00	0.00
d	0.00	0.00	0.00	2.94	44.85	47.79	4.41	0.00	0.00	0.00

As it is the execution of the turning maneuver and not the direction that should be considered important, the graphs on the right also show the distributions of the absolute values.

As it is the execution of the turning maneuver and not the direction that should be considered important, Figure 10 shows the distributions of the absolute values.

In this case, there is a similar regularity as for the distributions of the extreme values of the acceleration and braking processes, meaning that, with some approximation, it can be said that the higher the driving speed on a given road type (see Figure 3), the more concentrated are the distributions of the extreme values of the right and left turning processes, shown in Figure 9. However, a new regularity appears here, in that in pairs, for road types a–b and c–d, the distributions of extreme values are very similar. This is particularly clear in the right-hand graphs, which show the distributions of absolute values.

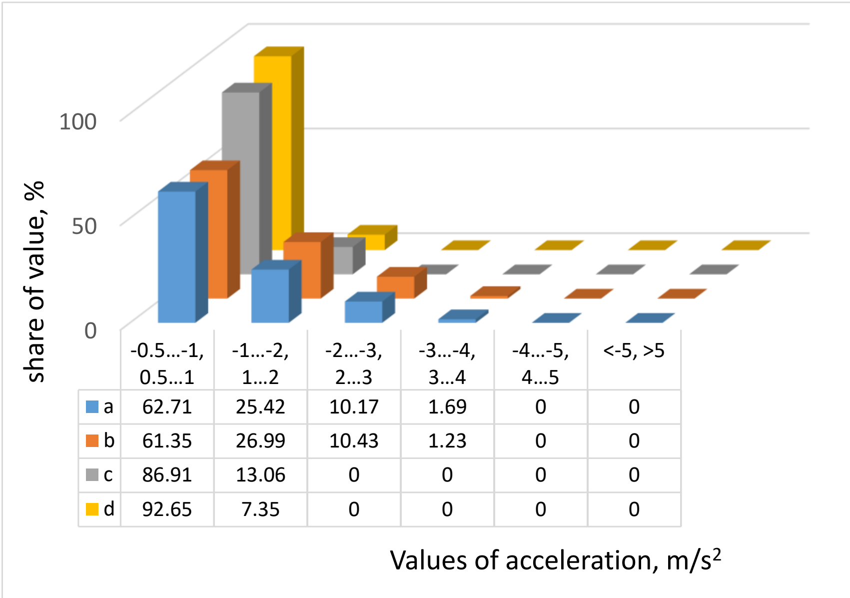


Figure 10. Distributions of absolute values of the extreme of lateral acceleration during turning maneuvers for various route sections: (a) city road; (b) suburban road; (c) expressway (dual carriageway); (d) highway.

5. Conclusions

The analysis presented in this paper confirms that the type and quality of the road and the organization of road traffic have a significant influence on the structure of the maneuvers undertaken by the driver. The research was carried out on a route consisting of four road sections that can be considered typical road types in many countries: a road in a built-up area (city), a single carriageway road with two lanes in an undeveloped area, an expressway (dual carriageway), and a highway. The results presented here show that this variation in roads allowed the demonstration of significant differences in a vehicle's driving patterns.

The analysis of the processes of acceleration and braking of the car and the execution of curvilinear motion confirms the thesis formulated on the basis of preliminary research that the type of road has a strong influence on the manner of execution of all these maneuvers and the frequency of their occurrence. The paper formulates conventional criteria for distinguishing the aforementioned maneuvers in the driving process, based on the recorded values of longitudinal and lateral accelerations. The criteria formulated were not purely subjective but were analyzed and verified in experimental studies and computer simulations.

The analysis of the structure of maneuvers undertaken by the driver was based on two parameters: the extreme value of acceleration occurring during the execution of a given maneuver (the maximum value for positive accelerations and the minimum value for negative accelerations) and the frequency of maneuvers during the passage of a given route.

The extreme values of the car acceleration and braking maneuvers on each route are illustrated in Figures 6 and 8. For both of these maneuvers, the highest (in absolute value) accelerations occur in the case of urban driving—up to 3 m/s^2 during car acceleration and up to 4–5 m/s^2 during braking. For the subsequent roads, which allow driving at increasingly higher speeds, the extreme values of acceleration for these maneuvers are increasingly smaller, and for the highway, they do not exceed the value of 1 m/s^2 (it should be noted here that during the passage of the route, there was not a single critical situation that would certainly force the driver to brake with very high intensity). The frequency of acceleration and braking maneuvers also shows a very strong dependence on road type. On average, alternating or consecutive acceleration and braking processes occurred every 13 s in the city, every 36 s outside the city, every 7 min on an expressway, and every 14 min on a highway. This means that acceleration and braking maneuvers in urban traffic conditions occurred about 65 times more often than on the highway.

The extreme values of the right and left turning maneuvers of the car on each route are illustrated in Figures 7 and 9. For both of these maneuvers (as for acceleration and braking), the highest, in absolute value, accelerations occur in urban traffic and on non-urban roads-up to 3–4 m/s^2. On an expressway, the extreme values for turning maneuvers (in both directions) are up to 2 m/s^2, while on a highway they are around 1 m/s^2. Unlike acceleration and braking maneuvers, for which there is a very strong dependence on the frequency of their occurrence on the type of road, in the case of turning maneuvers, for all four types of the road, the frequency of these maneuvers is very similar and is even almost identical for three of the road types: for a city road, every 26 s, and for a suburban road and a highway, every 25 s, respectively. Only the frequency of turning maneuvers on the expressway differs from these values, as maneuvers occur every 11 s. This is more than twice as often as on the other three routes, but it should be remembered that in the case of acceleration and braking maneuvers, the variation was many times greater. However, you have to be aware that, taking into account the different speeds of routes, maneuvers appear at different road intervals.

In the case of turning maneuvers, it is worth noting a regularity in that in pairs, for road types a–b and c–d, the distributions of extreme values (Figure 9) are very similar. This is particularly clear in the right-hand graphs, which show the distributions of absolute values.

The presented work is part of a research project aimed at developing a system to assess the manner of driving a vehicle. Analyses are realized for the purpose of determining the safety of moving drivers and capturing those who carry out dangerous maneuvers. This can be used, for example, to determine the cost of insurance, which will be higher for unsafe drivers.

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