

# TENDENCIES RECOGNITION AND ANALYSIS OF CRITICAL SITUATIONS BY THE ACTIVE SAFETY SYSTEMS

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## ABSTRACT

Critical situations, which can arise at car's motion and should be prevented by its safety systems, are subdivided into two levels. The micro-level is connected directly to wheel-road-interaction, and the macro-level with the car's behavior. For creation of effective control philosophy of the systems of active safety a new approach for

description of tire grip - wheel slip – dependencies is offered that gives the basic performance for an evaluation of critical situations. For authentic recognition of critical situations the system of active safety should be constructed on intelligent principles with parallel information channels and with possibility of self-configuration.

## INTRODUCTION

Modern automotive industry pays special attention on increasing of automobile active safety. New technologies used for the automobile systems, particularly principles X-by-Wire, has opened prospects for integration of Antilock Braking System (ABS), Traction Control System (TCS) and other systems of active safety (SAS) into a united complex with the goal of creation the Intellectual Safe Vehicle. At the same time the principles of mono-parametrical discrete threshold regulation that have employed for control algorithms ABS as far back as in 1970s does not match integrated SAS, continuously functioning during the whole of motion process.

In order to raise the efficiency of SAS to the higher qualitative level a new opinion on a vehicle that simultaneously should be considered both a source and a tool overcoming a critical road situation is required.

The goal of the represented work is to determine an area of possible critical situations, criteria of their estimation and ways of SAS organization for prevention or minimization of their adverse consequences.

## CRITICAL SITUATIONS AT MOVEMENT OF THE AUTOMOBILE

### Concept of a Critical Situation

We shall name situations in which the automobile has not sufficient stability and steerability for safe movement, and also an efficiency of braking or acceleration is inadmissibly reduced, as critical ones.

Critical situations during of the automobile driving can arise under influence of various factors and unforeseen circumstances and, as a rule, all of them are characterised by high dynamics and multiwayness of their development. As a result of that the vehicle quickly approaching to a boundary area of potential capabilities, promptly loses both stability, and steerability. Simultaneously a physical and psychological driver burden is sharply risen while he must accomplish complicated managing maneuvers and actions, and as result a level of safety is degraded.

In many respects a boundary area of a driving vehicle is determined by grip quality of a wheel with road. The skilled driver, being guided by the subjective reasons, estimates reachable efficiency and, operating a steering and a braking systems (if necessary, using a feeding of a fuel to an engine) he will act so as to avoid a critical situation and to extricate the automobile from dangerous area. However, at very complex dynamical situations, even skilled driver has no capability to execute effective and safe vehicle management.

The systems of active safety are assigned to decide such complicated problems.

The advanced SAS is to collect, analyze the information on behavior of a vehicle in the current road-operational conditions and to function during

whole working cycle (from a switching on of ignition system and right up to full vehicle stop). It will allow to make short-term forecasting of development of a road-operational situation. For a correct choice or changing of operational conditions a driver gets the forecast results by way of recommendations and alarm from various information-warning devices. In a case of approaching of motion parameters to an area of their critical values SAS should give an alarm signal to the driver and begin preventive regulation of driving.

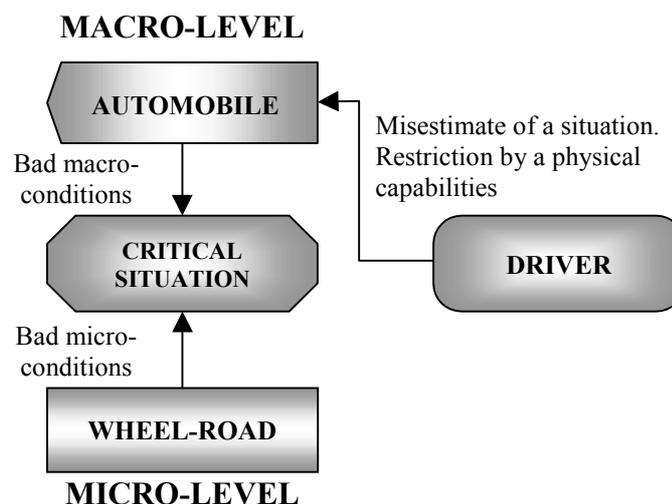
SAS carries out and uses the short-term forecast during the whole development cycle of a critical situation for realization of a preventive control and fast adaptation.

Under designing SAS there is a question concerning an optimal set of a critical situations, which should be under control for providing of safe

driving. The structure of system and software support and, finally, functional - economic benefits depend on it.

Descriptions of road situations which most negatively influence motion of the vehicle in various sources [1-3] are given. In this connection, for creating of SAS it is expedient to build up a classification of such processes.

At first we shall carry out classification of dangerous sources which can arise in system " the driver - the automobile - a wheel - road ", fig. 1. We shall consider occurrence factors of a critical situation can be at a micro-level (wheel - road interaction parameters) and at a macro-level (vehicle motion parameters). It is evident a driver is also considered as source of critical situations, but work of system of active safety at a micro-level should be as much as possible independent of influence of the human factor.



**Figure 1 Connection of a Critical Situation with "Driver-Automobile-Wheel-Road" System**

**Critical Situations on Micro- and a Macro-level**

Critical situations at a micro-level arise in process of a wheel-road interaction under conditions when a wheel is run within boundary motion areas of grip and spin.

It is possible to mark out the following subclasses:

- 1) Adverse grip properties of a wheel;
  - 1.1) Low grip coefficient;
  - 1.2) Change of grip coefficient during vehicle motion;

- 1.3) Distinction of grip coefficient along vehicle sides (split- $\mu$  surfaces);
- 2) Boundary wheel slip;
  - 3) Deterioration and break of a wheel-road contact;
    - 3.1) Water, snow within of a wheel-road contact, hydroplaning;
    - 3.2) Negative influence of a road micro-structure;
    - 3.3) Negative influence of operational conditions;

The critical macro-level situations are connected with such behavior of a vehicle running under influence of external factors at the boundary areas (on stability and controllability) that forces wheels to work within critical area of lateral slip what is followed a skid, an overturn etc. Subclasses of critical situations at a macro-level can be determined as follows:

- 1) Infringement of required driving rectilinearity;
- 2) Infringement of assigned trajectory of curvilinear driving;
- 2.1) Curvilinear driving on wet road;

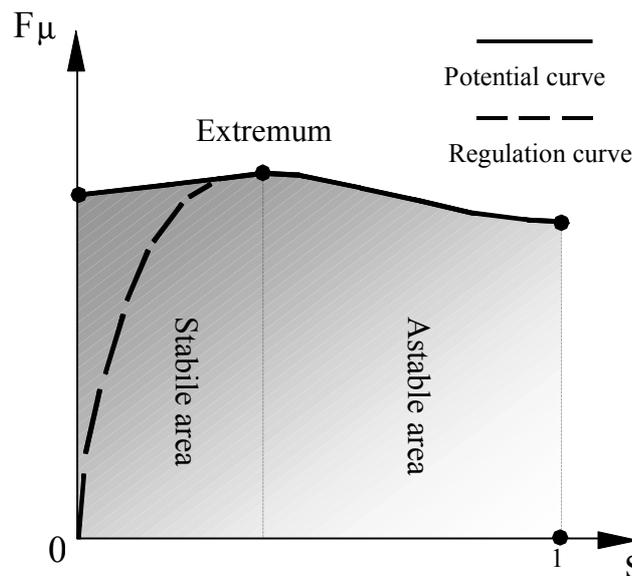
- 2.2) Superfluous yawing moment;
- 2.3) Driving on a road having lengths of variable curvature;
- 2.4) Transition situations;
- 2.5) Change of motion modes.

Only those situations are referred to the submitted subclasses which are not connected directly to processes in a wheel-road contact, and are caused exclusively by influence on a vehicle of external factors (wind load, curvature of road etc).

### Qualitative evaluation of a critical situation

The SAS creation process is joined with a question solution concerning estimation criteria of contribution of any known kind of critical situation into the total level of traffic safety of a vehicle so as to use obtained dependencies in work algorithms of SAS.

At a micro-level for this purpose there is a sense to proceed from a ratio of a potential force,  $F\mu^P$ , [4, 5] to a real (regulation) force,  $F\mu^R$ , within a wheel-road contact, fig. 2.



**Figure 2 Change of Potential and Current Force in Wheel-Road Contact at Dependence from Relative Slip**

In a common case a potential force within a wheel-road contact,  $F\mu^P$ , is a function of several variable parameters:

$$F\mu^P = f(V_s, R_z, F\mu_x^{def}, F\mu_x^{adh}, F\mu_y) \quad (1)$$

Here a speed of a relative slip,  $V_s$ , determines the beginning of  $F\mu^P$ -s- curve and road reaction,  $R_z$ , determines its drift. The general shape of the function is formed by deformative,  $F\mu_x^{def}$ , adhesive,

$F\mu_x^{adh}$ , and lateral,  $F\mu_y$ , force components within a wheel-road contact. Depending on road conditions (dry, wet, icy etc.) and a vehicle motion kind (rectilinear or curvilinear) prevails one of these components that determines passing of a curve (as monotonous decrease, extremal dependence etc.). Both characteristics coincide at a point of the global extremum  $F\mu^R$ -s- curve.

It means, that the wheel has reached boundary critical conditions, i.e., on the one hand, the grip

potential of a tire along a lateral direction is practically exhausted, on the other hand, continuation of a such control mode by a wheel will have resulted in its locking. In result the certain external impacts, for example, lateral force, can negatively influence onto vehicle stability, what, in turn, will lead to occurrence of a critical situation at macro-level.

For an estimation of a use degree of a wheel potential, we shall introduce a coefficient of active safety at micro-level  $Ks_{mic}$ :

$$Ks_{mic} = 1 - \frac{F\mu^R}{F\mu^P} \quad (2)$$

Thus, at absence of progressive motion of a wheel  $Ks_{mic}=1$ , and when wheel attains of critical border  $Ks_{mic}=0$ . First of all the offered coefficient shows an available management potential of a wheel. Taking account providing of high braking or tractive power (efficiency) it is possible to offer (as a first approximation)  $Ks_{mic}=0,75 \dots 0,95$ .

The choice of criterion for an estimation of a critical situation at a macro-level is not simple. Here a vehicle course drifting, transverse acceleration or an inertial acceleration (speed) relatively of a vertical axis might become global parameters. The given parameters can be connected with each other, therefore as an instance we shall consider definition of active safety coefficient for macro-level,  $Ks_{mac}$ , by the vehicle course slip angle:

## SAS INFORMATION PART

As already mentioned the logic of intelligent SAS operation is directed onto realization of a continuous control, a forecasting and preventive actions. For that SAS should betimes determine tendencies and fluctuations dynamics relatively of optimal values of the control parameters by the objects on macro- and at a micro-level and as well as their approaching to the area of critical values.

It means it is necessary to process information streams so to receive not only the current values of parameters, but also their time dependencies.

Realization of flexible structure and high performance of SAS is possible on the basis of modern microelectronic, mechatronic components and information technologies. For example, the reprogrammable central processing unit containing

$$Ks_{mac} = \frac{\Delta\beta}{\Delta\beta_{rec}} = \frac{|\beta_d - \beta_r|}{\Delta\beta_{rec}} \quad (3)$$

by  $\Delta\beta \leq \Delta\beta_{rec}$ ,

$$Ks_{mac} = 1 \quad (4)$$

by  $\Delta\beta > \Delta\beta_{rec}$ .

Where  $\beta_d$  - the course angle set by the driver;  $\beta_r$  - an actual (real) course angle;  $\Delta\beta$  - an angle of a course drift;  $\Delta\beta_{rec}$  - the maximal allowable value of an slip angle recommended for the given situation. The active safety coefficients of micro- and macro-levels are united by some weighting coefficients  $v_{mic}$  and  $v_{mac}$  to yield thus the total active safety coefficient,  $Ks$ :

$$Ks = v_{mac} \cdot Ks_{mac} + v_{mic} \cdot Ks_{mic} \quad (5)$$

When a vehicle maneuver is absent (usual motion)  $v_{mic} = v_{mac} = 0,5$ . Otherwise weighting coefficients are redistributed, however their sum is always equal to 1. For example, at usual braking along a straight line the behavior of single wheels is determinative factor, therefore  $v_{mic} > v_{mac}$ . On the contrary, at any kind of curvilinear motion is important a maintenance of the assigned trajectory of the vehicle driving and  $v_{mic} < v_{mac}$ .

Thus the given evaluation technique of a road situation criticality allows to select the most important determinative parameters from the big information stream analyzed by the SAS control unit and properly to correct control algorithm.

on a crystal the several independent processing devices give an opportunity to accomplish their flexible using, grouping and regrouping taking account kinds, priorities and volumes of carrying out tasks. Integration with programmable controllers of sensory elements allows not only adequately to trace dynamics of change and to process controllable parameters, but also to send an information package into the high-speed input-output channel. The use of nonvolatile and reprogrammable "Flash"-memory allows to store the necessary information about self-educating of SAS on a vehicle and data about failures and malfunctions of systems and units of a vehicle, including the information about operation modes of the basic systems and units of a vehicle before accident (" a black box ").

Modern integrated accelerometers, laser gyroscopes, sensors of a real vehicle speed, sensors of pressure and position which are used for computation of parameters both micro and macro-level have high precision and low price. Integration of data-control channels by a high-speed network (CAN or fiber line) allows to redistribute resources

or reconfigure a system in case of failure of any element. At the same time in view of steady depreciation and constant growth of reliability, an integration degree and speed of electronic components, price of a system relatively of the new qualitative level and SAS capability will be changed a little.

### ACTUATOR STRUCTURE

For minimization of the delays, which have been accumulated in an executive line, an anticipatory control by brake cylinders is required. Electro-pneumatic or Electro-hydraulic braking systems solve such problems, fig. 3.

They use the electric gear only for realization of short-term efforts which are aimed at both on creation of brake effort on a brake gear and for counteraction to effort enclosed on the part of an

executive part of brake system. Operation time will be determined by capabilities of a traditional executive part of system.

Application of the combined driving systems will allow to quickly estimate reaction of vehicle wheels to provide fast correction and a dosated brake force (moment) what will open a way to use of preventive control algorithms and it will reduce consumption of a working medium.

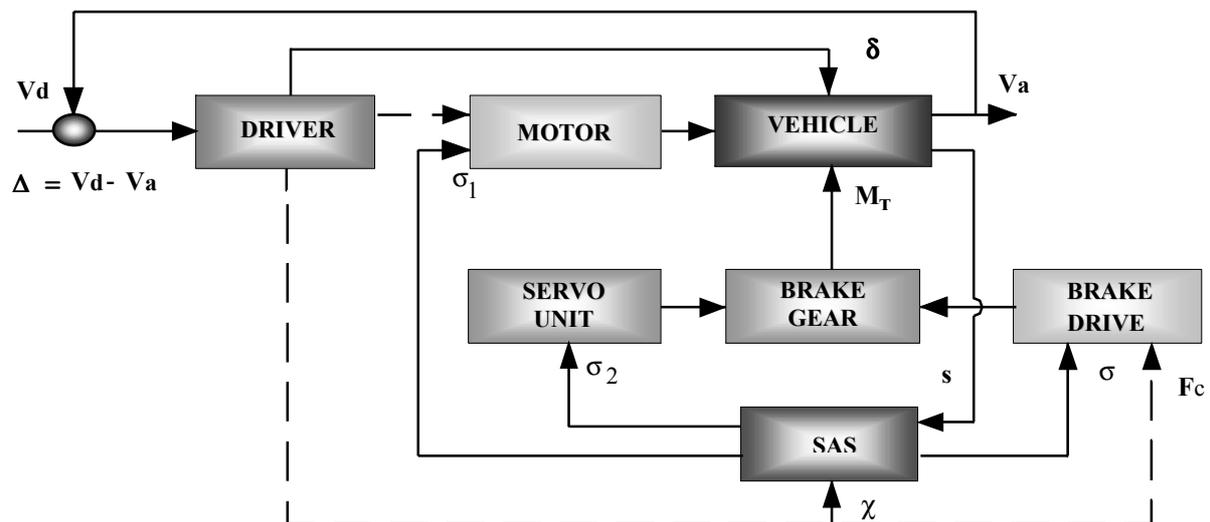


Figure 3 Electro-X Braking System incorporated into "driver-vehicle-wheel-road " environment

### SAS CONCEPT-STRUCTURE

Having referred to theoretical ideas, modern information components and executive devices it is possible to offer the following set of requirements for creation of an advanced system and its concept-structure, fig. 4:

- at the base of SAS control philosophy should lie a principle of providing a necessary level of vehicle motion safety that is determined by the potential characteristics of forces within a wheel-road contact (micro-level) and by potential of vehicle stability (macro-level);
- for maintenance of qualitative control the data-computation part of SAS should have parallel structure with several independent information

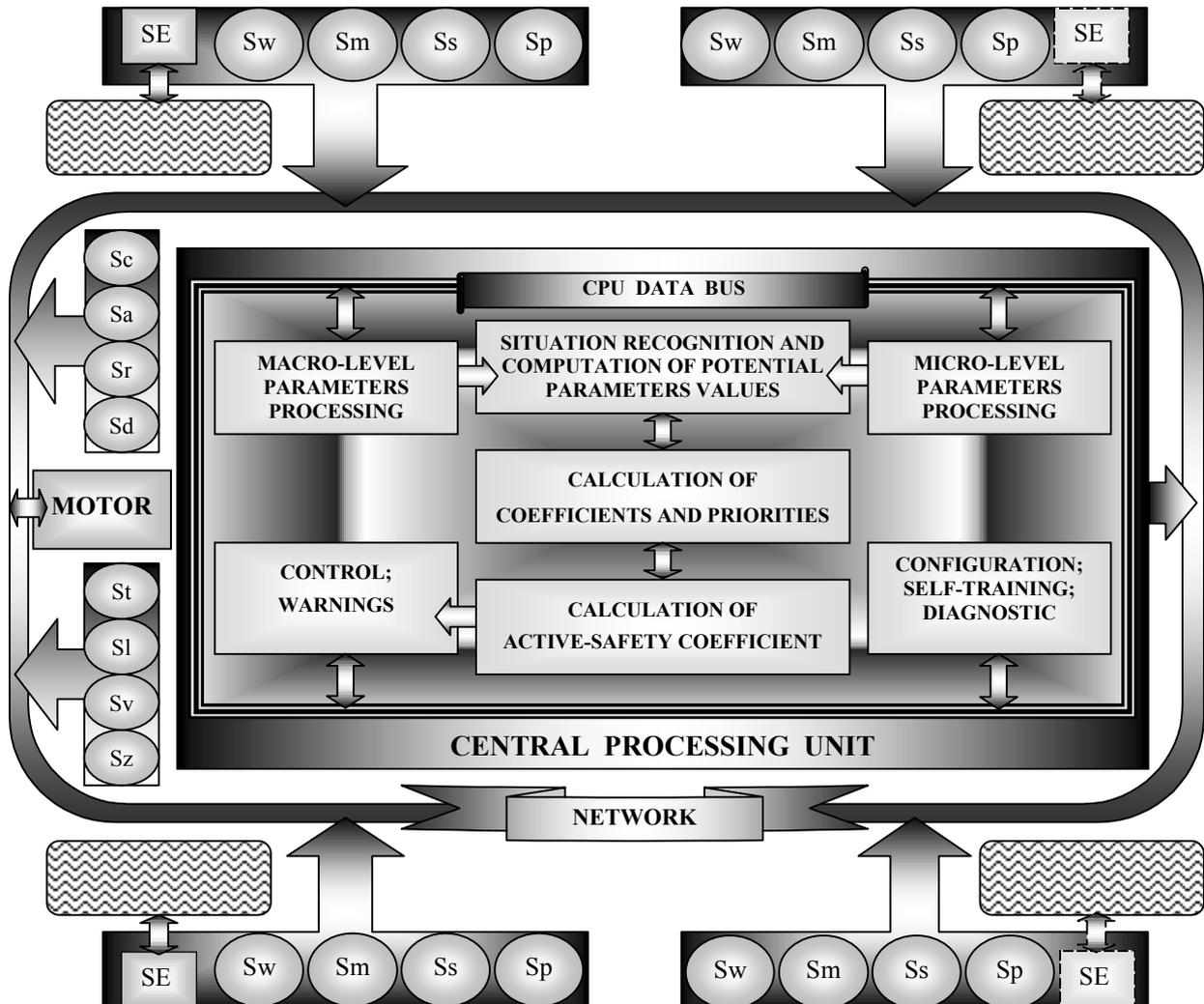
channels as a result the system will get information flexibility and high reliability;

- the management of SAS executive part should be carried out preventively with adapting to critical situations and behavior of the driver;
- SAS should determine commands priorities and devices statuses in a network for a concrete control situation and also to redistribute resources in a case of irregularity of data exchange and work of actuator elements;
- SAS should carry out realignment of elements within "data-computation-control" system

depending on the stored operational experience conjointly with concrete vehicle;

- SAS should provide the fast and dosated performance of executive devices.

The offered SAS concept-structure is optimally connected to the driver and a road-operational situation.



**Figure 4 SAS concept -structure**

Sa, Sd - pedal sensors; Sc - steering control sensor; Sw, Sm, Ss - sensors: angular speed of wheel, brake moment and suspension; Sz - longitudinal and cross accelerometers; the Sl- level (roll) sensor; St, Sp - temperature and pressure sensors; Sv -vehicle velocity sensor; SE- servo-executor, Sr - distance sensor.

## CONCLUSIONS

Despite means variety for maintenance of the active vehicle safety there is a number of problems in this area as long as there is not harmonious and objective theory of wheel behavior and the vehicle in critical situations and the place for active safety system is not determined in this theory. Without having pretensions to completeness of a statement we have made attempt to present some starting points most essential in our opinion for creation of the such theory. In this connection it would be

desirable to emphasize the following positions of the work.

- 1) Critical situations at vehicle driving can arise on two levels. The micro-level is connected to wheel work, macro is linked to behavior of the automobile. In the certain conditions the macro-level critical situations can be caused by processes at a micro-level.

2) Danger of any kind of critical situation might be estimated by some criterion. For active safety system it will provide more objective choice of control actions by brake system, an engine etc. As criteria it is possible to use the offered coefficients of active safety.

3) Into a base of the SAS organization should be put the principles preventive control by objects of regulation, a self-training algorithm and self-configurable system. It will allow to realize preextreme ideology, intelligent control with adaptation to critical situations both macro- and micro-level.

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