THE BALTIC JOURNAL OF ROAD AND BRIDGE ENGINEERING
2024/19(1)

ISSN 1822-427X/eISSN 1822-4288
2024 Volume 19 Issue 1: 114–135
https://doi.org/10.7250/bjrbe.2024-19.630

ROAD TRAFFIC FLOW SPEED ON RURAL ROADS IN LATVIA

JURIS KREICBERGS[1,*], KATERINA FOLLA[2], JURIS SMIRNOVS[3]

[1] *Department of Automotive Engineering, Riga Technical University, Latvia*

[2] *Department of Transportation Planning and Engineering, National Technical University of Athens, Greece*

[3] *Department of Roads and Bridges, Riga Technical University, Latvia*

Received 27 November 2023; accepted 4 March 2024

Abstract. The aim of this article is to perform a comprehensive analysis of the data obtained during flow speed measurements on Latvian national roads. An algorithm for data selection was developed and implemented allowing for an analysis of comparable and unbiased traffic flow measurement data. In the course of the work, more than 150 000 000 traffic flow data records were received from the State Limited Liability Company Latvian State Roads for the period from autumn 2011 to the end of 2022. Above 30 000 000 records from 15 road sites were selected and processed. The results obtained during the analysis were visualized by depicting flow characteristics – average daily traffic, car proportion in traffic flow, average speed, speed histograms, speed rates V_{25}, V_{50}, V_{75}, V_{90}, V_{95}, V_{99} and proportions of vehicles driven below various speed levels and speeding data. The data characterising the situation on Latvian national roads are intended to be used in the future traffic safety research.

Keywords: annual traffic speed variations, big data analysis, free flow traffic, road traffic safety, traffic parameters measurements.

* Corresponding author. E-mail: Juris.Kreicbergs@rtu.lv

Juris KREICBERGS (ORCID ID 0009-0007-4653-1869)
Katerina FOLLA (ORCID ID 0000-0002-4489-5200)
Juris SMIRNOVS (ORCID ID 0000-0003-3709-7179)

Introduction

Travelling speed of the traffic flow is an important characteristic of transport systems. Excessive or inappropriate speed has been recognised as a major threat to safety on the roads being a factor in about one third of fatal crashes (European Commission, 2021). The Latvian Road Traffic Safety Plan for 2021–2027 (Republic of Latvia Cabinet, 2021) states that exceeding of the permitted driving speed, committed intentionally or unintentionally, is among the serious challenges that have to be solved by the future road traffic safety policy makers and they must henceforth pay more extensive attention towards creating safe and thought-out speed control, concurrently using various solutions oriented towards compliance with the speed.

Fatalities on Latvian roads had an essential decrease from above 500 in the early 2000s to a local minimum of 177 in 2012 when first photo radars were introduced on Latvian roads (CSDD, 2024) and then rose back to above 200 in 2014 when the first photo radar system was dismantled. This encouraged to look for available speed data to be analysed along a more extensive time period.

The study of speeds on Latvian roads was stimulated by the participation in Baseline project where results of roadside measurements in 15 European countries (Van den Broek et al., 2023) showed that on urban roads 27% to 79% of the passenger car drivers were observed to exceed the speed limit, on rural roads 7% to 71% and on motorways 11% to 60%. These data reflect measurements of car speeds in free traffic flow during daytime on weekdays. This study also showed that Latvia had the lowest speed compliance value on rural roads among the 15 European countries and therefore the analysis of longer time series speed data seemed being of high value both for research and for traffic safety policy making.

Since 2011, Latvian State Roads Ltd has published average and maximum speeds split by various time periods on now already above 40 traffic flow measurement points (Latvijas Valsts Ceļi, 2024) and accumulated raw data for a further analysis. In early 2023, it was decided to utilise gathered data for an in-depth analysis. The aim of this paper is to derive and perform a comprehensive analysis of speed characteristics on Latvian major and regional motor roads to be able in the succeeding research phases to compare them with speeds characterising traffic safety on similar roads in other countries, to find correlation between different speed characteristics and traffic safety indicators, to calculate speed dependent energy consumption and CO_2 emissions. The results of succeeding research phases are intended to be published separately when they will become available.

1. The influence of traffic speed on road traffic safety

The influence of driving speed on road traffic safety outcomes is evidenced by a wide range of scientific studies. It is also emphasised by the world-recognized road traffic safety manuals – The Handbook of Road Safety Measures (Elvik et al., 2009) and Road Safety Manual (PIARC, 2019). Since road traffic is an integral part of the life of our society, specialists from several fields collaborate in traffic research – engineers, psychologists, lawyers, business and social scientists. US traffic safety expert Dr. Leonard Evans in his book "Traffic Safety" (Evans, 2004) states that speed as a contributing factor is involved in all road crashes: no speed, no crashes. Several studies show that speed is a significant contributing factor in about 30% of road traffic crashes with fatal consequences (Taylor et al., 2000; European Commission, 2021).

The findings about the influence of speed on crash risk and crash severity are summarised in the report of the international organisation IRTAD Traffic Safety Data and Analysis Group (IRTAD, 2018). With higher driving speeds, the number of crashes and the crash severity increase disproportionally. With lower speeds, the number of crashes and the crash severity decrease. Speed influences the severity of any crash because the kinetic energy of a vehicle is proportional to the square of the speed (v^2). In crashes at higher speeds, more energy is released when colliding with another vehicle, road user or obstacle. Part of this energy is absorbed by a human body, which leads to serious consequences of the crash. At high speeds, the possibility of failing to handle oncoming hazards in a proper time and of vehicle handling errors is more likely because the driver has less time to avoid a collision in the event of a conflict. One of the most widely used mathematical relationships illustrating the effect of speed changes on traffic safety is Swedish researcher's Göran Nilsson's Power Model (Nilsson, 2004). It clearly shows that the speed has influence both on crash occurrence and the severity of crashes and the impact is the strongest on a fatality rate, a slightly lower impact on severe injuries and injuries, having still strong influence on the number of road crashes.

The conventional solution to lower risks is to set speed limits according to traffic and infrastructure conditions. At the same time, it is known that the speed limits are often violated. Usually 10% to 20% of the drivers in the European Union exceed the speed limit by more than 10 km/h (European Road Safety Observatory, 2006). It was also confirmed by the recent measurements in Baseline project (Van den Broek et al., 2023). ESRA survey results (Holocher & Holte, 2019), based on self-reports, showed that in 2018, 56% of European car drivers indicated that they had deliberately driven faster than the speed limit in built-up areas at least once in the previous month. The respective percentage of car drivers exceeding speed limits on rural roads was 67% and on motorways 62%.

In the European Union, road safety experts have often recommended lower speed limits. For example, in France, on the 1st July 2018, the permitted driving speed on two-lane highways outside populated areas was reduced from 90 km/h to 80 km/h (Randelhoff, 2021a). The evaluation of the implemented measure indicated a significant improvement in safety, with a decrease in the number of casualties in road crashes and a small loss of driving time – approximately one second per kilometre. The implementation of the mentioned decision can be considered successful because the result was achieved with low investment costs. Nevertheless, in this case in France reducing the permitted driving speed was unpopular among the population. This led to protests, after which the department considered to increase the speed limit regionally again to 90 km/h.

According to the data characterising the speed limit enforcement across various countries (Adminaité-Fodor & Jost, 2019), in 2017 the number of speed tickets issued in Latvia per thousand inhabitants was the fourth largest – 186 protocols. Higher numbers were achieved in Belgium – 299, Luxembourg – 428 and the Netherlands – 457 protocols/1000 inhabitants. At the same time unreasonable speed limitation is strongly inadvisable. In order for the speed reduction to be observed, the road users must understand its necessity and it must correspond to the existing technical equipment and class of the road, as well as the traffic flow. A significant reduction in speed in a place where crashes are not observed will not be understood and will therefore be ignored by a large number of drivers (Leblud, 2017).

Germany is the country where speed limits are not set on a separate part of the road network of excellent quality having excellent equipment, which has received the international designation – Autobahn. Studies (Holthaus et al., 2020), which analysed the speed of car traffic on Autobahn type roads without speed limits, confirm that approximately 55% of the identified 629 252 cars driving on road sections without speed limits, reached a maximum speed of over 140 km/h. This means that most drivers spend at least part of their journey on highway with no speed limit driving above 130 km/h. It should be noted that there are no speed limits on 70.4% of this type of road network. According to statistical data (Randelhoff, 2021b), in this Autobahn-type road network, the numerical value of the crash rate has always been lower than in the transition to the German road network. This information confirms the importance of road infrastructure in the field of improving the level of traffic safety.

A whole series of factors influence the choice of speed of vehicle drivers. Several studies have extensively analysed the influence of the geometric parameters of the highway and the condition of the road surface (Semeida & El-Shabrawy, 2016; Aydin & Topal, 2019), climatic conditions (Ivajnšič et al., 2021; Stamos et al., 2016), design of vehicles and their technical condition (Mikulić et al., 2023), traffic flow and its composition (Mohan, 2022) on road traffic speed.

Drivers choose their driving speed, often without considering local and temporary conditions related to traffic and weather. The choice of speed is related to drivers' motives, attitude and risk perception. In addition, the speed selection is influenced by road characteristics and road environment, as well as vehicle characteristics.

The driving speed affects not only road safety, but also exhaust emissions, fuel consumption (Kunkler et al., 2021), traffic noise levels and the quality of life for people who live or work near the road. In Germany, society is discussing the possible setting of speed limits on Autobahn-type roads, which could theoretically reduce the amount of fuel consumed and, therefore, also reduce the amount of CO_2 produced. The authors of the study (Holthaus et al., 2020), however, point out that the effect of the general speed limit on CO_2 emissions could be less than expected because the recommended speed of 130 km/h is rarely exceeded on average, even on sections of highways where there are no speed limits. Using the methods and data developed in the current research in the future studies would help to test this effect also for Latvian roads.

Data on the speed and composition of the road transport flow are frequently obtained with the help of automatic systems (Al-Kaisy et al., 2018). For example, statistics from data obtained in the USA and Canada are widely used to determine LOS on highways. In the study (Aigner Breuss et al., 2017), it has been stated that the main indicators used in traffic speed research are the following: mean speed, speed V_{85} (85^{th} percentile speed), speed limits and speed dispersion. Having several hundreds of millions of speed recordings from automatic systems lead to an obvious decision to perform a detailed speed analysis on the Latvian roads.

Fundamental traffic data combined with crash data and corresponding analyses are therefore crucial to support the necessary traffic safety decisions and help practitioners better understand the size of the phenomenon. The most important data for this purpose are performance indicators on speed and speeding, which are directly associated with crashes and casualties and can be later used for the evaluation of implemented traffic safety measures. Such speed data on Latvian major and regional roads are presented in the current study, in which a comprehensive analysis of data obtained during flow speed measurements is carried out.

2. Research methodology

More than 150 000 000 traffic flow records were received from the State Limited Liability Company Latvian State Roads (LVC) for the period from July 2011 to the end of 2022. The data from M680 Vehicle Count and Classifier inductive loops included speed as a natural number in kilometres per hour, measurement time with a precision up to one tenth of the second, information on traffic lane and direction, gap/headway, vehicle length and type.

For this research, only cars were distinguished from the other types and the calculations were made either for entire traffic flow of all vehicle types, referring to vehicle speed or cars in free traffic, where the gap before and after the car was at least five seconds. Any reference to a car speed in this paper refers to all cars in free flow only.

It was found that, for various reasons, the measurement periods at the stations were different – from 10 min per hour to continuous measurement. Different measurement durations do not cause a data shift, data on measurements in 10 min were collected from each hour, ensuring that in the hours when longer measurements were made, the 10-minute sections were shifted to each other and the measurements were viewed at different times of the day. The research uses measurement data only from those days when data were available for at least 10 min from each hour throughout the day, except for night hours, when vehicles might not have been observed during the measurements.

An Excel Visual Basics algorithm for data selection and processing was developed and implemented, selecting unbiased traffic flow measurement data. Although Excel is not well suited for processing big data, it was used because the data structure was unknown at the beginning of data processing and the advantage of data visualization and filtering helped to avoid errors in data processing.

The procedure of data analysis below was followed and the respective results were obtained:

1. The data were selected and processed with the developed algorithm.

2. Visualization of data processing results both for the traffic flow as a whole and separately for cars travelling in free traffic flow was created, which for the first time included information about:

- The part of the road transport flow travelling at a speed that did not exceed the permitted driving speed limit, as well as travelling at other speed values with a fixed step of 5 or 10 km/h;
- Speed for V_{85} values within years and months;
- Changes in other speeds (V_{25}, V_{50}, V_{75}, V_{90}, V_{95}, V_{99}) during the examined period;
- Cumulative and relative frequency histograms at each of the measurement stations;
- Average driving speeds;
- Traffic flow intensity data.

Since the aim was to generalize the speed change trends to reflect the speed changes on Latvian major and regional roads, after the analysis of speeds at individual measurement points, 15 measurement stations were selected and summary of measurements at all selected stations was created and presented in this paper. The measurement stations for the summary were selected based on the following parameters:

- Asphalt concrete pavement;
- One driving lane in each direction;
- Hard shoulder;
- No intersections essentially affecting speed;
- Visibility distance of at least 500 m;
- Clearly visible horizontal markings;
- The permitted driving speed of 90 km/h;
- Speed mode is not affected by stationary speed cameras;
- Speeding is technically possible.

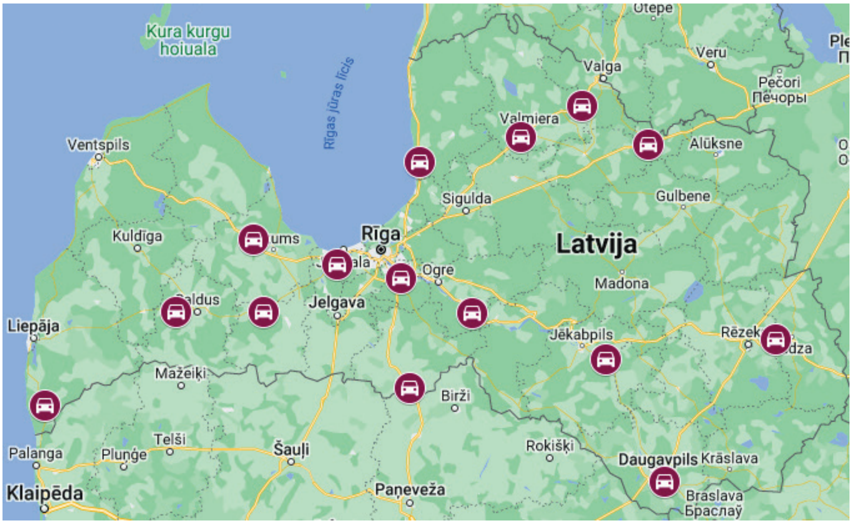

Figure 1. Location of measuring stations selected for this study

More than 30 000 000 measurements were selected according to the set parameters. Figure 1 shows the locations of the measuring stations on Latvian highways, the data of which were selected and analysed in the current study.

The selected locations by the mentioned criteria well represent all regions of Latvia covering all major directions of major motor roads towards Estonia, Russia Belorussia and Lithuania and are representative to reflect the general trends of speed changes on Latvian major roads in the time period analysed.

3. Dynamics of changes in average annual daily traffic and transport flow composition

The annual average daily traffic (AADT) on selected locations has shown a slight upward trend since 2011, increasing from approximately 3500 vehicles per day in 2011 to 4600 vehicles per day in 2019. In 2020, there is a decrease in AADT, presumably due to COVID-19, growing back to 4500 vehicles per day in 2022. During the year, the maximum average daily traffic (ADT) is reached in July and August – close to 5000 vehicles per day (see Figure 2).

In the course of the research, traffic flow on weekdays and weekends was evaluated separately. It was established that during the daytime on weekends (Day/Wknd), there was a slightly higher ADT exceeding 5000 vehicles per day than on weekdays (Day/Wk) having 5% less traffic (see Figure 3). During night-time (Night/Wknd and Night/Wk), the respective difference between weekends and weekdays was more than 20%.

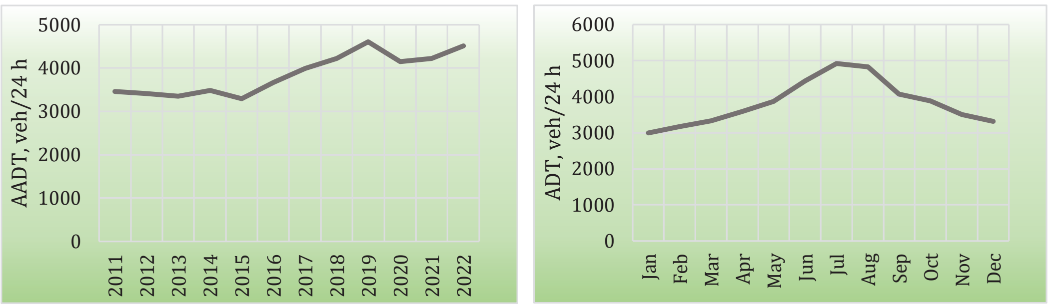

Figure 2. Dynamics of changes in the AADT and ADT in the period of 2011–2022

Although during the night-time the traffic and flow density were significantly lower, allowing the driver of the vehicle to freely choose the driving speed, the average speed at night was slightly lower than during daytime both on weekdays and at weekends, probably because of restricted visibility. Nevertheless, the average speed at weekend nights was slightly higher than on weekday nights, probably due to the lower percentage of commercial vehicles in the traffic.

One of the parameters characterising transport flows is the share of cars and the share of free-running cars in the total flow. The proportion of vehicles moving in free traffic characterises the flow saturation and for this particular analysis reflects the credibility of data for cars in free flow only since the cars in free traffic still represent an essential part of the entire traffic flow.

Figure 4 summarises information about the dynamics of changes in the transport flow composition in the examined time period.

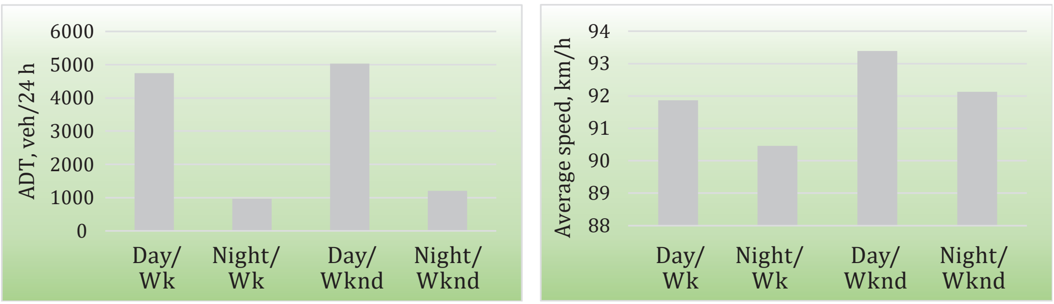

Figure 3. Changes in ADT and average speed during weekdays and weekends. Day/Wk – working day; Night/Wk – weekday night; Day/Wknd – weekend day; Night/Wknd – weekend night.

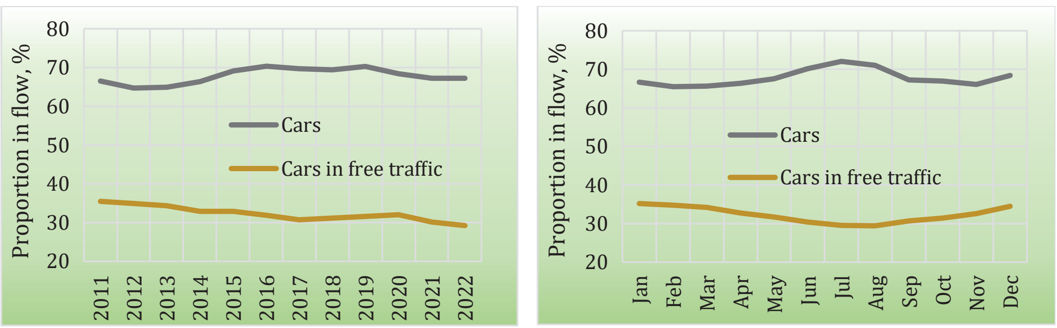

Figure 4. Dynamics of changes in the proportion of cars and cars in free traffic in the analysed time period

The obtained data allow us to conclude that the traffic flow in the road sections near the measuring stations is mainly made up of cars – their share in the traffic flow throughout the entire time period fluctuated around 70%. Over the period between 2011 and 2022, the proportion of freely driving cars slightly decreased, with the respective ratio of cars in free traffic being below 30% in 2022. Analysing the changes of the mentioned indicator over the years, it was also observed that along with the increase of the average daily intensity in the summer months, the proportion of cars in free traffic decreased over the same months.

3.1. Speed relative and cumulative frequency histograms

The big data allowed creating histogram graphs of the relative frequency of driving speed with Δv = 1 km/h. Figure 5 clearly shows a representation of the relative frequency of driving speeds on selected Latvian roads. The coloured bars represent characteristic speeds from traffic law and praxis – the speed limit is shown in red, by law the monetary fines for speeding start if exceeding 100 km/h (the blue bar) while taking into account the measurement tolerances the fines start close to 105 km/h (the dark red bar).

In this case, the most frequently fixed speed value is 88 km/h. It should be emphasised that a tendency can be observed to exceed the speed limit of 90 km/h.

The cumulative frequency histogram of driving speeds (see Figure 6) provides a clearer illustration of the proportion of vehicles driving within the speed limits and below the monetary fine speed.

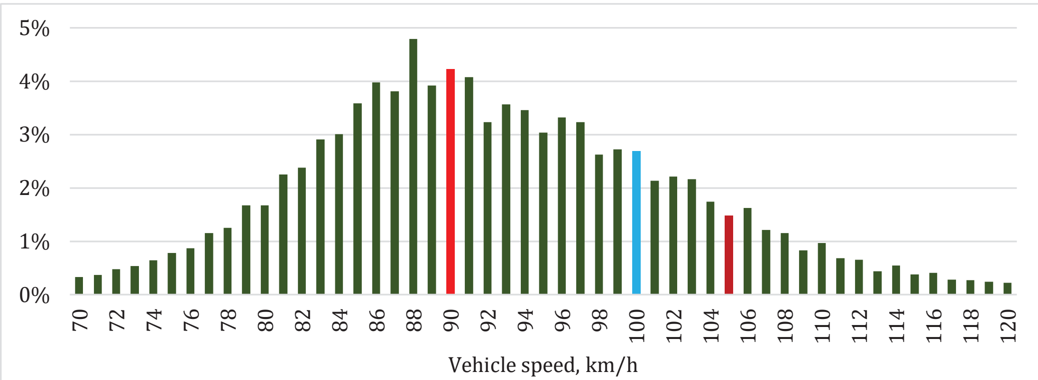

Figure 5. Relative frequency histogram of the whole transport flow

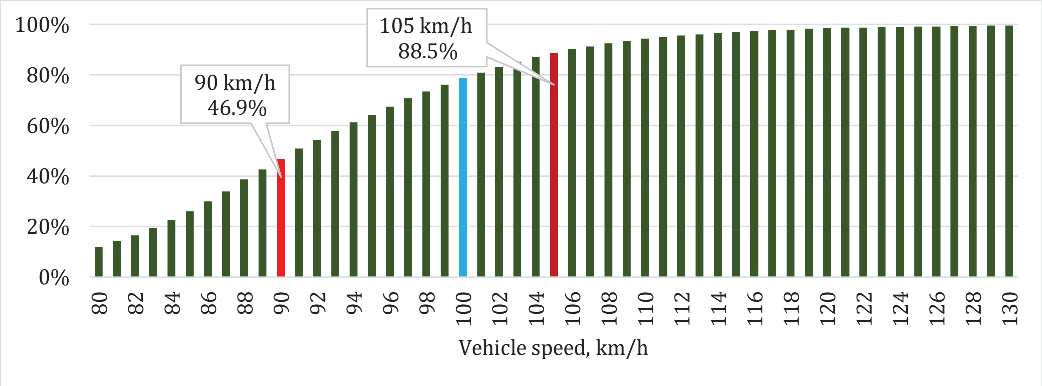

Figure 6. Cumulative frequency histogram of travel speed of the whole traffic flow

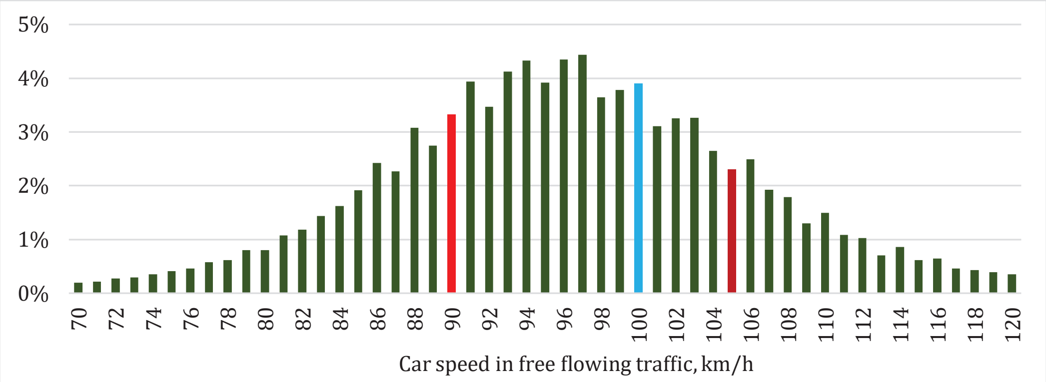

Figure 7. Histogram of the relative frequency of the speed of cars in free traffic

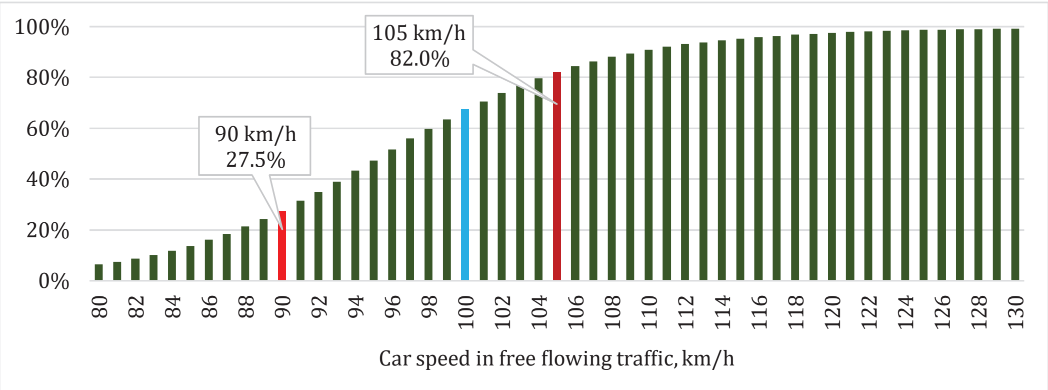

Figure 8. Cumulative frequency histogram of car speeds in free traffic

The cumulative frequency graph shows that less than 50% of vehicle drivers observe the speed of 90 km/h (see Figure 6). 80% of drivers do not exceed the limit of 100 km/h, but slightly less than 90% of drivers do not exceed 105 km/h. This allows us to conclude that at least 10% of the participants of the transport flow drive at a speed exceeding 105 km/h.

According to the histogram of the relative frequency of the speed of cars in free traffic, the set speed limit of 90 km/h is observed by an even smaller number of flow participants than in the entire traffic flow (see Figure 7).

The most frequently fixed speed value of this part of vehicles is 97 km/h, which is 9 km/h higher than the most frequent speed of the entire traffic flow.

The cumulative frequency graph shows that less than 30% of freely driving car drivers follow the speed limit of 90 km/h (see Figure 8).

Only 68% of drivers do not exceed the speed of 100 km/h, while only 82% of drivers do not exceed 105 km/h. This allows concluding that when there were no physical obstructions, a huge proportion of cars were speeding, with more than 5% of drivers exceeding 114 km/h at the speed limit set at 90 km/h.

3.2. Dynamics of average speed changes

When analysing transport flow parameters, attention is most often paid to the numerical values of the average driving speed and the dynamics of its changes over the years. Figure 9 shows the dynamics of changes in the average speed of cars in free-flowing traffic on the left and of the entire transport flow on the right.

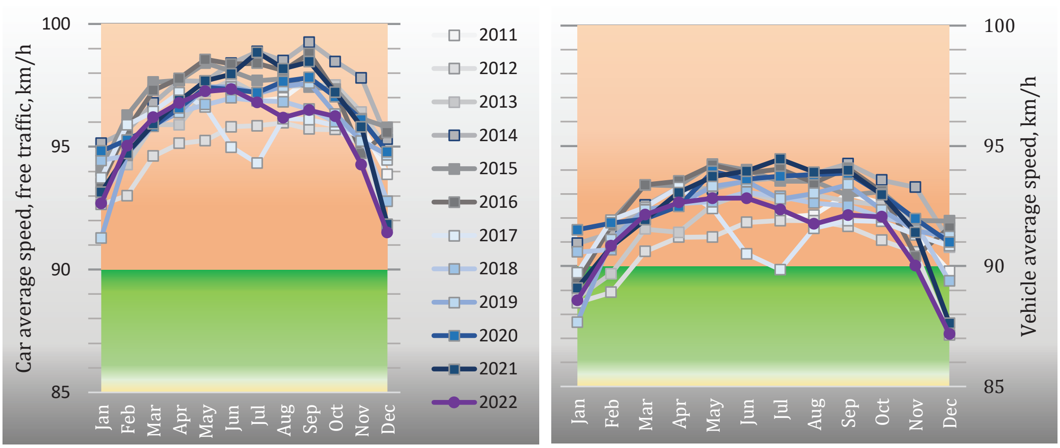

Figure 9. The average speed of the flow by year and month (cars in free traffic on the left, the entire flow on the right)

Over the years the average monthly speed for the entire flow changed from the minimum value of 86 km/h in December 2012 to 94.5 km/h in July 2021. As expected, the highest average speed values are recorded during the summertime, while the speed decreases in the wintertime. In 2012 and 2017, due to extensive road reconstruction works, lower average speed values were recorded in the middle of the year. If not counting these two years the lowest average speed (91.5 km/h) for the entire year was recorded in 2022 and the highest (93.1 km/h) in 2014.

The graph of changes in the average speed of cars in free traffic shows similar change trends as for the entire transport flow, only the numerical values of the average driving speed are higher. There is no month with difference below 3.3 km/h and no month with difference above 5.2 km/h. The largest difference was observed in July 2014 and the smallest in January 2020.

In Figures 9–14, green colour is used for speeds within the speed limit, while the red zone is well above the speed limit. Out of the total 138 measurement months, only in 16 winter months the average speed was not higher than the legal speed limit, while for cars in free traffic flow, there was not a single month with average speed within the legal limit.

3.3. The dynamics of changes in the rate of different percentage coverage

Latvian Road design Standard LVS 190-1:2000 "Road track" defines that V_{85} is required for the calculation of the stopping sight distance S_{STOP} and the required overtaking sight distance S_{OVER}. Minimum and maximum values of V_{85} are observed during the same years with those of the average speed (see Figure 10).

The lowest value of V_{85} for the entire flow was observed at 101.5 km/h in 2022 and the highest at 103.8 km/h in 2014. For the cars in free traffic flow, the respective lowest value was 105.3 km/h and the highest was 108.1 km/h. The monthly maximum V_{85} reached 109.8 km/h in September 2014, while the monthly minimum was 101.1 km/h in January 2019.

It should be noted that other speeds besides V_{85} should also be considered in traffic organisation measures. Therefore, the authors of the paper also calculated the speed of different percentage coverage – V_{25}, V_{50}, V_{75}, V_{90}, V_{95}, V_{99}. Figure 11 shows the results of the various flows from 25% to 99%.

All changes in flow rates caused by seasonal and weather conditions are clearly visible. In the wintertime, the speed decreases, but in the summertime, it increases. The thicker red line in the graph shows the V_{85}

changes. In 28 months out of 138, it was observed that 1% of cars in free traffic had a speed higher than 130 km/h, in 84 months 5% of the entire flow exceeded the speed limit by more than 20 km/h in conditions that seemingly allowed for faster driving.

One of the most important indicators characterising the driving mode is the proportion of traffic flow that does not exceed a certain speed limit. Usually, on rural roads, speed changes in the range from 60 km/h to 130 km/h are chosen with a step of Δv = 10 km/h or Δv = 5 km/h.

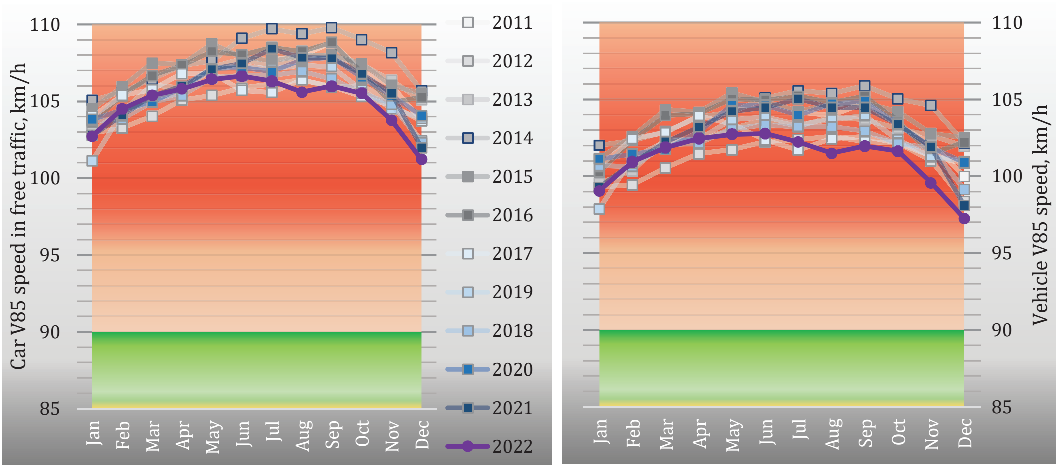

Figure 10. Dynamics of v_{85} changes (cars in free traffic on the left, entire flow on the right)

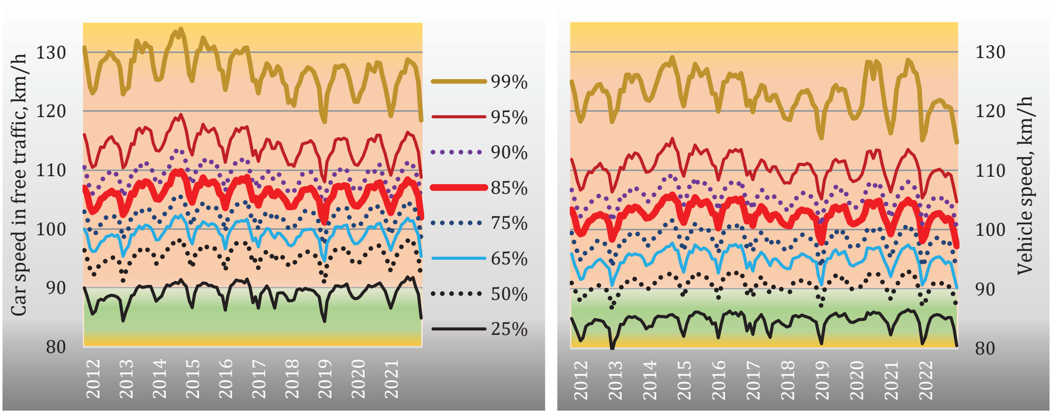

Figure 11. Speed changes of various percentage coverage (cars in free traffic on the left, the entire flow on the right)

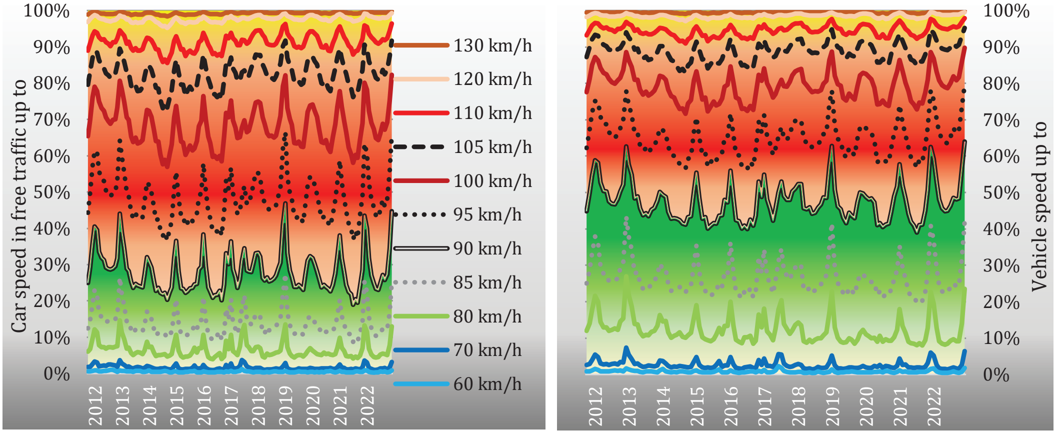

Figure 12. Monthly changes in the proportion of groups of vehicles traveling at different speeds (cars in free traffic on the left, entire flow on the right)

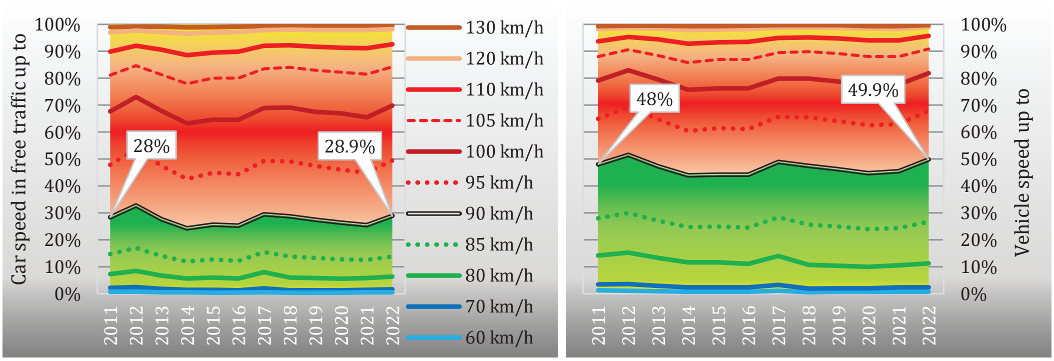

Figure 13. Annual changes in the proportion of groups of vehicles traveling at different speeds (cars in free traffic on the left, entire flow on the right)

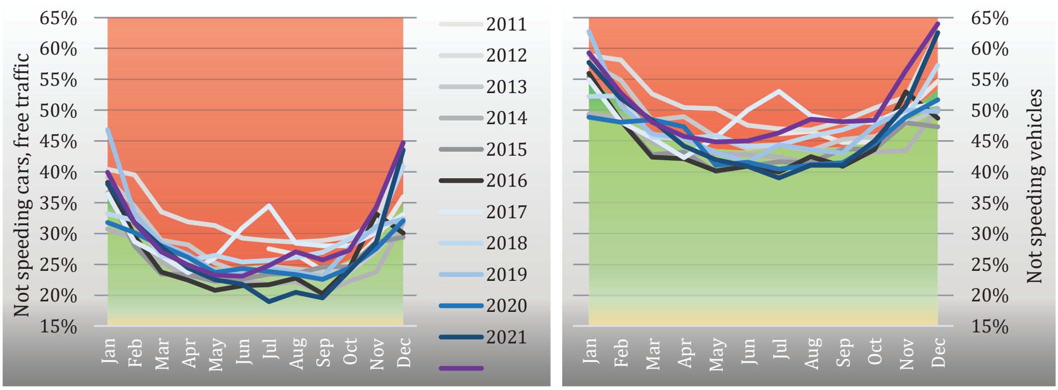

Figure 14. Changes in the proportion of vehicles traveling at a speed of up to 90 km/h (cars in free traffic on the left, entire flow on the right)

Figure 12 shows the spectrum of groups of vehicles traveling at different speeds.

The figure clearly shows the impact of seasonality, however, this time, for instance, the group driving at speeds of up to 90 km/h exhibits its regional maximum during the winter, when flow speeds are lower. Speed around 105 km/h in Latvia is worth analysing since monetary fines for speeding start close to this speeding value only. The highest whole flow rate that did not exceed 105 km/h was recorded in December 2022 (95.2%), while for the cars in free traffic, the respective highest rate was 91.7% in January 2019 and December 2022, up from 73.1% in July 2014. It is noted that on average almost 20% of travelling cars in free flow could receive speeding fines. On the other hand, the quite low percentage of vehicles travelling at a speed lower than 80 and 70 km/h may illustrate on average the existence of good driving conditions for maintaining the permitted speed.

Since Figure 12 makes a comparison over the years quite complicated, the graphs of annual values for the period of 2011–2022 are shown in Figure 13.

Having in mind the road construction works in 2012 and 2017, it can be seen that 2022 demonstrated a small positive tendency towards speed reduction for the speeds from 90 km/h and higher.

Obedience to the traffic law on typical Latvian two-lane highways may be characterised by the proportion of vehicles in the flow that does not exceed the specified speed limit of 90 km/h (see Figure 14).

This proportion for the entire flow differs significantly from the respective proportion of the cars driving in free traffic. The highest proportion of speed violators was observed in July 2021, when above 80% of cars in free traffic were speeding. There is no month, including winter months, when half of the cars in free traffic drove within a speed limit – the highest value was 46.9% in January 2019.

For the entire flow, the highest percentage of vehicles travelling at a speed up to 90 km/h (64.0%) was observed in December 2022. Although this is still well below reasonable traffic safety targets, the timing of the best speed compliance in 2022 coincides with the historically lowest number of 113 traffic fatalities on Latvian roads (CSDD, 2023), providing a solid basis for further investigation and discussion.

4. Discussion

Speed measurements were carried out on a continuous basis over the last 12 years in Latvia, providing a wealth of data on travelling speeds on major motor roads, which could be used by researchers, policy makers and road safety practitioners. An extensive processing and analysis of these data has been performed for the first time, aiming to capture the overall situation in Latvia and the most common speed-related behavioural patterns of Latvian drivers.

The data selected with the developed algorithm and software were processed and analysed (above 30 000 000 measurements). Visualization of data processing results was created, which for the first time included information about the part of the road transport flow travelling at a speed lower than the legal speed limit, as well as at speed values with a set step of 5 or 10 km/h; evolution of V_{85} on an annual and monthly basis; changes in other speed percentiles (V_{25}, V_{50}, V_{75}, V_{90}, V_{95}, V_{99}) during the examined period; cumulative and relative frequency histograms; average driving speeds and traffic flow intensity data. The visualization was performed for both the total traffic flow and separately for cars travelling in free traffic. Time-series data of speeds on Latvian roads may allow us to better understand drivers' behaviour and observe potential changes over time. The combination of various speed related indicators (i.e., average travelling speed, V_{85}, speeding ratios, etc.) in the analyses allowed drawing more complete conclusions for both the transport system operational level, as well as the road safety performance level.

The results obtained in the course of the analysis show that, similarly to other European countries, only a small percentage of vehicle drivers on Latvian roads drive at a speed up to the legally allowed speed limit. Over the whole time period examined in the current study (2011–2022), the monthly indicator of the percentage of vehicles travelling within the legal speed limits fluctuated between 39% and 64% in Latvia, which means that the proportion of violators ranged between 36% and 61%. When examining this indicator on an annual basis over the same period, its values fluctuated between 43% and 52%, meaning that over the last 12 years about half of drivers did not observe the maximum legal speed limits.

Similar indicators are available for the European Union countries, reflecting a better or worse performance, depending the country. Based on national statistics, it was found that the vehicles travelling within legal speed limits on rural roads ranged between 9% and 63% among the EU countries (Adminaité-Fodor et al., 2019). More recently, speed related data have been collected by 15 EU Member States under a common methodology within the EU-funded Baseline project. Based on these results, the vehicles travelling within speed limits ranged between 29% and 93% among the participating countries (Van den Broek et al., 2023). It is obvious that Latvia is among the countries with the worst performance in relation to speeding on rural roads. However, it should be noted that when examining speeding, a straightforward comparison among the performance of the countries is not always possible, mainly due to the different speed limits that are in force in the EU countries and also due to different methodological approaches to data collection (definition of rural roads, free flow traffic, etc.).

Similar results were obtained earlier from the SARTRE3 project (SARTRE3, 2004). The data were collected through surveys of self-declared behaviour. Project results indicated that car drivers who violated speed limits often, very often or always differed based on the type of road, as follows: 24% on motorways; 18% on major roads between cities; 12% on rural roads; and 8% on roads inside urban areas. The results obtained in Latvia for rural roads were essentially higher than the mentioned indicator. It should be noted that the results of the SARTRE3 project represent only countries that participated in the project, and not the entire EU region.

The observed differences could be explained by a lower traffic flow density and a relatively high share of free-running vehicles in the total flow, different enforcement practices among the countries or cultural deviations and road users' perspectives. For instance, speed enforcement on Latvian roads is relatively intensive, as evidenced by the fact that the number of fines issued per 1000 inhabitants is the fourth largest in the EU. Also, as demonstrated by studies of the subsequent ESRA project, the perceived likelihood of being checked by the police for respecting speed limits varies among the European countries between 11% in Denmark and 55% in France. At the European level, 36% of respondents consider it is likely to be checked by the police for respecting the speed limits on a typical journey (Laiou et al., 2019). However, it should be considered that these results are based on self-reported data and, thus, may have some disadvantages, such as a bias due to the tendency of the respondents to provide a more favourable image of themselves, non-accurate recall or a selective non-response bias.

A seasonal pattern of travelling speeds in Latvia is also obvious. The data analysis clearly showed an increase in the absolute speed values during the summer months and a decrease during the winter over the whole examined period. At the same time, it should also be noted that, despite the adverse driving conditions in the winter months, the average speed of the total traffic flow is not less than 90 km/h, which probably indicates a good level of road maintenance. However, further analyses are needed, combining various types of data in order to identify such a relationship.

A relationship between the recorded speeds and road traffic fatalities seems to exist, which, however, was not analysed in the current study.

Therefore, reliable and high-quality crash data are needed to be analysed with the speed related data, which can lead to the appropriate evidence-based speed measures and policies. On the basis of the existing data, it is worth noting that the highest number of fatalities in Latvia was recorded in 2014, when the highest speed values were observed, while in 2022 the historical minimum of traffic fatalities in Latvia coincided with the lowest observed speeds.

Cross-country analyses and comparison with other European countries could also reveal the weaknesses or best practices of the countries in relation to speed performance and highlight the road safety areas that need further improvement in Latvia. For this purpose, the collection of more types of data is recommended. Such data concern not only drivers' behaviour, but also the implemented policy measures related to speed and speed management, enforcement practices or significant events and changes that may have affected traffic and behavioural patterns (e.g., new infrastructure projects, extreme weather events, pandemics, etc.).

Conclusions

For the first time in Latvia a wide selection of traffic speed parameters on major and regional motor roads has been calculated and analysed.

The vehicle speed data measured by Latvian State Roads in the time period from 2011 till 2022 show essential non-compliance with speed limits when the traffic conditions technically allow speeding. The percentage of cars in free traffic driven on rural roads within speed limit of 90 km/h in non-winter conditions has been below 30%, in some months even below 20%.

The V_{85} values for the entire flow range between 101.5 km/h and 103.8 km/h over the examined period. When the road traffic conditions allow speeding, 85% of vehicles have been driven on Latvian major motor roads, depending on month, with a speed up to 101.5 km/h till 103.8 km/h. The respective V_{85} values for the cars in free traffic flow range from 105.3 km/h to 108.1 km/h.

The speeds in winter months are essentially lower than in summer months. Nevertheless, the obtained results allow us to conclude that Latvia's major motor roads and their level of maintenance all-year-round ensure the continuous driving mode of the traffic flow with the permitted speed of 90 km/h.

The results of this analysis confirm that a significant amount of speed data is available for further research allowing for an overall assessment of speed performance on the Latvian main road network, thus providing useful support for decision makers working on the improvement of road transport safety in Latvia. The collection and analysis of such data at the national level at regular intervals and at a more detailed level are essential for the adoption and documentation of targeted measures and actions.

FUNDING

The research has been supported by Motor Insurers' Bureau of Latvia from funds allocated by the Latvian Road Safety Council for road traffic accident prevention measures.

REFERENCES

Adminaité-Fodor D., & Jost, G. (2019). *Reducing speed in Europe* (PIN Flash Report 36). https://etsc.eu/wp-content/uploads/PIN-flash-report-36-Final.pdf

Aigner-Breuss, E., Braun, E., Eichhorn, A., & Kaiser, S. (2017). *Speed of traffic*. European road safety decision support system, developed by the H2020, project SafetyCube. www.roadsafety-dss.eu

Al-Kaisy, A., Amirhossein, J., Washburn, S., Lutinnen, T., & Dowling, R. (2018). Performance measures on two-lane highways: Survey of practice. *Research in Transportation Economics*, *71*, 61–67. https://doi.org/10.1016/j.retrec.2018.07.001

Aydin, M. M., & Topal, A. (2019). Effects of pavement surface deformations on traffic flow. *Transport*, *34*(2), 204–214. https://doi.org/10.3846/transport.2019.8631

CSDD. (2024). *The road traffic safety statistics*. Latvian Road Traffic Safety Directorate. https://www.csdd.lv/en/road-accidents/the-road-traffic-safety-statistics

Elvik, R., Truls, V., Hoye, A., & Sorensen, M. (2009) *The handbook of road safety measures* (2nd ed.). Emerald Group Publishing. https://doi.org/10.1108/9781848552517

European Commission. (2021). *Road safety thematic report – Speeding*. European Road Safety Observatory. Brussels, European Commission, Directorate General for Transport. https://road-safety.transport.ec.europa.eu/system/files/2021-07/road_safety_thematic_report_speeding.pdf

European Road Safety Observatory. (2006). *Speeding*. retrieved January 20, 2007. www.erso.eu

Evans, L. (2004). *Traffic safety*. Science Serving Society.

Holocher, S., & Holte, H. (2019). *Speeding* (ESRA2 Thematic report Nr. 2). ESRA project (E-Survey of Road users' Attitudes). Bergisch Gladbach, Bergisch

Gladbach, Germany: Federal Highway Research Institute. https://www.esranet.eu/storage/minisites/esra2018thematicreportno2speeding.pdf

Holthaus, T., Goebels, C., & Leerkamp, B. (2020). *Evaluation of driven speed on German motorways without speed limits.* Bergische Universität Wuppertal: Lehr- und Forschungsgebiet für Güterverkehrsplanung und Transportlogistik, Wuppertal. https://www.gut.uni-wuppertal.de/fileadmin/bauing/leerkamp/Homepage_alt/Downloads/202003_Tempolimit/20200305-Evaluation_speed_FCD.pdf

IRTAD. (2018). *Speed and crash risk* (IRTAD Report). International Transport Forum.
https://www.itf-oecd.org/sites/default/files/docs/speed-crash-risk.pdf

Ivajnšič, D., Horvat, N., Žiberna, I., Kotnik, E.K., & Davidović, D. (2021). Revealing the spatial pattern of weather-related road traffic crashes in Slovenia. *Appl. Sci.*, *11*, Article 6506. https://doi.org/10.3390/app11146506

Kunkler, J., Braun, M., & Kellner, F. (2021). Speed limit induced CO_2 reduction on motorways: Enhancing discussion transparency through data enrichment of road networks. *Sustainability*, *13*(1), Article 395.
https://doi.org/10.3390/su13010395

Latvijas Valsts Ceļi. (2024). *Satiksmes intensitāte*.
https://lvceli.lv/celu-tikls/celu-kartes/satiksmes-intensitate-karte/

Laiou, A., Theofilatos, A., Yannis, G., Meesmann, U., Torfs, K., & Trotta, M. (2019). An exploration of European road users' safety attitudes towards speeding. *Transportation Safety and Security*, *13*(5), 552–573.
https://doi.org/10.1080/19439962.2019.1650144

Leblud, J. (2017). *Reduction of speed limit*. European Road Safety Decision Support System, developed by the H2020 project SafetyCube.
www.roadsafety-dss.eu

Mikulić, I, Bošković, I, & Zovak, G. (2020). Effects of driving style and vehicle maintenance on vehicle roadworthiness. *Promet – Traffic & Transportation*, *32*(5), 667–677. https://doi.org/10.7307/ptt.v32i5.3443

Mohan, R. (2022). On the modelling of speed-concentration curves for multi-class traffic lacking lane discipline using area occupancy. *Transportation Letters*, *14*(5), 447–463.
https://doi.org/10.1080/19427867.2021.1888197

Nilsson, G. (2004). *Traffic safety dimensions and the power model to describe the effect of speed on safety*. Bulletin 221, Lund Institute of Technology, Lund. https://portal.research.lu.se/files/4394446/1693353.pdf

On Motor Roads. Law of the Republic of Latvia. (1992). Retrieved from
https://likumi.lv/ta/en/en/id/65363-on-motor-roads

Republic of Latvia Cabinet Order No. 712. (2021, October 6). *On road traffic safety plan for 2021–2027.* https://likumi.lv/ta/en/en/id/326640-on-road-traffic-safety-plan-for-20212027

PIARC. (2019) *Road safety manual.* https://roadsafety.piarc.org/en

Randelhoff, M. (2021a). *Herabsetzung der zulässigen Höchstgeschwindigkeit auf französischen Landstraßen von 90 auf 80 km/h*: *Wirkung auf Verkehrssicherheit und Reisezeiten*. https://www.zukunft-mobilitaet.

net/172390/analyse/frankreich-landstrassen-tempolimit-80kmh-90kmh-wirkung-evaluation-reisezeiten-verkehrstote

Randelhoff, M. (2021b). *Verkehrstote auf deutschen Autobahnen im Vergleich zum europäischen Ausland*. https://www.zukunft-mobilitaet.net/172160/analyse/tempolimit-verkehrstote-auf-deutschen-autobahnen-vergleich-ausland-eu/

SARTRE 3. (2004). *European drivers and road risk. Part 1: report on principal results*. INRETS, Paris. https://www.dacota-project.eu/Links/erso/knowledge/Fixed/20_speed/ref%2053%20sartre%203_part%201.pdf

Semeida, A., & El-Shabrawy, M. (2016). Impact of pavement condition on passenger car traffic. *Građevinar, 68*(8), 635–644. https://doi.org/10.14256/JCE.1466.2015

Stamos, I., Salanova Grau, J. M., Mitsakis, E., & Aifadopoulou, G. (2016). Modeling Effects of Precipitation on Vehicle Speed: Floating Car Data Approach. *Transportation Research Record*, *2551*(1), 100–110. https://doi.org/10.3141/2551-12

Taylor, M., Lynam, D.A. & Baruya, A. (2000). *The effect of drivers' speed on the frequency of accidents* (TRL Report TRL421). Transport Research Laboratory, Crowthorne. https://trl.co.uk/uploads/trl/documents/TRL421.pdf

Todoruţ, A., Cordos, N., Duma, I., Barabas, I., Burnete, N., Efrim, R. M., & Dragoste, M. D. (2023). Possibilities of assessing the vehicle stability parameters in the case of rollover and rolling accidents. *Acta Technica Napocensis. Series: Applied Mathematics, Mechanics, and Engineering*, 66(1), 35–50. https://atna-mam.utcluj.ro/index.php/Acta/article/view/2096

Van den Broek, B., Aarts, L., & Silverans, P. (2023). *Baseline report on the KPI speeding*. Baseline project, Brussels: Vias institute. https://baseline.vias.be/en/publications/kpi-reports/