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Original scientific paper

# The impact of trailer active safety system on improving the safety of transport of dangerous goods

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*Abstract* – **The intense technological growth results in the increase of demands for mobility of dangerous goods, mostly carried on the roads. The regulations that define the Transport of Dangerous Goods, give special emphasis to the mandatory equipment that must be installed (electronic suspension and braking systems) as well as its mandatory control of technical correctness. The efficiency of the braking system as well as the vehicle suspension system significantly affects the length of the stopping distance when moving through populated areas, moving at night or in heavy traffic and is of great importance in relation to the overall traffic safety. Proper technical control of vehicles with built-in electronic systems, includes well-trained workers, quality diagnostic equipment and the necessary awareness of transport participants about the importance of technical correctness of vehicles. All these factors and the impact of correctness of the braking and suspension systems on the vehicle safety are analysed in this paper.**

*Keywords* – **Technical requirements for vehicles, transport of dangerous goods, ADR.**

## I. Introduction

Requirements for increased safety for dangerous goods transport are regulated by European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), which regulates set of unique conditions for dangerous goods transport in 50 countries.

In this paper, means for inspection of technical correctness of suspension and breaking system are shown and impact of tire pressure is explained. Also in this paper, explanation is given about tire load according to international and national laws, with goal of increasing transport safety and efficiency.

Having reliable and robust breaking system is of highest priority especially in modern times. Efficiency of breaking system i.e. stopping distance when moving through populated areas, at night or in heavy traffic is of great importance in relation to overall traffic safety.

Braking characteristics are based on two important assumptions (2):

- Instant increase of the slowdown to the maximum or required value;
- The distribution of braking forces across the axles, allowing full use of available traction.

The first assumption is almost impossible to achieve because there is always the reaction time (reaction of the driver), while the second assumption, on vehicles with electronically controlled systems, can be achieved.

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Braking diagram, shows the dependence of deceleration and braking force (force on the master brake cylinder) in the time cycle, Fig. 1 (real brake diagram and simplified diagram).

These diagrams clearly show the increase in deceleration depending on the change in force on the vehicle's master brake cylinder over time.

The process of braking with complete vehicle based on such diagrams can be divided into time intervals in which the changes in the braking forces are linear. The durations of these time intervals are denoted by $t_1$, $t_2$, $t_3$, $t_4$, $t_5$ and $t_6$.

Time interval $t_{ak}$ is the time of active braking ($t_{ak} = t_4 + t_5$), while $t_u$ is the total time that passed until the vehicle stops ($t_u = t_1 + t_2 + t_4 + t_5$).

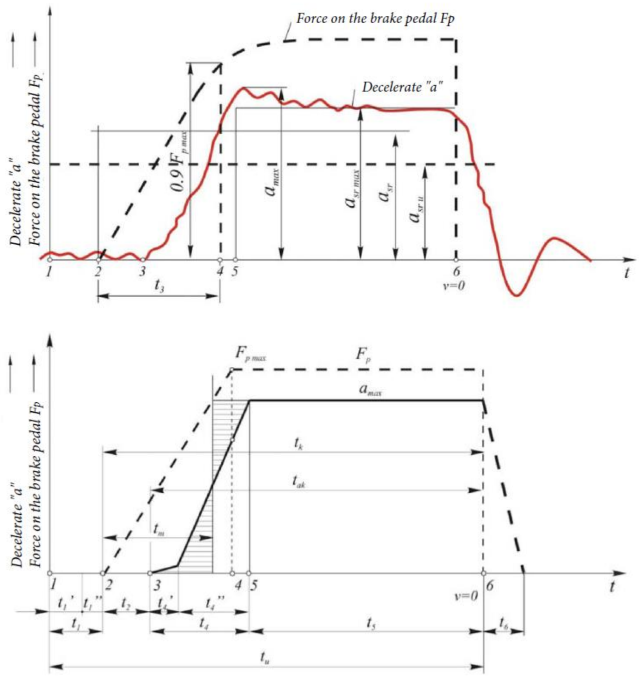



Fig. 1 Real brake diagram acquired from measurement and simplified breaking diagram (theoretical).

If the active braking time is added to the response time of the braking system $t_2$, the actual braking time $t_k = t_{ak} + t_2$ is obtained.

In the case of a vehicle where we have a trailer, and if the adjustment time of the trailer and towing vehicle is $\Delta t_1 = 0{,}6s$ and when the trailer braking precedes the braking of the towing vehicle, the stopping distance is longer by 11 - 14% than the stopping distance corresponding to if the towing vehicle's braking would precede that of the trailer.

The smallest stopping distance when stopping a complete vehicle is achieved only when the adjustment period of the braking system of both the towing and trailer vehicle equals 0

($t_1 = t_2 = 0$), and when there is the maximum utilization of the grip in the contact surface - tire, which is the case with the complete vehicle equipped with electronically controlled braking systems.

The adjustment of the towing vehicle and the trailer (1) is also defined in Regulation ECE R13, Directive 71/320, Section 8.5.2.1.28.5. The length of the stopping distance, as well as the stability of the complete vehicle when braking, depends on the degree of adjustment of the towing vehicle and the trailer. With the well-adjusted towing vehicle and trailer, the dependence of braking force from load or the deceleration angle of the towing vehicle and trailer is constant. For towing vehicles the force on the trailer coupler is equal to 0, and for the connection of the semi-trailer to the towing vehicle, the ratio of horizontal and vertical forces in the connection itself corresponds to the deceleration angle.

From the total rolling resistance and observing our concept shown on Fig. 2 on which we will base all our further tests it is experimentally shown (tests conducted by Goodyear Company) that 17% of the total rolling resistance goes to the front wheels of the towing vehicle, 33% to the driving wheels towing vehicle and 50% of the total resistance is the tire resistance on the semi-trailer, at speed of 80 km / h.

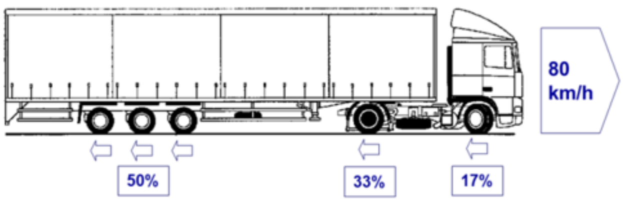



Fig. 2 Rolling resistance percentage on one set of vehicles.

Rolling resistance is also significantly influenced by wheel orientation as one of the most important safety parameters on a vehicle that needs to be checked periodically.

Abovementioned 50% of the total rolling resistance related to the rolling resistance of the trailer tires draws attention to the importance of the tires on the braking process itself. One-third of the fuel consumption of commercial vehicles is due to rolling resistance. This means that of the total fuel consumption, approximately 12 l / 100 km is due to tires. Tire pressure is defined based on the axle load, all depending on the tire manufacturer's recommendation, type of mounting (drive axle, control axle or semi-trailer axle) and tire size.

Vehicle stability depends on the concept of the suspension system. The HALDEX test results indicate that the stability of the vehicle should be such that the lateral acceleration at which the vehicle reaches the tipping point is not less than $4m/s^2$, in accordance with ECE Regulation R 111.

Research from the DAF vehicle manufacturer's company has shown that with improper suspension systems, traction can be reduced by up to 20%.

## II. Research Results

Testing on the brake rollers can only provide rough information of the actual braking performance of the vehicle, i.e. of the quality of the brake system (2). The technical solution of the brake test rollers does not allow for real grip conditions, low speeds of movement (the test is performed at a speed of rollers corresponding to a speed of $3-8\ km\ /\ h$, unrealistic alignment of the wheels on the substrate (they lie on circular surfaces, of relatively small diameter, which creates the effects of "jamming" the brake wheel between the rollers on which it rests.) However, for a very simple procedure, such tests are suitable for technical checks and for this level of required information.

In this part of paper efficiency of breaking system will be addressed. One of the conditions that complete vehicle has to fulfill is the correct axle load, i.e. proper load distribution across the axles of the complete vehicle (3) (5). Article 21 of the Regulations stipulates that the axle load of a vehicle must not exceed the values declared by the manufacturer and indicated on the vehicle identification plate.

Also, Article 41 of the Regulations defines the assessment of the braking performance of a vehicle through the braking coefficient:

- Braking coefficient indicates the percentage of vehicle deceleration and gravitational acceleration. For the purposes of this regulation, it is adopted that the acceleration of the earth's gravity is $9{,}81m\ /\ s^{2}$.
- The vehicle braking coefficient is calculated as the ratio of the sum of all the forces generated during the measurement on the measuring device and the total mass of the vehicle multiplied by $9{,}81\ m\ /\ s^{2}$ and is expressed in percentages.
- The prescribed minimum values of the brake coefficient listed in Table I must be achieved by the action of a force on the brake system which shall not exceed the prescribed actuating force given in the same table.

TABLE I
REQUIRED MINIMUM VALUES OF BRAKE COEFFICIENT BY VEHICLE CATEGORY AND TYPE OF BRAKING

| TYPE OF VEHICLE | FOOT BRAKING | | |
|---|---|---|---|
| | Braking coefficient | Activation force | |
| | | Foot actuated | Hand actuated |
| | $K_r \geq [\%]$ | $F \leq [daN]$ | $F \leq [daN]$ |
| L | 40 | 50 | 20 |
| M1 | 50 | 50 | - |
| M2, M3 | 50 | 70 | - |
| N | 45 | 70 | - |
| O | 40 | $PK = 6{,}5bar*$ | - |
| T, C, $K_{5a}$ | 25 | 60 | 40 |
| R, $K_{5b}$ | 25 | - | - |

The maximum permissible difference between the braking forces braking on wheels on the same axle, at any given time from the time when the first braking force reaches one third of its maximum value, by the time the maximum braking forces are reached on both wheels is 30%. The basis for calculating the percentage of difference in braking force on wheels on the same axle, at all times, is the higher braking force at that moment. Non-uniformity of brake force per revolution of the wheel must not exceed 20%.

Figure 3 shows the layout of the brake diagram for the semi-trailer and trailer. In the example of stopping one trailer, the feed pressure on the red coupling head increases, as does the brake pressure ($Pzyl$) from 0 to 0.4 *bar*. At 0.7 bar the activation pressure is applied to the brake in the wheel of the vehicle, so that the vehicle can generate brake force from now on. This point, therefore the pressure to activate the complete semi-trailer brake, can be adjusted within the braking calculation for that type of semi-trailer. For trailers, we have two ARSK controllers with different input pressures, so we have to record and measure them both, and the behavior of the loaded trailer is shown in Figure 3 (4).

The front axle has a slightly higher inlet pressure (6.5 *bar*) than the rear axle inlet pressure (5.7 *bar*). This arrangement of pressures on the front and rear axles is very important when operating on the hills.

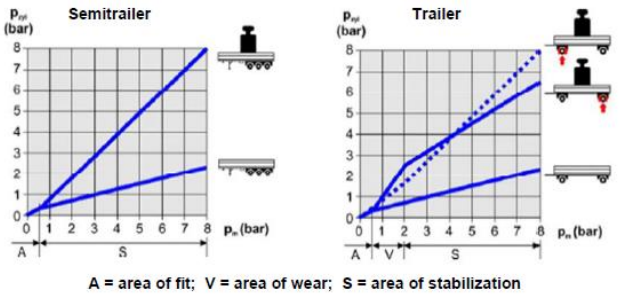
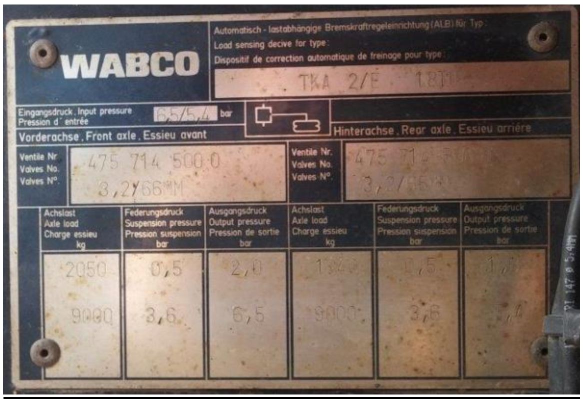



Fig. 3 Layout of brake diagram for semi-trailer and trailer.

If during the operation there is a change in the operating mode, inadequate pressure on the pressure gauges or improper loading, a diagnostic examination and analysis of the data should be carried out in order to take appropriate preventive or corrective measures if necessary.

In the next part of paper, ways of controlling the proper work of the braking system are going to be addressed. According to Directive 71/320 EWG Annex II, Section 1.1.4.2. Paragraph 7 and ECE Regulation no. 13 Annex 10 Paragraph 7, the vehicle must have the data plate required for testing the ARSK controller, as shown on Fig. 4 (example for trailer and semi-trailer).



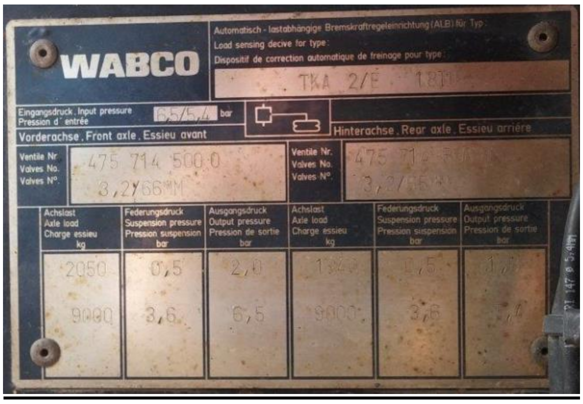




Fig. 4 WABCO System Plate Layout (for Trailer and Semi-Trailer).

The pressures entered in the ARSK (ALB) table were measured directly in front of and behind the ARSK controller, so as not to reflect the impact of other brake system devices on them. When designing the brake system, inspection terminals according to ISO standard 3583/1974 are always foreseen both in front of and behind the ARSK controller.

The command pressure can be measured in the two ways shown in Figure 5 by setting the gauge to:

- control port in front of ARSK;
- command line (yellow coupling head);


Fig. 5 Pressure on the control line at the coupling.

Press the master brake cylinder so that the pressure in the command line is increased to the pressure in the command line indicated on the table (usually 6.5 *bar*). If no plate is found, the master brake cylinder is fully actuated. On the control terminal "41" and "42" of the ARSK, a fine pressure regulator, Figure 6, is installed, which performs the simulation of the load in the cushion, i.e. fine-tuning the pressure from the unloaded position to the maximum pressure position indicated on the system board. The pressure measurement on the brake cylinder is done for the positions unloaded, semi-loaded and loaded.

Fig. 6 Position of the pressure regulator in the cushion as well as the connection point on the brake cylinder for pressure measurement.

The measured pressures on the unloaded vehicle shall not differ from the pressures shown in the table for the unloaded vehicle by more than +/- 0.3 bar. If the ARSK valve plate does not exist, the pressure behind the ARSK valve (pressure in the rear axle brake cylinder) must be less than the pressure in front of the ARSK valve (working pressure). Normal pressure values for brake cylinders of empty trailers are in the range of 1.5 bar to 2.5 bar.

If we look at the table showing the sizes recorded when checking the technical safety of the braking system on a commercial vehicle of category "O" (Table 2), it is easy to see that the columns in which the measured pressures in the pneumatic installation are to be entered are empty. This raises the question of the accuracy and quality of control during the technical inspection. If we do not have pressure, the question arises how to calculate the factor of correction of the braking force, when we know full well that its calculation requires both calculated pressure and pressure on the brake cylinder at maximum load. Table II.

TABLE II
REQUIRED MINIMUM VALUES OF BRAKE COEFFICIENT BY VEHICLE CATEGORY AND TYPE OF BRAKING

| | | | | |
|---|---|---|---|---|
| Contact pressure | bar | | | |
| Maximum *PM* | bar | 0,00 | 0,00 | 0,00 |
| Maximum *PZ* | bar | 0,00 | 0,00 | 0,00 |
| Maximum *PD* | N | | | |
| Calculated pressure | bar | 0,00 | 0,00 | 0,00 |

A brake coefficient is used to evaluate the effectiveness of the braking system. The mathematical formula (2) for calculating the maximum braking coefficient is:

$$k_{max} = F_k \cdot i_n / G \,,$$

where: $F_k$ - total braking force for the entire vehicle;

$G$ - total weight of the vehicle;

$i_n$ - axle braking force correction factor.

The brake force correction factor of the axles is mathematically obtained as $i_n = (P_e - 0{,}8)/(P_{zn} - 0{,}5)$ where $P_e$ is the designed pressure for the loaded vehicle and $P_{zn}$ is the cylinder pressure when the vehicle is empty. Usually the design pressure is taken at 6 or 6.5 *bar* and the reaction pressure in the cylinder is about 0.5 *bar*. One should always check the pressures against the system chart or, if there is none, then take the measured values.

Following section of paper will describe how to control vehicle movement history using ODR Tracker application (4). Data are displayed and analysed using the ODR Tracker application. In the generated report, the data are classified into three groups: statistics, active logging of all events and travel data. The report covers the last 200 trips, and for the purposes of the analysis below, the data from the first group were processed - statistics.

The analysis is based on 4,454,172 kilometers traveled, 174,778 vehicle hours and 87,750 vehicle journeys. On the basis of the statistics obtained, in order to determine the exploitation conditions more closely, the values of the operating indicators were calculated.

The data shown in Fig. 7 show that during the exploitation of the vehicles, 35% of the total distance traveled is in the load of 80-90% of the maximum load, and that is the exploitation when the payload of the vehicle is used. In this case, the load on all axles is equal to the load on the middle axle. Under load in the interval 0-20% on all axles the vehicle exceeds 50% of the total road length. Such information indicates an increased number of unloading places, which implies a more complex structure of the driver's working hours (activities in handling dangerous cargo at the unloading points), which can result in driver fatigue. On the other hand, if we look at the load on the middle axle, as much as 55% of the total distance traveled, the load on the middle axle is in the range of 20-50%, which indicates an incorrectly distributed load.

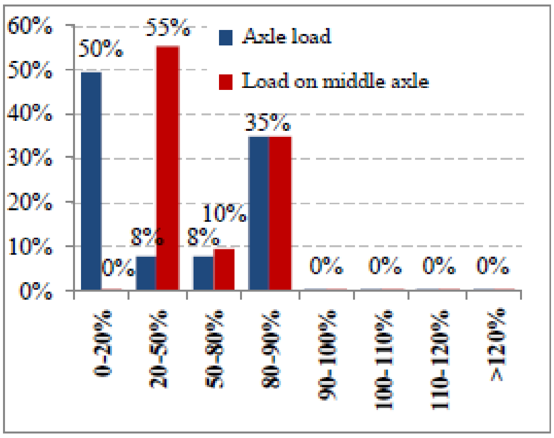



Fig. 7 Distribution of journey length depending on load.

In Figure 8 we can see that the middle axle of a trailer operating in urban driving conditions most of the way undergo a 20-50% load. Such data indicate that during the supply of urban areas, freight vehicles have a greater number of unloading points which are reached as equal participants in traffic with other participants.

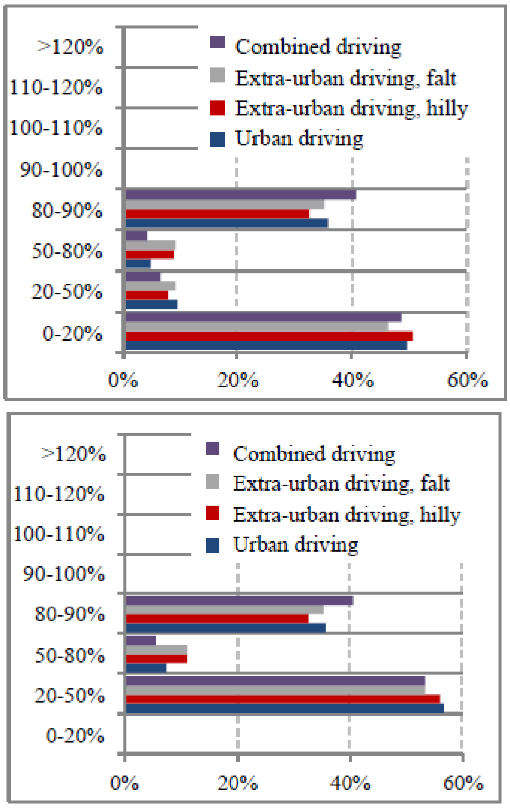



Fig. 8 Comparative view of loads on axles (top) and axles c, d (bottom) depending on operating conditions.

If the frequency and intensity of vehicle braking under different operating conditions is the same, this information is an alarm to the employer, i.e. the need to pay attention to drivers driving style. The technical safety of the vehicle is also reflected by the amount of time the pneumatic installation system was in the operating pressure mode, Fig. 9. If all active pressures above 4.5 *bar* are taken into account, the analysed fleet can be said to have been operational so far.

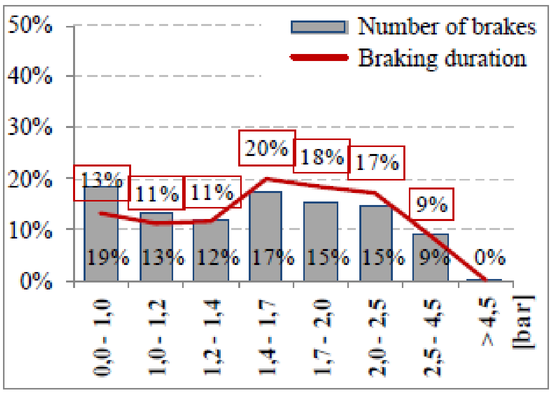



Fig. 9 Distribution of the total number of braking and the duration of braking relative to the control pressure.

If we analyze the data on the number of actuations of the master brake cylinder in relation to the configuration of the terrain, we find that 76% of the total braking was on flat terrain or ascent (Figure 10). Such information confirms that when driving a vehicle, the brakes were timely braked on the slopes, there was no need for sudden braking, and the risks of loss of stability and rollover were minimized.

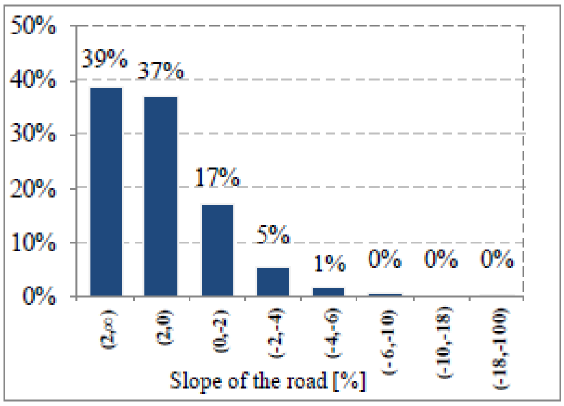



Fig. 10 Distribution of the number of brake activations relative to the decline of the road.

The influence of the earth's gravitational force on the movement of the vehicle is inevitable and is directly dependent on the weight of the vehicle.

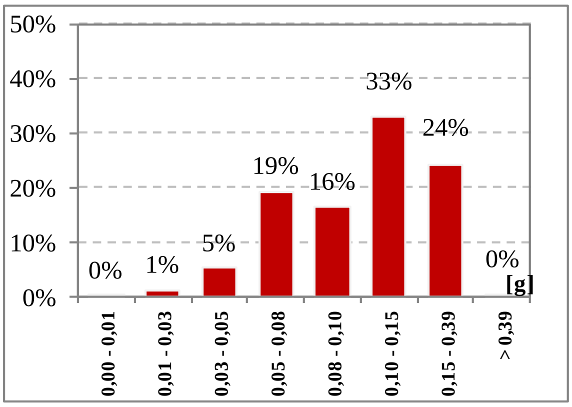



Fig. 11 Distribution of the number of brake activations relative to the deceleration achieved during braking.

Fig. 11 shows the dependence of number of activation of the master brake cylinder as a function of the deceleration expressed as a percentage of the acceleration of the earth's gravity. The fact that in 24% of the total vehicle brakes the deceleration was over 0.15 G is an indicator that it is necessary to act preventively on the driver in the field of safe and economical driving.

Regular control of the mean values of the control pressures, the number of actuations of the master brake cylinder, the number of actuations of the ABS and the RSS function give a clear picture of the mode of operation of the vehicle, whether it was aggressive driving, unsafe steering or defensive exploitation. The activation of the second stage of the RSS function is an indicator that the driver has not adjusted the mode of operation of the vehicle to the road conditions.

From Fig. 12, it can be seen that the number of activations of the ABS system over 10,000 kilometers has increased compared to the previous period of exploitation of the vehicle. This result may be due to seasonal changes in operating conditions, a change in the driver operating the vehicle, or changes in the mode of supply of the vehicle (changes in the load schedule of the vehicle). With each of these changes in vehicle operation, a diagnostic examination and analysis of the data should be carried out in order to identify, if necessary, an appropriate corrective measure or an already applied measure to recognize it as a preventive measure and to apply it to other vehicles in the fleet as an example of good practice.

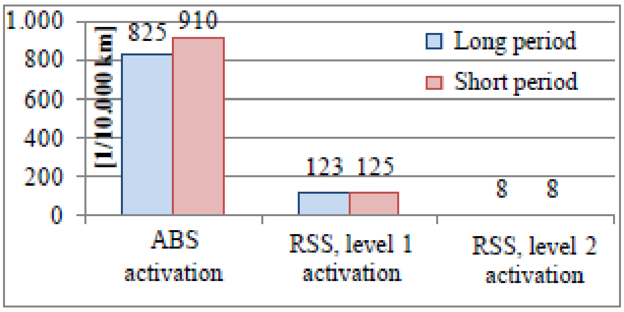



Fig. 12 Frequency of response of electronic vehicle systems.

If we consider the RSS (Roll Stability Support) response of the system in relation to the conditions of exploitation (Fig. 13), the highest number of responses was in the combined driving conditions and in the out-of-town driving conditions in the hilly areas. Such results are the result of driving in different conditions and constant adaptation of the vehicle to the conditions of the road, and the configuration of the terrain.

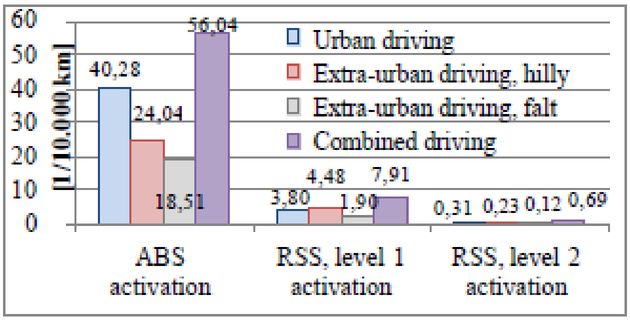



Fig. 13 Frequency of response of electronic vehicle systems in relation to vehicle operating conditions.

Any diversion from the desired trajectory and loss of control over the movement of vehicles in this sense, represents a dangerous traffic situation for all road users.

## III. Conclusion

The international rules and directives, as well as the national rules on the conditions that must be met by vehicles for safe traffic, are absolutely clear. However, the lack of quality national procedures, the lack of adequate equipment on the inspection lines, the lack of trained workers on the inspection lines, affect the quality of the technical inspection as well as the safety of all road users.

The largest part of the fleet is equipped with electronically controlled systems, as the designers recognized the need for safe transport. By using diagnostic equipment, you can control the exploitation of your fleet and decrease the need for corrective the maintenance and thus have a positive effect on reducing the running costs of the fleet.

Development of quality control rules for vehicles on technical inspection lines, continuous training of employees on technical inspection lines, provision of appropriate control equipment are prerequisites for quality control and, consequently, increased safety of all road users.

This paper presents a normal course of testing (applied by the surrounding countries) as well as the observed shortcomings in the control of commercial vehicles of category "O". The lack of possibility to measure the axle load (in most technical inspections) is compensated by requiring the vehicle owner to bring a record of the load as well as a confirmation of the date of calibration of the scale. The braking rate for the maximum permissible vehicle mass is not calculated, which is another major omission. The influence of the system that prevents the wheels from locking during sudden braking on the technical inspection lines is not recognized, which again represents a shortcoming in the control.

In all vehicles, non-compliance of the braking system on the vehicle can lead to serious damage to the safety of all road users, to the safety of property and persons, the environment.For this reason, the control of the technical safety of vehicles is a legal obligation, but in order to produce results, habits and access to the control method must be changed, the existing literature used for employee training adapted to legal requirements, regular checking of the level of knowledge of employees, equipping of inspection lines and in the end, in this segment of our life, the profession must prevail and not be burdened with politics (the current situation).

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