ANALYSIS OF THE INFLUENCE OF PERCEPTION TIME ON STOPPING DISTANCE FROM THE ANGLE OF PSYCHOPHYSICAL FACTORS

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Summary

The course of the braking process is critical for the safety of road traffic. The importance of all the factors that can affect the vehicle stopping distance becomes particularly conspicuous in critical situations. The braking process may be analysed in terms of its mechanics, especially the contact forces and the dynamics of the working parts of the braking system; on the other hand, it may also be examined from the point of view of psychophysical factors. The latter aspect begins to be noticed when the stress-induced factors caused by activities of military nature are taken into account. In the article, the authors have analysed the factors that affect the driver's perception time and the impact of this time on the vehicle braking distance as a function of vehicle speed. Analytical calculation results have also been presented to illustrate the relationships governing this process and to show the influence of changes in the stopping time on the vehicle stopping distance. In consideration of special vehicles used in military missions, some additional factors that might affect the time of risk have been highlighted. The said factors have been tabulated in accordance with the hierarchy of their occurrence. Some discrepancies noticed in the literature data published over the years and concerning the stopping time have also been pointed out.

Keywords: braking, stopping distance, braking distance, psychophysical factors, reaction time, perception time, military vehicles

1. The course and effectiveness of the process of rectilinear braking

The vehicle braking efficiency is usually measured by the length of the distance travelled by the vehicle from the emerging of an obstacle to the instant when the vehicle is stopped or

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by the average deceleration developed during the braking process. The braking efficiency depends on three major factors [1, 13, 15, 18, 19]:

- psychical and physical features of the driver;
- design characteristics and performance of the vehicle braking system;
- tyre-to-road adhesion coefficient.

At an assumption that the driver is able to press the brake pedal with a force that would cause the vehicle wheels to be locked up, the length of the distance necessary for a motor vehicle to stop depends, on the one hand, on the values of the maximum tangential forces that can develop between the vehicle tyres and the road surface (chiefly depending on the physical properties of the tyres and the road surface) and on the other hand, on the time elapsing from the emerging of an obstacle to the instant when the full braking force is developed by the braking system and this time depends on the driver (perception of the obstacle, making of a decision to start the braking process) [2, 4, 13, 15, 19]. The vehicle stopping time consists of the following parts, according to [15]:

- perception time t_{r1}, i.e. the time from the emerging of an obstacle within driver's field of vision to the instant when the driver's sight becomes fully acute and the obstacle is recognized;
- principal psychical reaction time t_{r2}, i.e. the time covering the period that is related to recognizing the situation, making a decision on the type of the manoeuvre to be performed (to avoid the obstacle, to apply brakes, etc.), and starting the actions aimed at performing the manoeuvre chosen (beginning of foot relocation from the accelerator pedal to the brake pedal); this time depends on the functioning of driver's central nervous system (brain, spinal cord), which sends appropriately processed stimuli through nerve fibres and the peripheral nervous system to effectors (muscular tissues);
- foot relocation time t_{r3}, i.e. the time from the start of releasing the accelerator pedal to the instant of putting the foot onto the brake pedal (motor reaction);
- brake response time t_0, i.e. the time from the instant of putting the foot onto the brake pedal to the appearance of a braking force;
- deceleration rise time t_n, i.e. the time from the appearance of a braking force to the instant when the braking deceleration value reaches the level desired by the driver or the level determined by the lockup of wheels or by the operation of the vehicle ABS system;
- time t_h of full braking, i.e. the time from the desired braking force value being achieved to the instant of the vehicle being stopped.

In graphical form, the structure of the vehicle stopping time has been shown in Fig. 1.

The time elapsing from the emerging of an obstacle to the releasing of the accelerator pedal, taken in aggregate, is referred to as the psychical reaction time. If the time needed to move the foot from the accelerator pedal to the brake pedal (foot relocation time), i.e. the motor reaction time (t_{r3}), is added to it, then the sum is referred to as driver's psychomotor reaction time ($t_r = t_{r1} + t_{r2} + t_{r3}$); during this period, the vehicle speed remains approximately

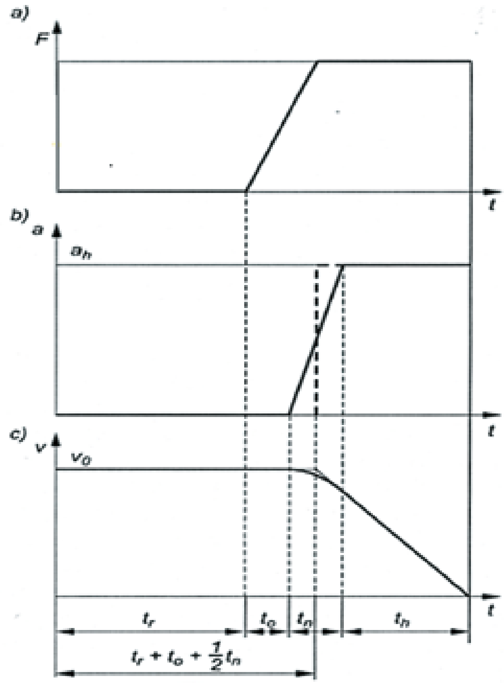

Fig. 1. Simplified time history of the vehicle stopping process: a) brake pedal force; b) braking deceleration; c) vehicle speed [15]

equal to the one with which the vehicle moved when the driver made a decision to apply brakes. The braking process as such actually begins after the end of this period.

For the purposes of the simulation and experimental tests carried out by a team headed by Prof. Stańczyk, a concept of "risk time"[3] was adopted. The risk time was defined as the time available to the driver between noticing and possible hitting an obstacle. It is utilized by the driver for carrying out manoeuvres aimed at avoiding a collision or, at least, reducing the collision effects. The risk time, utilized by the driver for defensive actions, was calculated as the ratio of the distance between the vehicle and the obstacle to the vehicle speed at the instant when the accident hazard emerged [8].

Experimental determination of the time intervals mentioned above is considered difficult because they depend on multitude of factors and the psychomotor reaction time of individual drivers may vary within a wide range, which is illustrated by the data given in Table 1.

The information about the safety level ensured by critical vehicle component systems often happens to be incomplete. As an example, the psychomotor reaction time is not taken

[3] Subsequently, this notion was termed TTC ("time-to-collision"). Translator's note.

Table 1. Values of the time intervals important for the course of the vehicle stopping process [15]

	Driver's psychomotor reaction time t_r			Time related to the functioning of the braking system	
	Psychical reaction		Motor reaction		
	Perception time t_{r1} [s]	Principal psychical reaction time t_{r2} [s]	Foot relocation time t_{r3} [s]	Brake response time t_0 [s]	Braking deceleration rise time t_n [s]
Average value	0,48	0,45	0,19	0,05	0,17
Lower limit of the confidence interval (2 %)	0,32	0,22	0,15	0,03	0,14
Upper limit of the confidence interval (98 %)	0,55	0,58	0,21	0,06	0,18

into account in the analysis of results of braking process examination within experimental tests carried out in compliance with UN ECE Regulation No. 13. In this case, the examination leads to "pure" evaluation of the effectiveness of operation of the braking system.

As regards the analysis of driver's reaction time in pre-accident situations, special attention is deserved by the Polish research works done in the recent years [6, 7, 8]. Based on the research carried out, a correlation was shown to exist between the reaction time values obtained in virtual and real conditions, although the reaction time values recorded during experiments on a testing track were found to be significantly higher. However, attention should be paid to the findings related to comparisons between the reaction time values obtained on the testing track, motor vehicle driving simulator, and simple devices used for psycho-technical tests. The results obtained from tests on simple psycho-technical test devices were found to show no correlation with those obtained from experiments on the testing track or driving simulator. This proves that the reaction time measured on simple psycho-technical test devices cannot be treated as the actual time of driver's reaction in real road traffic situations and should not be used for the reconstruction of road accidents [8].

Table 2. Brake response time, according to literature data [2, 13, 15, 16, 17, 18, 19]

Source	Brake response time [s]		
	Hydraulic actuating system	Pneumatic actuating system	Electro-pneumatic operating system
S. Arczyński	0.3	0.5	
T. Wrzesiński	0.1–0.3		
A. Reński	0.05		
K. Studziński	0.02–0.05	0.2–0.5	
L. Prochowski, J. Unarski, W. Wach	0.15–0.3	0.3–0.5	0.15–0.35

As regards the dynamics of operation of the braking system, an analysis of the data available from the reference literature of Polish origin, summarized in Table 2, reveals considerable differences in the data ranges having been specified. Such data adopted for analytical methods may lead to significant discrepancies in the results obtained.

2. Psychophysical factors important for the braking process

From the point of view of road traffic safety, the impact of the factors influencing the driver to such an extent that they induce changes in driver's behaviour must be taken into account. Before the braking process is initiated, the vehicle covers quite a long stretch of the road. A significant role is played in this case by the vehicle driver's reaction time. As mentioned previously, this time includes the perception time (t_{r1}), i.e. the time that elapses from the instant when the obstacle can be noticed to the instant when driver's central nervous system begins to respond. The perception time depends on the following:

- obstacle's position in relation to driver's line-of-sight (the obstacle is more difficult to be noticed if it emerges on the outskirts of the field of vision);
- obstacle's movement (a moving obstacle is easier to be noticed than a motionless one);
- obstacle's size and contrast against the background.

In some literature sources, the perception time is considered as integral with the time interval referred to as "reaction time". The reaction time depends on psychophysical characteristics of the driver. It gradually shortens and stabilizes, in result of training and the passage of time, when the driver gains basic experience; only from the end of this period, the length of this time may be said to depend on other factors, such as driver's age, experience, or psychophysical condition, type of the drive (e.g. prolonged monotonous drive causes the reaction time to grow longer), traffic situation and the element of surprise (when the vehicle approaches a crossroads or a pedestrian crossing, the reaction time is shorter than it is in the case of sudden emerging of an obstacle). The driver's reaction time may be considerably affected by difficult driving conditions, time of the day, noise, vibrations, ergonomic problems (e.g. incorrect arrangement of vehicle controls) [10, 12, 15, 18]. All these factors can cause the perception and reaction time to vary in quite a wide range. As an example, the reaction time may vary [18]:

- from 0.35 s to 1.2 s in the daytime and
- from 0.4 s to 1.8 s in the night.

For a specific single driver, the difference between the reaction time in the daytime and in the night is about 0.2 s; the lower and upper limits apply to about 2 % and about 98 % of the drivers' population, respectively. Moreover, the impact of variability of road situations on the lengthening of driver's reaction time is stronger for elder drivers. The reaction time markedly changes in drivers aged more than 40 (worsening of the eye's adaptation time, lowering of the sensitivity to external stimuli). The biggest changes take place in people 50 to 60 years old. When the driver is more than 75, the reaction time may lengthen even twice. These values additionally increase with growing tiredness or in consequence of alcohol consumption. Depending on physical features (e.g. the driver is tired or well rested), health condition (e.g. headache), complexity of the traffic situation (surprise caused by uniqueness of the situation), road type (town street, suburban road, motorway), daily rhythm, meteorological phenomena (changes in atmospheric pressure and ambient temperature), or the degree of concentration (e.g. prolonged noise in the vehicle cabin may cause the reaction time to be lengthened by more than 10 %), the total perception and reaction time may vary from 1 s even to 5 s. A decrease in vigilance manifests itself in weakening driver's perceptive ability: the driver's ability to notice an obstacle grows worse, which results in a delay in starting the appropriate manoeuvre in a hazardous situation [15, 18].

The time values taken for the calculations of the length of the vehicle stopping distance in the subsequent part of this article are the reaction time values estimated on the grounds of laboratory simulation tests. Most of such tests consist in measurements of the time of driver's reaction to a simple signal (e.g. measurements of the time elapsing from a red light getting on to the brake pedal being depressed), which means that the tests do not adequately represent the real conditions in which the driver is functioning when participating in road traffic. The reaction times thus measured are much shorter than they actually are; therefore, they should not be considered as fully reliable. The actual value of the reaction time cannot be accurately determined because of uniqueness of both a specific traffic situation and driver's condition.

Other factors that have a very important impact on the driver's reaction time include alcohol, narcotics, or psychotropic drugs.

3. Psychophysical factors arising from the uniqueness of military issues

Section 2 presents the factors that affect the driver's reaction time, especially the perception time. As it has been emphasized, these factors exert their impacts with different intensities, depending on individual features of driver's constitution and on his/her experience. In general, the influence of individual factors is limited by standards and regulations regarding the time of work, exposure to dynamic loads, noise, field of vision from vehicle interior, forces to be applied to vehicle controls, etc. Effective limitations are imposed by the requirement of type approval of individual vehicle systems and components, which results in standardization of critical vehicle parts.

Where the uniqueness of military issues has to be taken into consideration, the impact of psychophysical factors may be more intensive. If tasks of logistic and combat nature are to be performed, special vehicles or vehicles intended for special purposes must be used. The construction of such vehicles stems from the specific nature of the military tasks or works to be done. It is reasonable that military vehicle systems and components are not subject to the requirement of type approval because their construction is rigorously dictated by the functions to be fulfilled. In consequence, the vehicles being built significantly differ from each other in terms of their construction. It can be noticed that the diversification of the vehicle construction may result in space limitations inside the vehicle, darkening of the driver compartment, high values of the forces to be applied to vehicle controls, significant quantity of vehicle controls and indicators to be used or observed, limited field of vision (affected by the necessity of using optical instruments), raised noise level, excessive or insufficient temperature inside the vehicle interior), or vibrations of vehicle parts.

Apart from the construction of military vehicles, an increased impact of psychophysical factors may be caused by the nature of the tasks being done. The task-induced intensification of the impact of selected factors, depending on the tasks performed, has been presented in Table 3.

Table 3. Psychophysical factors arising from the military tasks being performed

Task type	Psychophysical factors	Remarks
Surveillance	Eye strain and central nervous system fatigue, raised or lowered temperature, high humidity	– Interior temperature ranging from 0 °C to 55 °C – Humidity exceeding 90 %
Patrolling	Noise, dynamic effects, general tiredness, electromagnetic radiation	– Noise exceeding 90 dBA – Dynamic effects within the range of nuisance
March	Noise, dynamic effects, general tiredness	– Noise exceeding 90 dBA – Dynamic effects within the range of nuisance
Dynamic off-road drive	Noise, dynamic loads, raised temperature	– Noise exceeding 90 dBA – Dynamic effects within the range of health loss – Temperature exceeding 40 °C
Combat mission	Noise, dynamic loads, raised temperature, unfavourable air composition in the vehicle interior, raised air pressure, electromagnetic radiation, extreme stress	– Noise exceeding 100 dBA – Dynamic effects within the range of health loss – Temperature exceeding 40 °C – Gunpowder gases and raised CO_2 concentration inside the driver compartment

4. Research on the stopping distance from the instant of driver's reaction

For the impact of psychophysical factors to be visualized, analytical research was undertaken. The objective of the research work was to determine and analyse the vehicle braking distance from the instant of first driver's reaction to the instant of the vehicle being stopped, with taking into account driver's reaction time, brake response time, braking deceleration rise time, and braking deceleration value, based on literature data [4, 5, 13, 15, 18, 19], with the following parameters being introduced as variables:

– driver's perception time (t_{r1});

- vehicle speed at the instant when the driver made a decision to apply brakes (v_0);
- tyre-to-road adhesion coefficient (μ).

The length of the vehicle stopping distance was calculated with the use of an equation where the total time t_R ($t_R = t_r + t_0$) of driver's reaction and vehicle response was divided into driver's perception time t_{r1}, driver's psychical reaction time t_{r2}, foot relocation time t_{r3} (time of moving the foot from the accelerator pedal to the brake pedal), and brake response time t_0. Thus, the said equation will take the form as follows:

$$S_z = v_0(t_0 + t_{r1} + t_{r2} + t_{r3} + \frac{t_n}{2}) + \frac{v_0^2}{2a_h}$$

where: S_z – length of the vehicle stopping distance; t_{r1} – perception time; t_{r2} – principal psychical reaction time; t_{r3} – foot relocation time; t_n – braking deceleration rise time; t_0 – brake response time; v_0 – initial vehicle speed; a_h – braking deceleration.

The stopping distance S_z is the sum of reaction distance S_R and braking distance S_H. The reaction distance S_R is the distance travelled by the vehicle from the instant when the obstacle was noticed to the instant when the vehicle brakes were applied; the braking distance S_H is the distance travelled by the vehicle from the instant when the vehicle brakes were applied to the instant when the vehicle stopped.

The length of the stopping distance was examined for selected vehicle drive speed values within a range from 50 km/h to 130 km/h in 10 km/h intervals. For the purposes of the analysis, the perception time was assumed as varying from 0.32 s to 0.82 s in 0.05 s intervals. For the other times, the average values (Table 4) were assumed for the calculations. It should be stressed here that for pneumatic braking systems, the brake response time is about 0.6 s and it is almost twice as long as that of hydraulic braking systems. For the calculations, the value of this time was assumed as t_0 = 0.05 s. The calculation trials were carried out for dry asphalt road surface (i.e. with assuming μ = 0.6 and a_h = 6 m/s^2). The analysis also includes a comparison of the stopping distance values calculated for different road surface types at statistical average values of the driver's reaction time and brake response time and for different values of vehicle drive speed.

Table 4. Time values adopted

	t_{r1}	t_{r2}	t_{r3}	t_0	t_n
	Perception time [s]	**Principal psychical reaction time [s]**	**Foot relocation time [s]**	**Brake response time [s]**	**Braking deceleration rise time [s]**
Lower limit	0.32	–	–	–	–
Upper limit	0.82	–	–	–	–
Average value	**0.42**	**0.45**	**0.19**	**0.045**	**0.17**

5. Calculation results and discussion

The results of calculations of the influence of driver's perception time t_{r1} on the length of the vehicle stopping distance, depending on the vehicle drive speed v_0 at the instant when the obstacle was noticed and on the braking deceleration a_h, have been illustrated in Fig. 2.

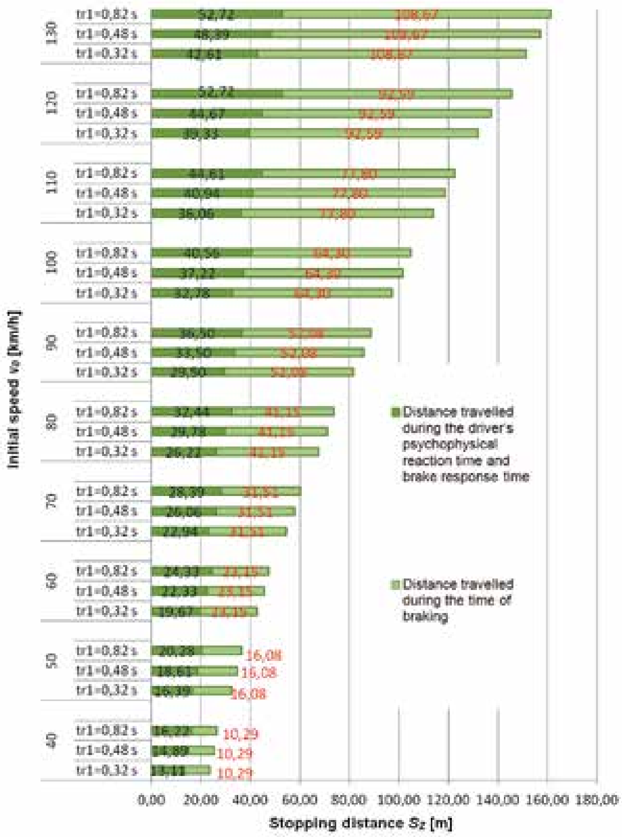

Fig. 2. Changes in the length of vehicle stopping distance depending on vehicle speed v_0 for different values of the perception time (i.e. for t_{r1} = 0.32 s, t_{r1} = 0.48 s, and t_{r1} = 0.82 s), at a_h = 6 m/s² [9]

The graph shows the lengths of vehicle stopping distance S_z for different values of the vehicle speed v_0 and for three different perception time values that are statistically possible, i.e. the minimum, average, and maximum of those subjected to the analysis (i.e. 0.32 s, 0.48 s, and 0.82 s, respectively). The higher the speed v_0 and the longer the time t_{r1}, the longer the vehicle stopping distance S_z, with this being applicable to the distance travelled both during the driver's psychophysical reaction time and brake response time and during the time of actual vehicle braking. The calculations of the braking distance S_H for the vehicle speed of 100 km/h confirm the literature data, i.e. for a motor truck with a pneumatic braking system and drum brakes, the braking distance length S_H is about 65 m.

Fig. 3 shows the influence of changes in the perception time (from 0.32 s to 0.82 s, in 0.05 s intervals) on the length of the stopping distance, for a single value of the initial vehicle speed (of v_0 = 40 km/h in this example).

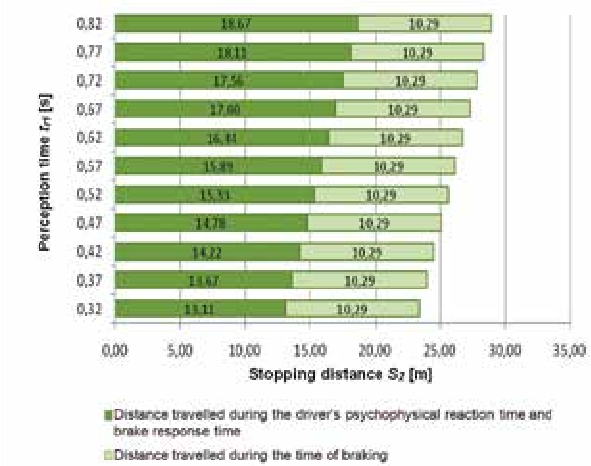

Fig. 3. Relation between the length of vehicle stopping distance and changes in the driver's perception time, for a single combination of the initial vehicle speed and braking acceleration, i.e. v_0 = 40 km/h and a_h = 6 m/s², respectively [9]

It can be noticed that for the braking deceleration and initial vehicle speed being constant, the length of the stopping distance increases with rising driver's reaction time, while the length of the distance travelled during actual operation of brakes to the instant of the vehicle being stopped remains constant (in this case, S_H = 10.29 m for v_0 = 40 km/h and a_h = 6 m/s²). Noteworthy is the significant impact of the increase in the psychophysical reaction time on the growth in the stopping distance, while the distance travelled during the time of actual braking remains unchanged regardless of changes in time t_r. The significant impact of driver's reaction time on the length of the stopping distance has been confirmed by research works [4, 5, 12], which have shown that the length of the stopping distance is most susceptible to changes in the driver's reaction time.

At a vehicle speed of 40 km/h, an increase in the perception time by 0.5 s results in a growth in the stopping distance length by 5.58 m, i.e. by 30 % of the distance travelled during the reaction time (S_R). At speeds of 60 km/h and 100 km/h, this growth is 8.33 m and 13.89 m, respectively, i.e. again 30 % of the distance travelled during the reaction time (S_R) in each case (see Figs. 4 and 5). At each initial vehicle speed value under analysis, the difference between the stopping distance length determined for t_{r1} = 0.82 s and that for t_{r1} = 0.32 s, for both the maximum and minimum driver's reaction time, increases with rising initial vehicle speed. In percentage terms, however, the growths in the distance travelled during the reaction time (S_R) remain at a constant level of about 30 % (at a perception time of t_{r1} = 0.48 s, on average, and a constant braking deceleration of a_h = 6 m/s²). A conclusion may be drawn, therefore, that any difference in the driver's reaction time will result in a growth in the distance travelled during the reaction time by a specific percentage figure regardless of the initial vehicle speed.

Fig. 4 shows the relation between vehicle stopping distance S_z and initial vehicle speed v_0 at a constant average driver's perception time (t_{r1} = 0.48 s) and a constant deceleration (a_h = 6 m/s²). For higher values of the initial speed v_0, in spite of constant driver's reaction time and constant value of the braking deceleration, the length of the vehicle stopping distance rises as well, due to a growth in both the length of the distance travelled during the time of psychophysical reaction of the driver and the length of the braking distance proper. However, the increment in the length of the distance S_R travelled during the driver's reaction time and vehicle response time associated with the growth in the initial vehicle speed remains constant, i.e. 3.69 m in this case.

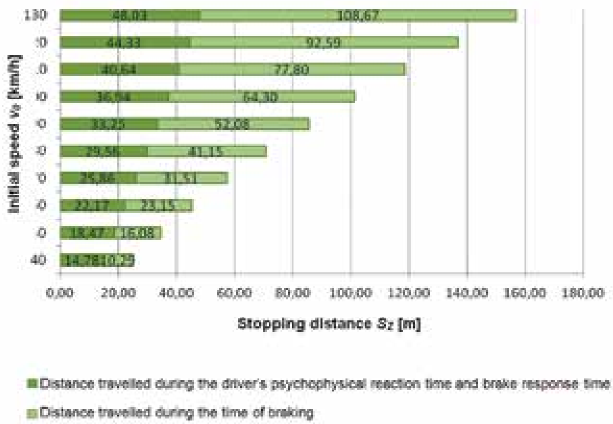

Fig. 4. Relation between the length of vehicle stopping distance and initial vehicle speed v_0 at a constant average driver's perception time and a constant deceleration [9]

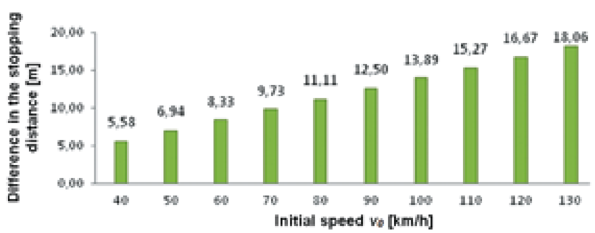

Fig. 5. Differences [m] between the lengths of the stopping distance determined for the driver's perception time values of t_{r1} = 0.82 s and t_{r1} = 0.32 s [9]

Fig. 6 shows the relation between the length of the stopping distance S_z and the initial vehicle speed v_0 and braking deceleration a_h (on different road surface types).

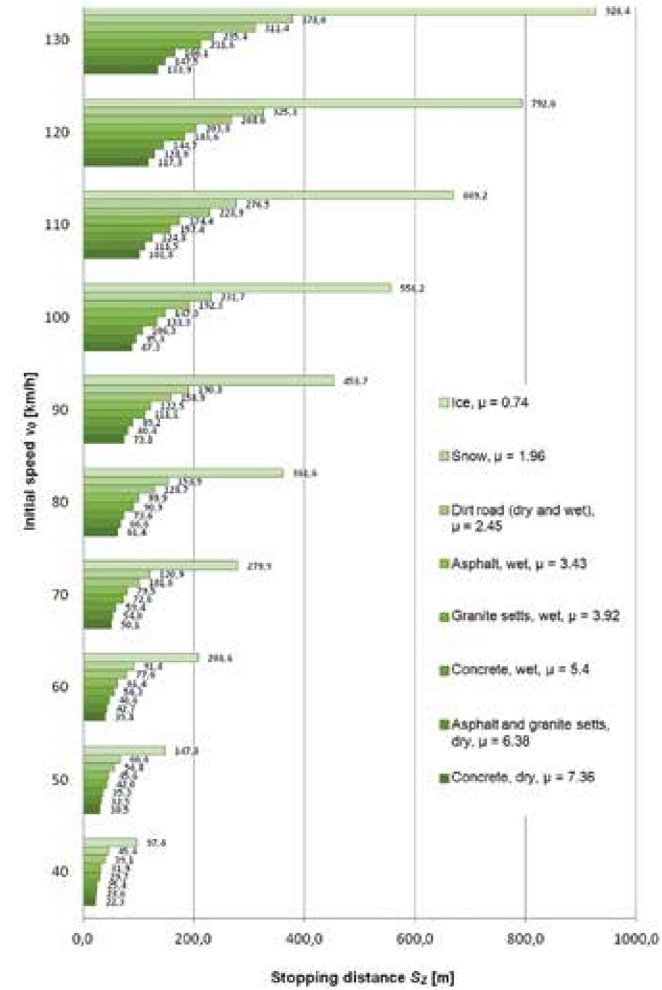

Fig. 6. Vehicle stopping distance vs. initial vehicle speed v_0 and braking deceleration a_h (for the values of t_r, t_n, and t_0 being constant and equal to the average values) [9]

Unfavourable road conditions combined with lower coefficient of adhesion and excessive vehicle speed lead to significant lengthening of the total stopping distance S_z. At a speed of 40 km/h, the length of the stopping distance on the icy road (97.4 m) exceeds that on the dry asphalt road surface (23.6 m) by about 73 m. For v_0 = 130 km/h (S_z = 926.4 m on the icy road and S_z = 147.5 m on the dry asphalt road surface), this difference is 778.9 m. It should be stressed, moreover, that the value of the coefficient of adhesion depends on vehicle speed.

Fig. 7 illustrates the percentage lengthening of the stopping distance in result of a growth in the perception time from 0.32 s to 0.82 s.

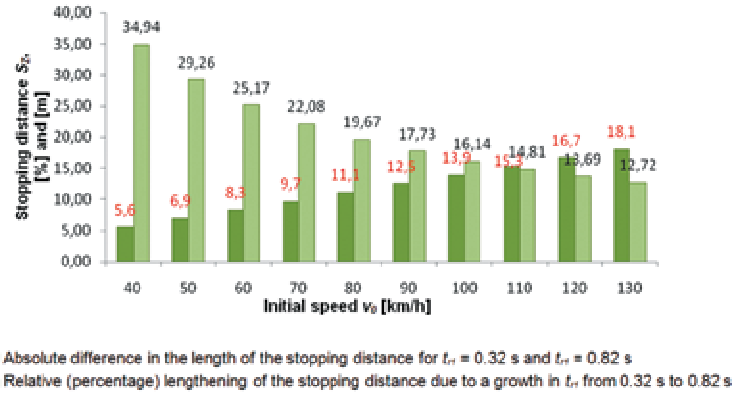

Fig. 7. Relative [%] and absolute [m] lengthening of the stopping distance due to a growth in the perception time from t_{r1} = 0.32 s to t_{r1} = 0.82 s

If the perception time rises from 0.32 s to 0.82 s then the stopping distance from an initial vehicle speed of 40 km/h becomes longer by 5.6 m, i.e. by almost 35 % of the total stopping distance ($S_{z,\ 0.32\ s}$ = 13.84 m and $S_{z,\ 0.82\ s}$ = 19.4 m). At a speed of 130 km/h, the same growth in the perception time lengthens the stopping distance by about 18 m (almost 13% of the total stopping distance ($S_{z,\ 0.32\ s}$ = 120 m and $S_{z,\ 0.82\ s}$ = 138.3 m). With increasing initial speed, the percentage lengthening of the stopping distance resulting from the growth in the perception time decreases, which has been illustrated in Fig. 7; in absolute terms, however, the stopping distance increases with growing initial vehicle speed, proportionally to the square of the speed.

Fig. 8 shows the length of the stopping distance from a selected speed (40 km/h in this case), depending on the reaction time and braking deceleration (total driver's reaction and vehicle response time t_R = 1.0 s and t_R = 1.2 s, braking deceleration a_h = 3 m/s^2 and a_h = 6 m/s^2). The stopping distance is shown in the graph as the point of intersection of the vehicle speed curve with the axis of abscissae. I can be clearly seen that a growth in the reaction time by 0.2 s, with the initial vehicle speed being unchanged, will result in the fact that the vehicle will travel an additional distance of 2.2 m before the braking system begins to operate and the total stopping distance will be lengthened by the same distance. On the other hand, a change in the road surface type and in the tyre-to-road adhesion coefficient will not cause any lengthening of the distance travelled during the time of driver's reaction and brake response, but the actual braking distance S_H will change (i.e. it will be longer by 10.3 m if the time value of t_R = 1.0 s remains unchanged).

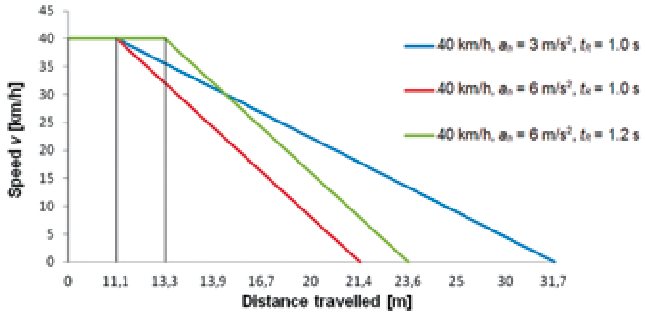

Fig. 8. Stopping distance at an initial speed of 40 km/h, depending on the reaction time and braking deceleration [9]

The calculation results indicate how strong impact is exerted by a change in driver's reaction time (or any of its components), initial vehicle speed before braking, or change in the road surface on the total vehicle stopping distance at emergency braking. The calculations represent idealized conditions (the braking process hardly ever is exclusively rectilinear) and they were carried out with assuming averaged values of the driver's reaction and brake response time. The considerable impact of psychophysical driver's condition, type and condition of the vehicle braking system and the vehicle as a whole, and environmental conditions on these parameters should be remembered. The statistical average reaction time of a well-rested and healthy driver is more than twice as long as the brake response time. Alcohol and narcotics, tiredness, sleep deficiency, nervousness, prolonged noise, telephone conversation, and advanced age have a significant impact on the lengthening of individual components of driver's reaction time and, in consequence, on the lengthening of the stopping distance. The stopping distance may become particularly long in the case of cumulation of unfavourable changes in the variables that can affect the stopping distance length.

6. Recapitulation

When analysing the length of the vehicle stopping distance from the instant of first driver's reaction, we may state that the braking process is significantly affected by driver-dependent parameters, vehicle type and its technical condition, type and condition of the surface on which the vehicle is driven, and vehicle speed.

The initial vehicle speed v_0 has a substantial impact on the lengthening of the braking distance. At similar braking deceleration values, the stopping distance length rises with the vehicle driving speed. At similar values of the initial vehicle speed, changes in the road surface type and the tyre-to-road adhesion coefficient do not affect the length of the distance travelled during the driver's reaction time; only the length of the actual braking distance S_H is subject to changes. The braking system type affects the braking distance:

the time of response of a pneumatic braking system is about 0.6 s and is almost twice as long as that of a hydraulic braking system, in result of which vehicles with hydraulic brakes offer shorter stopping distance lengths than vehicles with compressed-air brakes do; the stopping distance lengths of vehicles with EBS (electronic braking systems) are even shorter. While the braking system response time and the braking deceleration rise time for braking systems in good working order fall within specific limits, the driver's psychophysical reaction time is hardly predictable.

In the case of driving military vehicles, the psychophysical factors and the driver's reaction time have a significant impact on the stopping distance length. This impact is dramatically higher than it is in the case of other vehicles because of much wider range and levels of the factors that affect the psychophysical condition of the driver. For this reason, elimination of the impact of psychophysical factors by specialized training is a matter of great importance for the safety of vehicle crews. The exploration of the impact of individual factors on the driver's reaction time in combat hazard situations, carried out by experimental tests, should be a task of top priority.

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