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RUSSIAN FEDERATION

STUDY OF PERSPECTIVE ASPECTS OF EQUIPPING VEHICLES WITH AN INFORMATIVE BRAKE SIGNALING SYSTEM (IBSS)

The problem

A modern vehicle must be equipped with an effective light-signaling device of active safety capable in all cases of braking and (or) slowing down the vehicle to ensure the other road traffic participants with a maximum capability of preventing extreme emergencies and accidents or minimizing their consequences.

The contents

1. Necessary functions of the IBSS in a vehicle at braking and deceleration in normal, extreme and emergency situations, as well as during accidents and emergency stops caused thereby.
2. The IBSS structure.
3. The IBSS efficiency.

1. The necessary functions of the IBSS in a vehicle at braking and deceleration in normal, extreme and emergency situations, as well as during accidents and emergency stops caused thereby.

The study devoted to this problem, in particular, with respect to the Active Informative Brake Light (IBL) [1], which is a basic element of the IBSS, were conducted since 1993. During this study standard situations that require from the driver appropriate actions to prevent a possible accident were evaluated.

These actions, in particular, braking can create similar situations to the road traffic participants following the braking vehicle.

For convenience of the analysis of situations, in which a vehicle can find itself, a criterion of a situation is introduced as an interval of accident probability - P_{A1} (collision with an obstacle or with a vehicle going ahead).

In a normal situation P_{A1} = 0 to 0.05;

In an extreme situation P_{A1} = 0.05 to 0.5.

In an emergency situation P_{A1} = 0.5 to 0.95.

The accident is characterized by an interval of probability P_{A1} = 0.95 to 1.0.

The stop after the accident is characterized by a possibility of a secondary accident, i.e. head-on crash of the following traffic participant with the stopped vehicle. In so doing, at the first instant of time the probability of a secondary accident P_{A2} is essentially close to unity ($P_{A2} \sim 1.0$) decreasing with time.

Fig.1 (without any time scale) illustrates the negative character of the development of a situation from normal to emergency, and subsequent emergency stop is shown. It should be noted, however, that the negative development of the situation could be stopped and reversed to its normalization at the point F (beginning of the emergency crush).

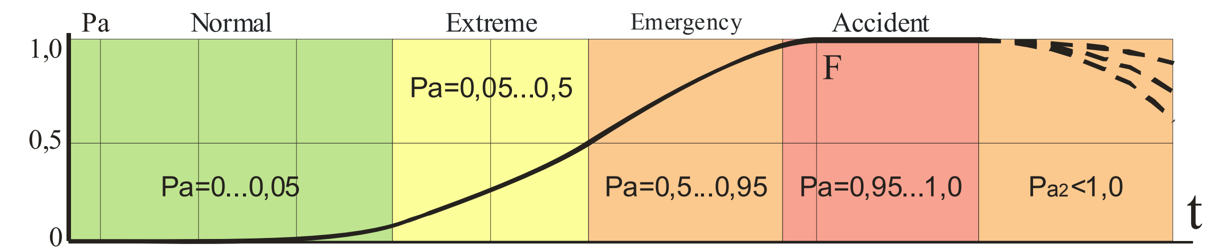


Fig. 1 Characteristics of probable situations and their development.

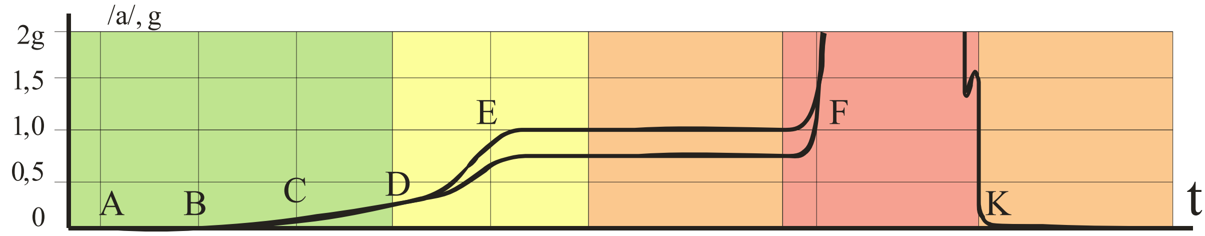


Fig. 2. The dependence of the time of detection of deceleration of a vehicle by approaching it from starting speed.

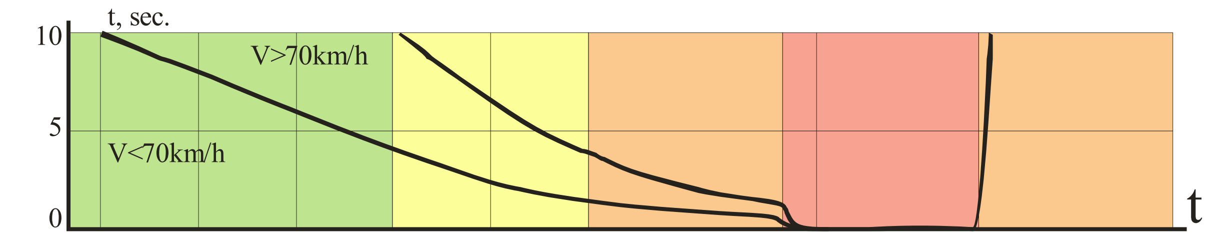


Fig. 3. The deceleration values correspond to the situations.

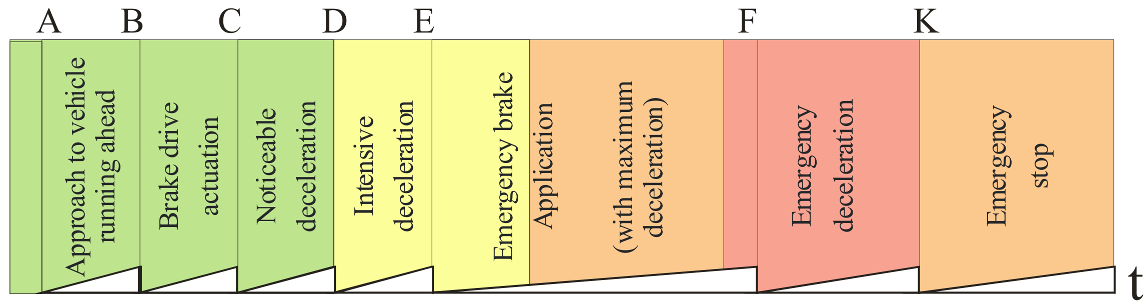


Fig. 4. A diagram of necessary light-signaling information.

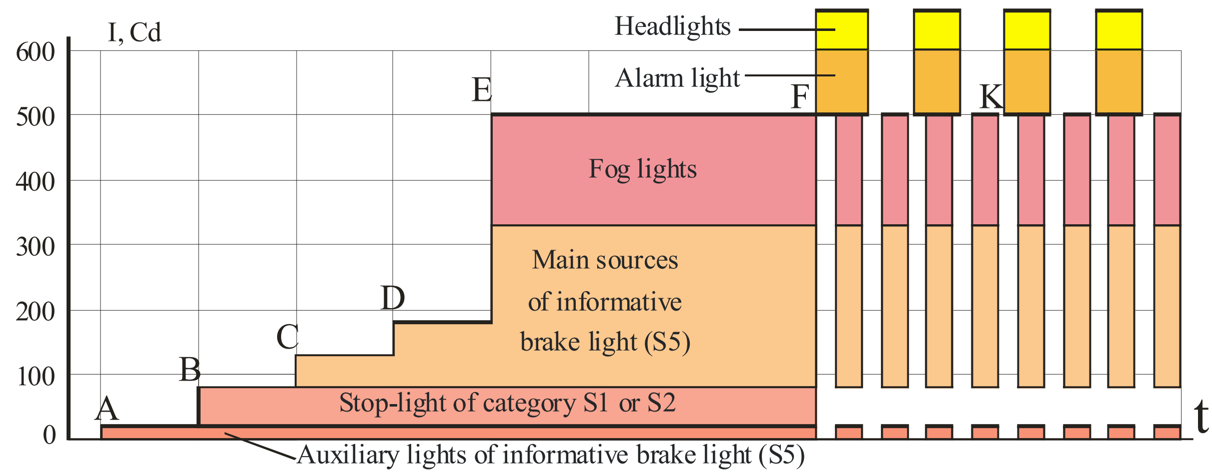


Fig. 5. A character of luminescence of signal lights of the informative light-signaling system in different situations.

1.1. Normal situation

The normal situation (see the left-hand part of Fig.1) is characterized by an interval of values P_A = 0 to 0.05 and predictable actions of the traffic participants, in particular, by braking, slowing down and stopping the vehicle. Using recorded of fixed rates of deceleration: 1.5; 2.0; 2.5; 3.0; 4.0; 5.0 and higher (up to 10) m/s^2 in a range of initial speeds of 20 to 120 km/hour, the dependence of a probability of attaining the above rates of deceleration – P / a / (v_0) have been obtained. At an initial speed v_0 = 50-60 km/hour they slightly differ from those cited in [2]. However, it has been found that the majority of drivers (up to 75-80%) brake their vehicles uniformly and 15-25% of drivers brake while approaching the stop point from a speed v_o ~ 80-100 km/hour and higher, can increase the deceleration up to 4 m/s^2, and 3-6% can decrease the deceleration to 5-6 m/s^2. Besides, individual cases of deceleration of up to 7 m/s^2 have been recorded.

As a whole, from the point of view of the deceleration, the normal situation is characterized by a range of decelerations from 1.5 to 3-4 m/s^2 with probability of about 0.85 and not exceeding 5-6 m/s^2 with probability of about 0.95 (see the left-hand part of Fig. 2).

1.2. Extreme and emergency situation

In contrast to the normal situation, the extreme and emergency situations are characterized by less predictable and unpredictable cases of braking with a rate of deceleration from 4-5 up to 8-10 m/s^2 (see Fig.2) depending on the visibility, observation, field of view and traffic conditions.

The most typical cases of extreme and emergency situations are listed in Table 1 based on the data of an expert study.

The analysis of the data which are listed in table 1, allows one to make the following remarks:

- an accident is a consequence of negative development of the emergency situation, and the emergency situation
- is a result of a negative development of the extreme situation, while the extreme situation stems from the normal one;
- the main sources of extreme and emergency situations are driver's mistakes in the estimation of the traffic conditions including diversion of his attention to other objects, errors in driving the vehicle and suddenly arising failures of the vehicle;
- cases of slowing down the vehicle are not indicated by signal lights without actuating the working brake (see item 3.1-4.2 in Table 1), as well as changes in the braking intensity (see item 1.1 of Table 1;
- accidents and the associated stops that also are not indicated by signal lights (see item 5.1-5.3 of Table 1), and the warning light in a dense traffic is inefficient not only in a fog but under good visibility conditions as well.

1.3. Development of extreme and emergency situations

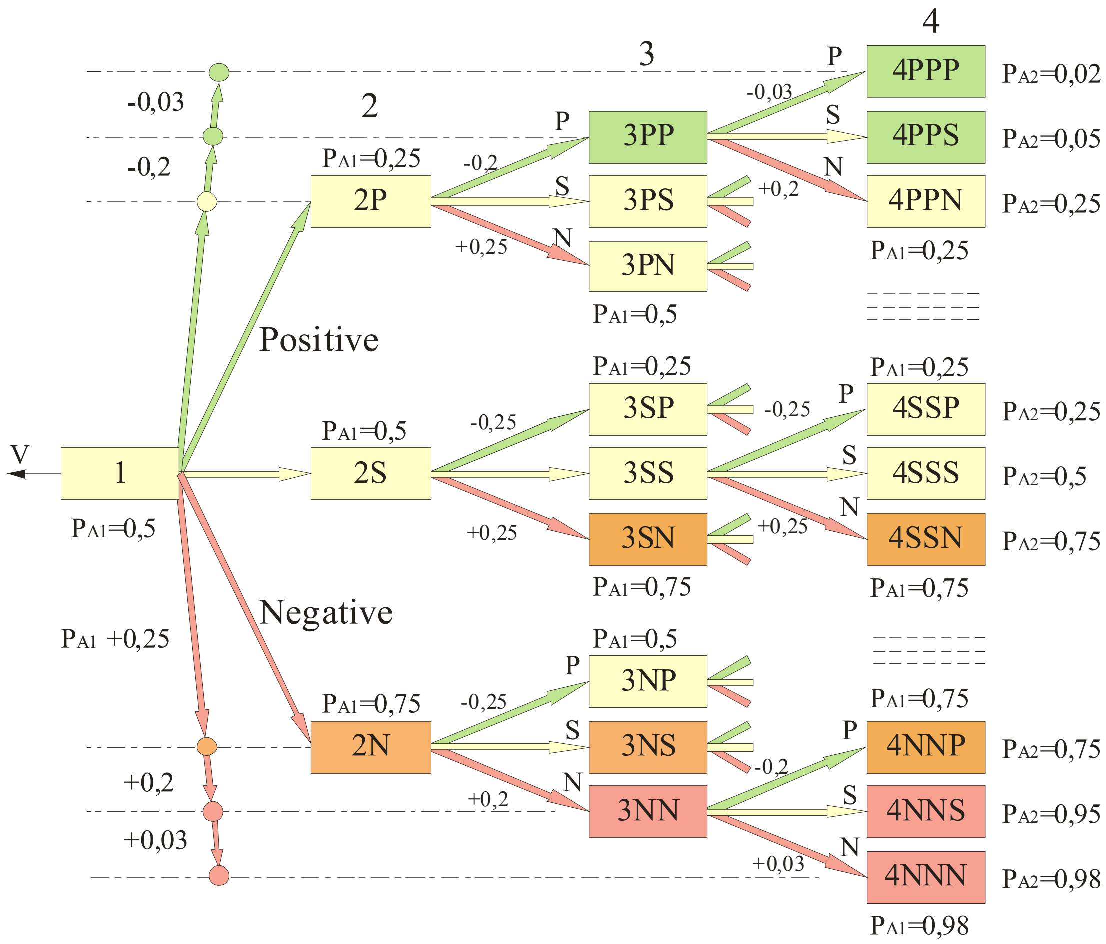
The development of an extreme situation (as well as an emergency one) (Fig. 1) can go both in positive and negative directions. In the former case well-timed and correct actions of the driver (immediate or emergency brake application, etc.) result in normalization of the situation ($P_A \rightarrow 0$), and in latter case, e.g. delayed braking, increases the extreme value ($P_A \rightarrow 1.0$). In so doing with respect to the traffic following participant, the situation can also be positive or negative, i.e. capable to transfer the drivers to normal, extreme or emergency situation with a probability of an accident or P_{A2}.

In a traffic flow the development of the situation, starting from the extreme one, is preferable considered on a simple model with elements of estimation of probability of an accident or P_{A2} as a collision with the following vehicle (Fig. 6).

Table 1. Typical cases of origination of extreme and emergency situations

Item No	Cause of Situation	Character of motion of a vehicle	Situation parameters			Presence of a signal
			\a\ m/s^2	t, Sec	P_A 0-1.0	
1. Driver's errors in estimation of traffic conditions						
1.1	Error in calculation of deceleration	Increase of deceleration to 5-6 m/s^2	< 6	0.5-3	< 0.02	-
1.2	Error in distance selection	Braking (with deceleration of up to 5-6 m/s^2)	< 6	0.5-3	< 0.02	+
2. Errors associated with changeover of the driver's attention						
2.1	Delay in detection of reduction of distance	Intensive braking	< 6	0.5-3	< 0.05	+
2.2	Delay in detection Of braking	Intensive or emergency Brake application	< 6 < 10	0.5-3 0.5-3	< 0.05 < 0.005	+ +
2.3	Delay in detection of an obstacle	Emergency Brake application	< 10	0.5-5	< 0.001	+
3. Driver's errors in vehicle control						
3.1	Engine stoppage at breakaway	Unexpected deceleration and Or stoppage	< 5	0.5-2	< 0.005	-
3.2	Actuation of low gear during Acceleration	Unexpected deceleration	< 5	0.5-2	< 0.0005	-
4. Suddenly arisen faults in vehicle						
4.1	Shutdown	Deceleration, stoppage on the traffic lane	< 7 0	2-20 ~500	< 0.001 < 0.005	- +
4.2	Fault of transmission or running gear	Deceleration. Stoppage on the traffic lane	< 7 0	~2-5 ~ 1000	< 0.0001 < 0.0005	- +
5 Gross errors in estimation of traffic conditions						
5.1	Collision with the vehicle running ahead	Collision. Stoppage on the traffic lane	< 30g 0	~ 0.5 ~500	< 0.00005 -	- +
5.2	Collision with an obstacle	Collision. Stoppage with vehicle displacement	~ 30g 0	~ 0.2 ~ 1000	< 0.00002	- -
5.3	Collision with an oncoming vehicle	Collision. Stoppage with vehicle displacement	> 30g 0	< 0.2 ~1000	< 0.00001 -	- -

+ is the presence of a signal; - is the absence of a signal



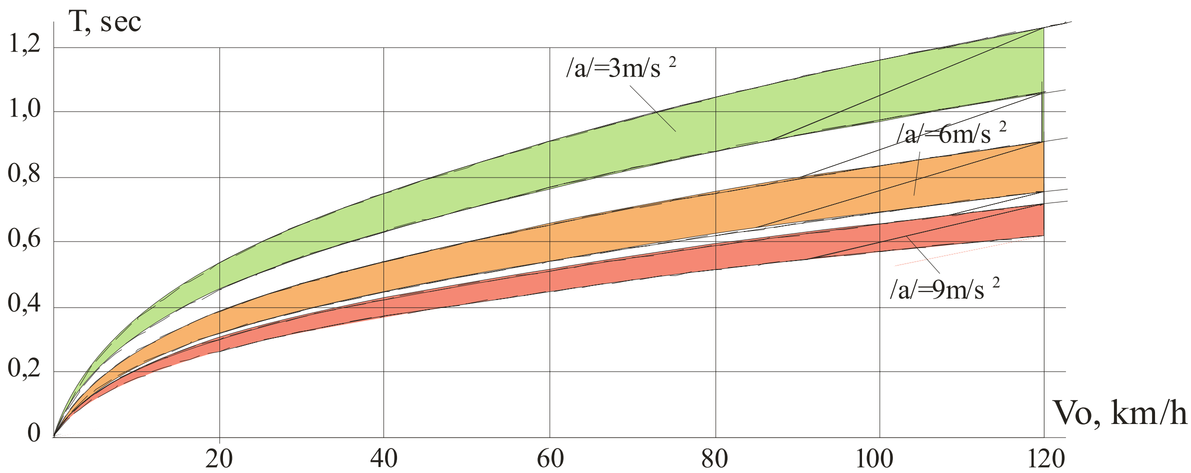


Fig. 7 An approximate time span of development of the situations

According to this model, the traffic participants 1, 2, 3 and 4 follow one another on the same traffic lane. The traffic participant 1 has found himself in an extreme situation, for example, has seen an obstacle too late. His actions on preventing the collision with the obstacle (braking) can be for traffic participant 2, from the point of view of probability of his collision with vehicle 1, as follows: positive - P, negative - N or not changing the situation - S. As a result, the traffic participant 2 can fall in situation 2P, 2N, or 2S, respectively. In this case, the probability of an accident (collision with transport vehicle 1) for him, in comparison which the situation for vehicle 1 ($P_{A1} = 0.5$) will decrease, for example, to $P_{A1} = 0.25$, increase, for example, to $P_{A1} = 0.75$.

The actions of traffic participant 2 in the situation 2P, 2N, or 2S can, in turn, be different for traffic participant 3: positive - P, negative - N, or neutral - S. As a result, traffic participant 3 can fall into one of nine situations: from normal - 3PP ($P_{A1} = 0.05$) up to emergency - 3NN ($P_{A1} = 0.95$).

Further development of the situation can proceed in a similar way and result either in its full normalization - 4PPP or in subsequent collision of the vehicles - 4NNN, or to intermediate positions: from 4PPS, 4PSP, 4SPP to 4NNS, 4NSN, 4SNN with a probability of collision with vehicle 3 running ahead. Apparently, the beginning and further development of the situation (from normal) can occur other increments of ΔP_A by a similar scenario both in positive and negative directions.

The direction and speed of development of the situation is effected by many factors, for example, conditions of visibility, field of view, motions, driver's skill, etc. However, from all factors capable of affecting the development of the situation from the signal lights part, it is necessary to separate the information for the driver and the temporary factor.

The scope of information on the vehicle going ahead and on the actions of its driver should be sufficient not only for exclusion of possible errors in the estimation of the traffic situation, determination of a required mode of motion (braking), and its correction, but also for prediction of further development of the situation.

The temporary factor characterizes the availability of time for estimating the situation taking into account time of response of the driver and the working brake operation, as well as the time of development of the situation.

The time of development of the situation is rather limited. In particular, the duration of development (a change) of a normal situation (Fig.3) can exceed ten seconds, the extreme situation – several seconds and the emergency situation - fractions of a second. Therefore, the possibility and probability of stopping the negative development of normal situation is much higher, than the extreme one, to say nothing of the emergency.

In this connection, the signal lights of the IBSS should be a source of information, first of all, on the development of a normal situation and its transfer into an extreme category, in particular, on the effect on the working brake drive, (point B in Fig. 3), on the noticeable deceleration (1.5-2.5 to 3 m/s^2 (point C in Fig. 2), on the rate of deceleration (2.5-3 to 5-6 m/s^2 (point C in Fig. 2) and emergency brake application (with deceleration of higher than 5-6 m/s^2 (point D in Fig. 2). The last three moments are very important since the visual information on the deceleration by a decrease of the distance between vehicle running ahead and the observer is possible at its reduction by at least 5-7%, and this requires a few fractions of a second (according to the graphs shown in Fig.7). It will be noted that the response time of the IBSS sensor is less by an order of magnitude and does not exceed 0.07 second.

Besides, the driver needs light signaling on a decrease of the distance between the vehicle running ahead and vehicle running in front of it. This information is necessary for prediction of development of the situation in case of a limited field of view (when the vehicle running ahead does not allow one to see the traffic participants running at the front of it).

A source of such an information for the IBSS (point A in Fig. 2) may be a signal for the driver or the actuating device of the cruise-control radar systems or automatic braking (if it is installed in the vehicle).

The ability of the IBSS signal lights to inform the traffic participant following the vehicle under limited visibility enables him not only to reduce the probability of collision with the vehicle running ahead, but also to predict a possibility of transfer of a normal situation to the category of an extreme one with an adequate probability. Besides, the IBSS is capable to creating a time reserve for the following vehicle by determining an approximate rate of deceleration on the scale of the IBL indicator, and not by the rapprochement with the vehicle running ahead (cases 3.1-4.2 and 1.1 in Table 1). Therefore, the IBSS provides a possibility of anticipatory actions, i.e. prevention of both emergency and extreme situations.

Under conditions of limited visibility the light intensity of the IBSS sources at active braking (deceleration) must be commensurable with the light intensity of the fog taillights, and be less than that at an emergency brake application. Besides, the emergency brake application is preferably accompanied by a continuous audible signal. It will allow the other traffic participants, including those driving on the adjacent traffic lanes, particularly in fog, to take actions for preventing collision with the braking vehicle in the case of its displacement relative to the traffic lane.

1.4. Accident and emergency stop

The accident is characterized by fast approach to an obstacle (another vehicle) and collision with it. In so ding the rate of deceleration rises up to dozens g (Fig. 1) within tens of milliseconds. Because of redistribution of energy between the objects of collision the trajectory of their motion and position in space changes. The character of movement and the position of the vehicle at a stop depend on many factors and, therefore, are unpredictable. This can result in an emergency or extreme situation for other traffic participants including those driving in the opposite direction. In this connection, the vehicle at the moment of collision, subsequent movement and evacuation from the traffic area after must be reliably indicated at all sides and be detected in poor visibility at a safe or maximum possible distance, because the braking distance, for example, at a speed of 120 km/hour at a deceleration of 8 m/s^2 is about 70 m.

It should be noted, that at the moment preceding the accident the driver can not have time to activate the working brake and after the stop be not able to immediately switch the alarm signal on. Therefore, the vehicle should have an automatic switch *for actuating an alarm signal*, i.e. simultaneous switching on an alarm signal according to Section 6.6 of Rule 48, as well as impulse fog taillights, auxiliary headlights, informative Brake Light (IBL) and audible emergency signal, according to Fig.5. The switch should be actuated by a sensor, which is capable to detect deceleration and acceleration including lateral loads of about 1.5 to 2 g, (see F in Fig.3). At manual switching, (see case 4.1 in Table 1) all lights must flash synchronously at a frequency adopted for alarm signaling according to Section 6.6 of Rules 48. The cutoff of the *alarm lights* is manual, independent.

2. The IBSS Structure

The IBSS structure is determined by its functions (see Figs. 4 and 5) and includes:

- nominal signal lights, including devices of category S1 or S2;
  an informative Brake Light (IBL) used instead of the device of category S3 comprising a device of category S3 and a deceleration indicator;
- a unit for automatic and manual switching on an alarm signal and lights supplementing them (fog taillights, IBL, dipped headlights) and audible signal in an impulse mode with individual or nominal switches (capable of responding to decelerations and accelerations, including lateral forces at a level of about 1.5 to 2g);

- switching elements of the IBL with fog taillights, an audible signal and a radar.

The IBL, in turn, consists of the following devices:
- a lighting device comprising 4 groups of basic light sources, first of which performs a function of a device of category S3, the second one informs on deceleration exceeding 1.5 m/s^2, the third one informs on deceleration exceeding 1.5 m/s^2, the fourth one informs on deceleration exceeding 2.5 to 3 m/s^2, and a group of auxiliary light sources performing a functions of a scale of deceleration and a source of information on approaching to the vehicle running ahead;
- a deceleration sensor capable to detecting achievement and excess of above three levels of deceleration;
- a control circuits controlling the lighting mode and correcting the intensity of the light sources according to a given algorithm and visibility conditions.

3. The IBSS efficiency

The efficiency of the IBSS as an active safety system compared to a stoplight is provided by new functional capabilities substantiated in this paper. It is characterized by new technical achievements and a high level of technical solutions obtained by other developers (see Table 2). It should be noted that some statements of Table 2 require clarification. For example, the monitoring of the deceleration by means of the IBL indicator (item 1.4) allows the traffic participant to determine its approximate value even after switching his attention to a braking vehicle from another point of observation.

A possibility of monitoring the approach to a vehicle running ahead using a radar not only reserves 0.2 to 0.3 seconds for the following driver (the response time of the working brake of the vehicle running ahead) on the reaction and actions, but also makes the vehicle equipped with a radar “protected not only in front but also from behind”.

The monitoring of deceleration without actuating the working brake on IBL, in contrast to monitoring without IBL (items 2.2-2.4 of Table 2) reserves time for the following driver running at an initial speed of 80 km/hour and at a deceleration of 6 m/s^2 of about 0.62-0.74 second, and during the braking (items 1.2-1.4, Table 2) with the same deceleration (the stop-signal is on) of about 0.37-0.49 second. These data are obtained using the graphs of Fig.7.

The above diagrams are constructed on the assumption of initial distance between the carriers being equal to the distance they travel in 1 sec plus 1.5 m.

It should be noted that glowing of the fog taillights, headlights, as well as the audible signals at accident and emergency stops (before they are switched off manually) can create discomfort to the other traffic participants and even make difficult the traffic itself. However, these difficulties are fully compensated by a possibility of detecting vehicles becoming an obstacle due to an accident or a failure at a safe distance, in particular under poor visibility conditions.

The experimental operation of some versions of the IBL in cars (instead of devices of category S3) has confirmed their high efficiency, favorable acceptance by other traffic participants, compatibility of vehicles equipped with these devices and known stops-signals in traffic flows. The drivers evaluated the IBL most favorably.

Table 2. Efficiency of the IBSS installed in a vehicle

Item No.	Technical result	Competitor and its level
1	***Braking using working brake***	
1.1	Correspondence of visual discomfort created by illuminated IBL to the deceleration level	DE (BMW) 100%
1.2	Control of action on the working brake drive	S3 100%
1.3	Control of deceleration value by illumination and brightness	DE (BMW), 80%
1.4	Control of deceleration by the scale of deceleration indicator	Not found
1.5	Prediction of emergency brake application	DE (BMW), 80%
1.6	Control of emergency brake application and its beginning	FR (PEUGEOT), 70%
1.7	The same in fog (by light and audible signals)	Not found
1.8	A possibility of monitoring the emergency brake application by other traffic participants (by an audible signal)	Not found
2	***Deceleration without actuating the working brake***	
2.1	A possibility of monitoring the approach to a vehicle running ahead by illumination of the indicator scale	Not found
2.2	Monitoring of deceleration without actuating the working brake by the character of glowing of an indicator	Not found
2.3	Monitoring the deceleration by an indicator scale	Not found
2.4	Monitoring the deceleration by light intensity and brightness	Possible
2.5	The same as in items 1.3-2.4 with automatic braking	Not found
3	***An accident (collision with an obstacle or another vehicle)***	
3.1	Monitoring the process of an accident and emergency displacement of a vehicle	Not found
3.2	The same for other traffic participants (including those running coming in the opposite directions)	Not found
3.3	The same in fog (by light and audible signals)	Not found
4	***Stoppage after an accident***	
4.1	A possibility of detection of a damaged vehicle from the moment of an accident without a time pause	Not found
4.2	The same for other traffic participants (including those running coming in the opposite directions)	Not found
4.3	The same in fog (by light and audible signals)	Not found
4.4	Visual distinction of the after-accident stoppage from a forced one (by nature of light and audible signals)	Not found
5	***Forced stoppage on a traffic lane***	
5.1	A possibility of detection of a vehicle stopped at a safe distance	Not found
5.2	The same for other traffic participants	Not found
5.3	The same in fog (by light and audible signals)	Not found

- known result
- higher efficiency
- new level of efficiency
- possible similar result in the competitors

Conclusions

1. The analysis of the IBSS efficiency as a whole has shown that application of this system in vehicles will allow one to effectively accomplish all tasks constituting the problem of light-signaling to prevent accidents caused by braking and deceleration, as well as to reduce the heaviness of their consequences both under good and poor visibility and in heavy traffic.

2. The IBSS, as a system of active safety in view of its advantages over other developments both in prevention and stopping of negative development of extreme and emergency situations and reduction of the heavy consequences of accidents, including those for the other traffic participants, practically has no alternative and is perspective for all vehicles.

Summary

The conducted studies have revealed special urgency of the problem of light display of braking, deceleration, accidents and emergency stops of vehicles.

In these studies an analysis has been made of the basic situations, in which a vehicle can happen to be. Possibilities and ways of neutralization of sources, stopping a negative development and normalization of extreme and emergency situations are shown.

The use of an informative Brake Light (IBL) and a unit of technical solutions making an informative braking signaling system (IBSS) has been substantiated.

The main characteristics of the IBL and the other elements of the IBSS have been determined, theoretically proved and experimentally confirmed. The main functions of the IBSS in different situations, as well as a possibility of obtaining the technical results characterizing its efficiency have been shown.

It has been shown that the light-signaling of braking, deceleration, an accident and an emergency stop of a vehicle on the basis of the IBSS gives the other traffic participants maximum capabilities of prevention of accidents and emergency situations, or reduction of heaviness of their consequences.

Therefore, the IBSS, as a light-signaling means of active safety, is very promising, and its installation in vehicles will lead to a considerably reduction of accidents on roads.

References

1. “Emergency brake light display in a vehicle”. Patent for invention No. 2051503 with a priority of November 11, 1994. International application PCT/RU94/00002. International publication WO 95/19276 of July 20, 1995.

2. Study on the Validity of Emergency Brake Light Display. Informal document No.9(51st GRE, 15-19 September 2003, agenda item l.1.2.9.).