Research Article

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Permissible distance – safety system of vehicles in use

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Abstract: The article presents and assesses the shortcomings of the applicable provisions regarding the maintenance of the necessary distance behind the preceding vehicle in road traffic. We are exposed to accidents when using vehicles. The human factor contributes greatly to their occurrence. A problem analysis was carried out with proposed changes. The conclusions indicate the need for conducting training and clarification of the provisions in the applicable road traffic law. The introduction of new technical devices for determining the distance, in extreme situations, does not eliminate the danger of colliding with the preceding vehicle. In this respect, the regulations are imprecise, and the lack of knowledge of drivers is huge. The proposed actions relate to the area of active safety system of vehicles in road traffic.

Keywords: vehicle operation, distance between vehicles, active safety

1 Introduction

Road transport is an area where car use plays an important role. Citizens of European Union (EU) Member States have unrestricted opportunities to cross the Union’s borders. The security system was based on the regulations contained in the Road Traffic Act. The laws of the Member States in the field of road traffic are based on the Vienna Road Convention [3]. Their purpose is to eliminate the dangers that occur during the operation of motor vehicle rolling stock. The Polish Highway Code (Road Traffic Act) [7] contains precise and imprecise rules. Among others in art. 20 above of the Act, the permissible speed values were determined. A road participant driving a car has certain limit values that apply. Cars are obligatorily equipped with speed meters. It is a measure of physical size that allows it to measure and read speed values at any time and thus assess the state in which it is located. It is clear and precise for all road users and controlling bodies.

But after delving into the provisions of the Highway Code, in some cases they are often “only seemingly precise”. For example, in terms of the value of the distance between vehicles in motion, this is not so precise. In the Road Traffic Act, in art. 19 paragraph 2.3 it is written “The driver of the vehicle is obliged to maintain the distance necessary to avoid a collision in the event of braking or stopping the preceding vehicle.” Precise spacing values are given only for the selected specific case. In art. 19 paragraph 2.4 of the Act: in para. 4.1 and 2) it is written: “Outside the built-up area in tunnels exceeding 500 m in length, the driver is obliged to maintain a distance from the preceding vehicle no less than:

1) 50 m – if he drives a vehicle with a maximum permissible weight not exceeding 3.5 Mg or a bus;
2) 80 m – if he manages a vehicle combination or a vehicle not mentioned in point 1.”

In other situations, the driver does not have specific guidelines as to the values of the distance between other vehicles. In addition, there is no indication given as to how to determine the applicable value. Apart from this special case, the legislator does not indicate minimum values that would be clear and precise for everyone in other situations. This should be assessed as a major drawback to this legal act. The values of measures, as well as the measures enabling the assessment of compliance with correct behavior were also not indicated. This includes both drivers, drivers of cars and authorities controlling the correctness of road behavior. This causes a situation in which traffic participants may freely interpret this part of the equation. This applies to both the driver who maintains the necessary distance behind the vehicle preceding it and the driver who, by changing lanes, enters between these vehicles – Figure 1.

Car 3 entering the adjacent lane (Figure 1) into the lane between vehicles 1 and 2, eliminates (in certain situations) the minimum distance necessary in extreme moments during sudden braking. The driver of car 3 is usually unaware that such a maneuver causes a dangerous situation. In order for the driver of vehicle 1 to keep the minimum distance,
it must brake to increase the distance to $S_{\text{min}}$ behind vehicle 3 which has entered. This is a common situation when using vehicles in traffic. Drivers do not know what the correct minimum distance behind the previous vehicle is that they are required to keep. In addition, they cannot correctly determine the actual distance between vehicles.

In addition, motorists may not be aware of the effects in which “cutting off other vehicles” creates. This refers to a vehicle merging into a lane without leaving a proper distance between other vehicles. Drivers do not understand that by entering between two vehicles distant from each other by $S_{\text{min}}$, they create a very dangerous situation of increased risk of accident. Also, they do not know how the law regulates the issue of maintaining a minimum distance that does not cause offenses due to “cutting off other vehicles”. It is commonly observed that drivers of vehicles used in road traffic maintain distances that are too small between vehicles. Daily practice, and routine behavior “show that it is not dangerous.” Vehicles commonly drive like this every day and nothing bad usually happens. However, when sudden, violent braking occurs, the following cars will have a problem to stop in such a situation. Because this is not common, there is a perception that short distances are standard and are not the cause of a collision. Drivers get used to this wrong behavior.

The purpose of this research is to analyze, compare and evaluate the relevant selected provisions of the Vienna Convention on Road Traffic [3] and the Act of the Polish Sejm Law on Road Traffic [7] in terms of the correctness of the provision. In particular, the analysis and assessment concerns provisions obliging the driver to maintain a sufficient distance (distance) behind the preceding vehicle in road traffic. Among other things, it analyzed what results from applicable regulations. In addition, the goal is to analyze the possibility of determining the value of a sufficient distance (distance) for different speeds of vehicles in the stream by the driver of the car. The thesis is as follows: the provisions of law in the EU and the Member States, regarding the maintenance of a sufficient distance between moving vehicles, contain deficiencies that negatively affect the safety system of road users.

The scope of consideration of the examined legal acts includes two legal acts: the Vienna Convention [3] and the Act of the Republic of Poland [7], regarding road traffic. The research covered legal regulations contained in applicable regulations concerning traffic participants driving cars on public roads. The selected problem for analysis is the distance between vehicles in the traffic of EU Member States and thus the EU. It is an important element of the safety system of road users.

The subjects of the study are vehicle drivers, participating in traffic on public roads in EU countries and also, the applicable rules – regulations (which are part of the safety system) that regulate road traffic in EU member states. They were based on the Vienna Convention on Road Traffic. They should generate appropriate behavior of road users. The disclosure of any contradictions and irregularities will allow the introduction of changes to improve the road safety system. The scientific research method used in the analysis and assessment is based on deduction and induction, and on the analysis of mathematical and kinematic relationships describing the movement of vehicles moving in a stream one by one on a public road.

The available literature did not encounter any analyzes of national legal acts and the Vienna Convention in terms of assessing compliance and correctness in this respect. The authors [1, 6, 10] dealt with the “dilemma zone” resulting from the existence of the yellow signal and the dangers caused by it. The human factor – due to the mistakes made, has a decisive significance here – the authors discuss it in their works [2, 5, 11]. In general, ergonomics deals with the adaptation of: working conditions and features of technical facilities to human psychophysical features – what is shown in the works [4, 9, 12]. No publications were found that would show defects in records in the regulations of the assessed provisions.

The following questions can be formulated: can legal provisions contain unclear, vague, imprecise wording? If such formulations were included, should we accept or tolerate them? Are we obliged to eliminate them from existing legislation? Should imprecise or undefined legal provision be clarified or removed? Which level of irregularity is acceptable and which is not?

2 Stopping car route

The size $S_z$ (which is the length of the stopping distance of the vehicle - shown in Figure 2) consists of three factors:
1. size of $S_{rk}$ – distance traveled by the vehicle during the driver’s reaction without braking,
2. size of $S_{nh}$ – length of the distance traveled by the vehicle during the increase of braking force (from a force of 0 to the final value imposed by the driver),
3. size of $S_h$ – the distance traveled by the vehicle with the assumed full braking force.

The distance traveled during the driver’s response is a function of: reaction time (individual characteristic of each driver), vehicle speed values. The distance traveled during the build-up of braking force is a function of: the driver’s reaction type, the vehicle speed value, the individual characteristics of each car’s braking system and the technical condition of the car. The distance traveled during braking of the vehicle is a function of: the coefficient of friction of the tire - road system (also depends on the condition of the tire, road surface and weather conditions) and the speed of the car.

Assuming selected states during vehicle operation, it is possible to determine the approximate values of individual components of the stopping distance [8]. Calculations of stopping distance (1) and decelerations (2) were made according to the following relationship for a simplified “trapezoidal” time course of braking deceleration:

$$S_z = S_{rk} + S_{nh} + S_h = V_p \cdot t_{rk} + V_p \cdot \frac{t_{nh}}{2} + \frac{V_p^2}{a \cdot 2} \quad (1)$$

$$a = \frac{V_p^2}{(S_z - S_{rk} - S_{nh}) \cdot 2} = \frac{V_p^2}{(S_z - V_p \cdot t_{rk} - V_p \cdot \frac{t_{nh}}{2}) \cdot 2} \quad (2)$$

where:
- $S_z$ – car stop distance,
- $S_{rk}$ – distance traveled during the driver’s response,
- $S_{nh}$ – distance traveled during braking force build-up,
- $S_h$ – distance traveled “during braking” with a constant deceleration,
- $V_p$ – value of speed at the access to the intersection - permissible, determined by the regulation,
- $t_{rk}$ – driver response time,
- $t_{nh}$ – braking force rise time,
- $a$ – car braking permanent deceleration.

The output data for the calculations were the extreme values from the possible ranges of these quantities adopted for the analysis of the course of accidents. The upper range of the driver’s reaction time and the upper range of the braking force rise time were assumed. Good weather conditions were chosen to show example calculations. A speed range of 50 km/h to 140 km/h was selected. Table 1 presents the calculated values of quantities that are components of the stopping distance (for $\mu = 0.8, t_{rk} = 1.2 \text{ s}, t_{nh} = 0.4 \text{ s}$) depending on the speed of the car [8]. Figure 3 presents the idea of stopping cars. They are shifted in space by the length of the first car and the distance traveled during the reaction of the driver of the second. The lighting of the rear break light sends a signal to the following car. If the stopping for both vehicles is identical, it is enough that the stopping distance

<table>
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<tr>
<th>L.p.</th>
<th>Data assumed</th>
<th>Calculated</th>
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<tr>
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<td>$V_p$ [km/h]</td>
<td>$V_p$ [m/s]</td>
</tr>
<tr>
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</tr>
<tr>
<td>10.</td>
<td>140.0</td>
<td>38.89</td>
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of the following car will be shifted in phase by the value as above, so that there is no collision or accident.

In perfect conditions, the minimum distance between vehicles should be the value of the $S_{Rk}$ distance traveled during the driver's reaction. In real conditions this road value should be much higher. A sufficiently long section of the $SZAPAS$ road must be taken into account, taking into account the risk of an unforeseen situation. This sufficiently long road section must be determined taking into account the adopted safety factor $\eta$.

When observing drivers’ habits in road traffic, their behavior on the road in real conditions are different. There are three scenarios for keeping the distance behind the vehicle ahead.

### Three areas – scenarios, maintaining space between vehicles

The distance behind the preceding car – the distance between vehicles (in a stream during operation in road traffic) can be distinguished, divided into the following scenarios – Figure 4.

**First (I) range** value of length resulting from excessive carelessness - distance between vehicles too short: $S_{rzecz,poj} < S_{min,poj}$. Enormous risk, practically certainty of hovering over the vehicle ahead in an extreme situation, with sudden, surprising, sudden braking of the vehicle ahead.

**Second (II) range** value of length resulting from sufficient caution of the driver – adequate length value (optimal $S_{rzecz,poj} = S_{min,poj}$ – not too small, not too large) to avoid collision or an accident. This provides minimal risk of collision with the vehicle ahead during sudden braking.

**Third (III) range** value of length resulting from excessive caution of the driver – an excessively large value of the length, beyond the necessary, optimal: $S_{rzecz,poj} > S_{min,poj}$. Huge chance – close to certainty, not hitting the vehicle in an extreme situation with sudden, surprising, sudden braking. There is virtually no risk of colliding with the vehicle ahead.

The correct value of the length is influenced by: the driver’s reaction time, vehicle speed, the situation whether the preceding vehicle braking abruptly uses the full braking distance or stops earlier, hitting an obstacle, or if it slips, etc. In the following part the procedure for determining the distance behind by car, taking into account the safety factor $\eta$.

**Figure 4:** Qualitative distinction and location of vehicle location areas behind preceding, depending on the caution or carelessness which characterizes the driver.

S_I – space behind the vehicle ahead, car 1 - I area with great carelessness,
S_II – space behind the vehicle ahead, car 2 - II area of sufficient caution,
S_III – space behind the vehicle ahead, car 3 - III area of excessive caution

### 3 A proposal to determine the minimum distance value for the preceding one vehicle

Question: what and when is the appropriate distance between vehicles? This should be clearly specified, specified and indicated in applicable regulations. In addition, during driving courses, future drivers should be taught how to determine such distance practically while driving. In some EU countries, special markers are painted on the roadways that help and facilitate the determination and maintenance of the correct distance behind the vehicle in front. There
are already devices that can be used to measure the real distance of the vehicle ahead.

The value of the minimum distance behind the vehicle ahead depends on their actual speed. Figure 5 presents the diagram for determining in ideal conditions the theoretical distance between the car following the rapidly braking preceding car. The stopping distance of car 2 is shifted in phase by the value of the length of car 1. In addition, for the car following the stopping distance has been increased by the spare distance due to the risk of unpredictable situations. Its value depends on the adopted safety factor $\eta$.

$$S_{\text{min,pol}} = S_{rk} + S_{\text{zapas}}$$  \hfill (3)

$$\eta = \frac{S_{\text{min,pol}}}{S_{rk}}$$  \hfill (4)

**The concept of determining the distance according to the “Half speed rule”**

The minimum value of the distance between vehicles ($S_{\text{HSV R}}$) will be determined according to the following formula: the value of speed expressed in kilometers per hour (moving vehicles, one after the other) divided by two, and the numerical result determines the value of the distance behind the preceding vehicle – expressed in meters. The formal record for determining the minimum distance between vehicles according to the “Half Speed Rule” (HSV R) is as follows:

$$S_{\text{HSV R}} = \left(\frac{1}{2} V_p\right) \text{[m]}$$  \hfill (5)

where:

$V_p$ [km/h] – dimensionless value.

When determining the value of the minimum distance between vehicles in the stream, it was assumed that the vehicles preceding and following would be able to stop on the section corresponding to the minimum stopping distance $S_{\text{patrz,min}}$. The actual speed value, parameters of atmospheric conditions on the road and the use of full braking performance when the brake is pressed in the previous car, a stop light that comes on will send a signal to the driver of the following car.

Selected output parameters were adopted and calculations were carried out for them. To determine the distance $S_{\text{min,pol}}$, the calculated value of the distance traveled during the reaction of the controlling $S_{rk}$ was multiplied by the safety factor $\eta$. Its value $\eta = 1.5$ was arbitrarily adopted. In order to determine the correlation of the quantities determined in this way, the minimum distance value was also calculated according to the “Half Speed Value Rule” (HSV R). The results of calculations for selected parameters and their comparison are presented in Table 2.

<table>
<thead>
<tr>
<th>L.p.</th>
<th>$V_p$ [km/h]</th>
<th>$S_{rk}$ [m]</th>
<th>$\eta \cdot S_{rk}$ [m]</th>
<th>$S_{\text{HSV R}}$ [m]</th>
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<tbody>
<tr>
<td>1.</td>
<td>50.0</td>
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<td>70.0</td>
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<td>4.</td>
<td>80.0</td>
<td>26.67</td>
<td>40.01</td>
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<td>5.</td>
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<td>100.0</td>
<td>33.33</td>
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<td>7.</td>
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<td>36.67</td>
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<td>40.06</td>
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<td>9.</td>
<td>130.0</td>
<td>43.33</td>
<td>65.00</td>
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<tr>
<td>10.</td>
<td>140.0</td>
<td>46.67</td>
<td>70.01</td>
<td>70.0</td>
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</table>

The value of the distance ($S_{\text{min,pol}} = \eta \cdot S_{rk}$) between vehicles in the stream, calculated for the adopted safety factor $\eta = 1.5$ is practically the same as the distance value calculated according to the “Half speed rule” (HSV R). That is, as the quotient of the number expressing the value of the actual speed (in [km/h]) divided by 2 and expressed in [m].

The correlation between the values calculated in this way are very high and satisfying. The proposed method of determining the distance between cars using HSV R is simple, practical and relatively easy to use.
4 Proposed entry in the Highway Code, minimum values in force road users

The Road Code (Road Traffic Act [9]) should contain the minimum distance values that the driver should be required to keep behind the vehicle preceding him. The proposed formula for determining the minimum distance between vehicles according to the “Half Speed Value Rule” (HSVR) can be introduced into applicable regulations. One form of recording should be a tabular representation of the minimum distances depending on the speed of both vehicles. The second form of entry should be providing a generalized formula. This should be correlated with algorithms in car devices that support the driver in driving the car. An example is Adaptive Cruise Control (ACC) – a device supporting the driver in automatically maintaining the speed value and the necessary minimum distance behind the vehicle ahead. The correlation with algorithms for autonomous cars are also particularly important.

This procedure for determining the distance applies to vehicles of standard length driving in very good atmospheric conditions. In other conditions, this distance between vehicles should be increased. Irrespective of the provision of this rule in law, one should carry out a continuous campaign to popularize this knowledge in the mass media. In addition, it is necessary to teach drivers proper correct assessment in practice of distance, before distance meters for the preceding vehicle are commonly introduced in cars.

5 Analysis of test results

The minimum distance between vehicles, taking into account the safety factor \( \eta \), provides for road reserves resulting from the risk of extraordinary events that are difficult to predict. The value of the safety factor \( \eta \) is estimated by an expert method and adopted arbitrarily. The stopping distance of a vehicle takes into account the maximum time values: steering response and increase of braking force. There may be occasions when these values will be smaller. Then the stopping distance will be shorter. The pessimistic variant was adopted, i.e. if there are more favorable conditions there will only be a shorter stopping distance. For a short driver response time \( t_{dh} = 0.8 \) s and for the same other parameters, the safety factor will be \( \eta = 2.25 \). This confirms the favorable direction of changes for the optimistic variant.

In some countries, e.g. United States of America (USA), there is a three-second rule. It allows drivers to determine the distance behind the vehicle ahead at different values of actual speed without additional devices. At the same time, the legislator in a simplified way practically tells drivers how to determine a sufficiently large distance to avoid collisions or accidents in extreme situations. The distance determined by this simplified method is not precise. The distance determined in this way has a value much higher in relation to the permissible minimum value. The legislator assists the driver in being cautious by creating such a provision.

For example: for the actual value of the speed of 50 km/h, according to the “three second rule” the distance should be about 42 m. This significantly exceeds (by about 10 m) the value of the stopping distance of the car \( S_2 \) for this speed. It should be taken into account that the vehicle which brakes suddenly will also stop after traveling the length of the car stopping distance the stop. In addition, it is unrealistic to maintain such a designated distance in urban traffic.

Whereas the minimum distance \( S_{\text{min}} \), calculated according to the proposed “Rule of Half Speed Value” should be 25.0 m. It may also seem unusually large in relation to the habits of road users who every day ride practically “bumper to bumper”. However, for the assumed safety factor \( \eta \), it seems to be a reasonable compromise. The smaller the distance, the smaller the safety factor.

Mathematical formulas are based on theoretical patterns of the phenomenon. The method of analysis of the examined process in the case of the theoretical model is negligible. The inaccuracy of determining the distance may result from the inaccuracy of determining the speed of vehicles. The speed measurement error is small, negligible and compensated by entering a safety factor. The calculations were made taking into account three significant digits of the numbers on which the operations were performed. The results were also given as three significant figures. Such simplification is contained in so-called “engineering inaccuracy” and is acceptable. The calculations made were used to qualitatively assess the analyzed phenomenon. The adopted simplifications are sufficient to draw qualitative conclusions of the analyzed problem.

6 Summary and Conclusions

There is always a risk of collision or accident when using vehicles in traffic. The human factor of road users is decisive here. The correct formulation of traffic regulations has a great impact on the safety in the operation of cars.
The previous entries in the current legal acts regarding road traffic are in some cases imprecise, indefinite. This situation has a negative impact on the safety system of road users. Support with good rules that apply to car drivers is necessary. The lack of clear rules is very important for drivers who want to drive with sufficient distance behind the vehicle ahead and those changing lanes to enter the gap between these vehicles. Knowledge of clear, understandable rules in this situation is necessary.

The application of the proposed “Half Speed Value Rule” is a way to maintain sufficient and necessary distance between the following car and the vehicle preceding it. At the same time, it takes into account the need to maintain not excessively large and not excessively small distances, especially difficult to enforce in urban traffic. It imposes a clear and understandable restriction on a participant in the traffic behind another vehicle. Also for those who would like to enter from the adjacent lane in their opinion “such an excessive distance”. It will be an obvious offense of driving on the road.

The proposed rule covers standard length vehicles traveling in good weather conditions. When the road conditions are bad, or if the vehicle is longer than the standard length (e.g. well above 5 m), remember to increase this distance.

Painted markers on the road should be considered that would make it easier for drivers to determine the correct distance. Firstly, in places of special rank due to the increased dangers occurring there. In tunnels (due to increased danger) such markers should be painted first.

References

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