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Statistical Modeling of Vehicles Collision When Using a DVR with the Function of Signaling about Dangerous Motion of the Vehicle to the Oncoming Lane

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Statistical Modeling of Vehicles Collision When Using a DVR with the Function of Signaling about Dangerous Motion of the Vehicle to the Oncoming Lane

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Abstract. There is a way of using a DVR for automatic collision warning of vehicles moving on the oncoming lane. This way is based on the analysis of the images parameters dynamics of vehicles on the road obtained with the help of a video recorder. The analysis determined the value that is compared with a threshold level. Its excess indicates an increased risk of collision of vehicles. At this time, the driver is notified of the need to change the parameters of the vehicle and the restructuring. When using this method, the question remains concerning the adjustment of the algorithm parameters. The aim of the work is to simulate statistically the probability of an accident with timely alarm to the driver about the risk of collision, as well as to study the effect of the alarm parameters on the probability of collision of vehicles moving on the oncoming lane. As a result of modeling, a series of dependencies on the collision probability of different parameters of the alarm algorithm, the car, the driver and the car movement is received. Based on the obtained dependences, it will be possible to conclude about the optimal setting of the parameters of the driver's alarm about the possibility of a collision, taking into account the status and performance of the road system, the car and the driver.

1. Introduction

Vehicles are an integral part of many sectors of the economy. In addition, cars are popular vehicles of many people around the world. It is estimated that their total number is increasing every year and, for example, in Russia it will have reached 45...50 million units by 2020-2025. The increased intensity of the use of vehicles has led to an increase in the number of road traffic accidents (RTA). So according to statistics, the annual number of traffic accidents in Russia exceeds 200 thousand, the number of deaths in them more than 40 thousand people and injured about 250 thousand people.

The main causes of road accidents can be divided into the following main groups:

1. violation of traffic rules and manoeuvring: failure to observe safe distances, sudden braking, lane change, overtaking violation of the rules, turn, U-turn, excess of the established speed of movement - about 55% of road accidents;
2. drunk driving-about 25% of road accidents;
3. ignoring the prohibiting signs, sleep at the wheel-about 20% of the accidents.

Thus, various violations of the rules of movement and maneuvering lead to more than half of the accidents. In some cases, the reasons for such violations are the lack of experience of drivers and their carelessness.



The analysis of the literature shows that at present manufacturers are trying to integrate active and passive safety systems and driver assistance systems, due to which the situation control of the car, the driver's warning about dangerous situations on the road or changing the parameters of the movement is carried out.

Thus in [1], çayır B. et al. described the issues of development and implementation of an active safety system based on machine vision and allowing to prevent accidents during the change of lanes and maneuvering in the flow. The operation of the system is based on the detection of unintentional or dangerous intersection of trajectories of neighboring vehicles considered by the car and the creation of visual and audible signals to warn the driver [1].

In [2], Chien J.-C. et al. presented a semi-integrated safety system of driver and pedestrian consisting of a camera focusing on the driver and a stereo system focusing on the road to detect road obstacles and pedestrians.

In [3], Liu G. et al. proposed a system to detect and alert the driver of blind spot in the daytime and at night. The operation of the system is based on the analysis of signals received by radar [3].

There are works on the possibility of using a smartphone to support the driver's activities. For example, in [4], Botzer A. et al. shown the operation of a special application for the smartphone notifying the driver of a possible collision with a moving car in front.

A number of studies are devoted to the study of the possibility of using various signals to warn the driver about the danger on the road. For example, in [5] Lubbe N. et al. compared the reaction times of braking, deceleration, and jerk when using the audiovisual, tactile, and optional Head-up display to warn of pedestrian collisions.

Thus in [6], Winkler S. et al. studied various strategies of visual warning of drivers. It is shown that despite the fact that general warnings provide good support to drivers, the warning strategy adapting to the situation and the driver's response (multi-stage warning), provides a more effective response to the situation. This has a positive effect on the rate of reaction and inhibition [6].

The use of a multi-stage collision warning system (first stage: informing the driver, second stage: warning the driver) was investigated in [7]. The experiments were carried out on the driving simulator. It is concluded that a too early signal may cause an incorrect reaction of the driver. The analysis of the driver's actions and the assessment of the corresponding time intervals led to the conclusion about the optimal alarm time [7].

The possibilities of using tactile signals to warn the driver of a collision are described in [8]. It is shown that such signals help to increase the driver's readiness for dangerous situations in comparison with traditional visual and audible warnings.

There are works that are devoted to the study of features and patterns of eye movement of drivers depending on the alarm conditions [9]. The results of such studies can be used to improve the effectiveness of the alarm system about the dangerous situation on the road.

The study of the effect of distracting sound signals on the speed of the driver's response to visual warnings was carried out in [10]. It is shown that such signals significantly increase the reaction rate of drivers and it is obtained that according to the simulation results about 50% of drivers may not have time to make a decision about the restructuring.

Thus, the task of developing and using the means of warning the driver about dangerous situations on the road is relevant. At the same time, the problem of signaling is not fully solved.

A method of using a video recorder for automatic collision warning of vehicles moving on the opposite lane is presented in [11]. This method is based on the analysis of the images parameters dynamics of vehicles on the road obtained with the help of a video recorder. The survey period is set and the area of vehicles on the image is determined at each moment of the survey. The ratio of the values of such areas in the neighboring moments of the survey is determined. The excess of the obtained value of the given threshold level indicates an increased risk of collision of vehicles. At this time, the driver is notified of the need to change the parameters of the vehicle and the restructuring.

In this paper, the options of the image dynamics on the DVR display are described, but not an assessment of the effectiveness of this method to prevent an accident, and the issue regarding the time of the alarm is not worked out.

The aim of the work is to simulate statistically the probability of an accident with timely alarm to the driver about the risk of collision, as well as to study the effect of the alarm parameters on the probability of collision of vehicles moving on the oncoming lane. At the same time, we will use the method described in [11] to assess the risk of collision of vehicles.

2. Simulation of the vehicles traffic

Let's consider the situation on the road, when the considered vehicle AM1, moving at a speed of V_1 , ahead of vehicle AM0, went to the oncoming lane. On the oncoming lane to meet it vehicle AM2 is moving at a speed of V_2 . The distance D is between vehicles AM1 and AM2, which D_0 is at the initial time ($t = 0$) (see figure 1). Let us set the following system parameters: t_r is a response time of the AM1 driver; t_b is response time of the TS1 control systems and the rebuilding of TS1. The width and height of AM2 are A and B respectively.

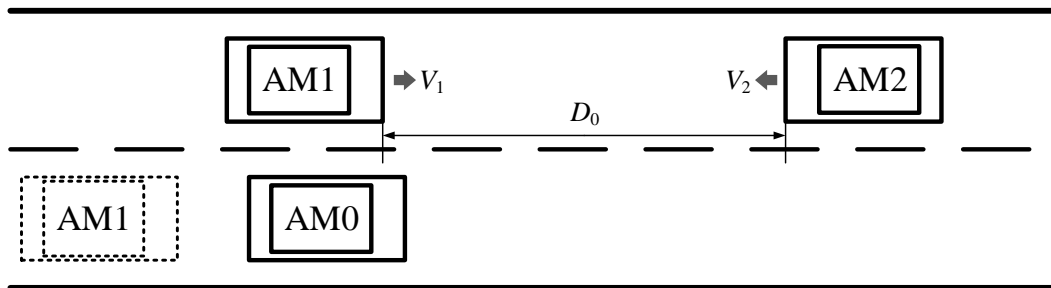


Figure 1. Model of movement of vehicles.

Vehicle AM1 is equipped with a video recorder, which displays the AM2 on the screen. The dimensions of the AM2 image on the DVR screen are a and b and change when the vehicles approach, i.e. when the distance D between them changes.

Let's set the projection point of vehicle AM2 and its display on the screen of the DVR. Let's define a vertical projection of the AM2 by GH segment, a lens of the DVR by OK segment, a vertical projection of the image AM2 on the screen of the DVR by FE segment. Let the distance from the lens to the DVR screen be d (see figure 2). Due to the similarity of triangles $\triangle OEF$ and $\triangle OGH$ is

$$\frac{b}{d} = \frac{B}{D}$$

and in the same way $\frac{a}{d} = \frac{A}{D}$.

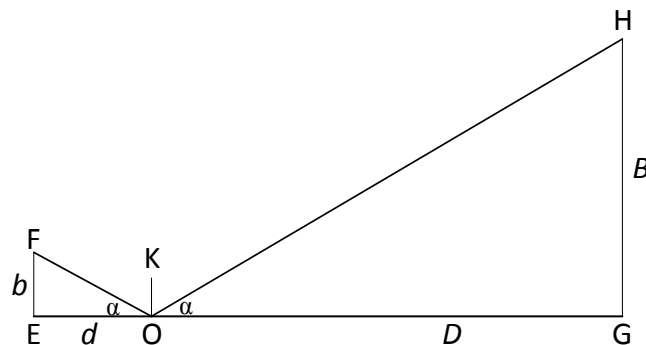


Figure 2. Projection of the AM2 and its display on the screen of the DVR.

Then

$$a = \frac{A \cdot d}{D} \text{ and } b = \frac{B \cdot d}{D}.$$

Since the values $A \cdot d$ и $B \cdot d$ are constants, the law of changing the size of the image AM2 a and b on the screen of the DVR on the distance between vehicles is an inversely proportional relationship. Respectively

$$a(D) = Ad \frac{1}{D} \text{ and } b(D) = Bd \frac{1}{D}.$$

The distance D between the vehicle changes over time according to the expression

$$D = D_0 - V_{con} \cdot t, \quad (1)$$

where V_{con} is the rate of convergence of AM1 and AM2, defined as the sum of V_1 and V_2 and considered as a constant. Respectively

$$V_{con} = V_1 + V_2.$$

Thus, we obtain expressions of the dynamics of linear dimensions over time:

$$a(t) = Ad \frac{1}{D_0 - (V_1 + V_2)t} \text{ and } b(t) = Bd \frac{1}{D_0 - (V_1 + V_2)t}.$$

We will assume that the image of car AM2 on the screen of the DVR is close to the rectangle, so its area is equal to

$$S(t) = a(t) \cdot b(t) = ABd^2 \frac{1}{(D_0 - (V_1 + V_2)t)^2}.$$

We will measure the area of AM2 image on the screen of the DVR at equal intervals Δt . We find the ratio $G(t_i)$ of such areas at the neighbouring time points t_i and t_{i-1} respectively:

$$G(t_i) = \frac{S(t_i)}{S(t_{i-1})} = \left(\frac{D_0 - (V_1 + V_2)(i-1)\Delta t}{D_0 - (V_1 + V_2)i\Delta t} \right)^2 = \left(\frac{D_0 - (V_1 + V_2)(i-1)\Delta t}{D_0 - (V_1 + V_2)i\Delta t} \right)^2 = \left(1 + \frac{(V_1 + V_2)\Delta t}{D_0 - (V_1 + V_2)i\Delta t} \right)^2, \quad (2)$$

где i is the number of time,

$$t_i = i \cdot \Delta t.$$

$G(t_i)$ changes from 0 at the initial time to infinity when cars collide. Therefore, by setting the threshold G_l level and comparing the current $G(t_i)$ value with this level, we can conclude that there is a risk of collision between AM1 and AM2. Accordingly, the signal $s(t)$ about the possible collision of cars will be formed from the condition

$$s(t) = \begin{cases} 1, & \text{if } G(t_i) \geq G_l, \\ 0, & \text{otherwise.} \end{cases}$$

The moment of signaling t_s or the moment number of signaling i_s is can be determined based on the condition

$$G(t_s) = G(i_s \Delta t) = G_s.$$

Using (2), we write the expression

$$\left(1 + \frac{(V_1 + V_2)\Delta t}{D_0 - (V_1 + V_2)t_s} \right)^2 = \left(1 + \frac{(V_1 + V_2)\Delta t}{D_0 - (V_1 + V_2)i_s \Delta t} \right)^2 = G_s,$$

from which we first define the largest integer i_s , and then t_s :

$$i_s = \left\lceil \frac{D_0}{(V_1 + V_2)\Delta t} - \frac{1}{\sqrt{G_s} - 1} \right\rceil$$

$$\text{and } t_s = \left\lceil \frac{D_0}{(V_1 + V_2)\Delta t} - \frac{1}{\sqrt{G_s} - 1} \right\rceil \Delta t.$$

According to (1) at time t_s the distance D_s between the cars will become equal to

$$D_s = D_0 - V_{con} t_s = D_0 - (V_1 + V_2) \left[\frac{D_0}{(V_1 + V_2) \Delta t} - \frac{1}{\sqrt{G_s} - 1} \right] \Delta t.$$

When evaluating the effectiveness of systems for collision warning of the AM1 and AM2 be aware that there is time t_r of the driver's reaction AM1 during which the awareness of the driver of the situation and decision about the need to rebuild, and time t_b of the operation of control systems of the AM1 and AM1 immediate rebuild. During this time the maneuver $t_r + t_b$ distance between vehicles will be reduced by the length of the maneuver

$$D_{man} = (t_r + t_b) \cdot V_{con} = (t_r + t_b) \cdot (V_1 + V_2).$$

Accordingly, if at the time of the alarm the distance D_s between the vehicles is less than D_{man} , the collision will occur. Thus, the condition of inefficiency of the alarm and collision of vehicles can be written as follows:

$$D_s < D_{man} \\ \text{or } D_0 - (V_1 + V_2) \left[\frac{D_0}{(V_1 + V_2) \Delta t} - \frac{1}{\sqrt{G_s} - 1} \right] \Delta t < (t_r + t_b) (V_1 + V_2). \quad (3)$$

Using this ratio, the probability of collision of AM1 with AM2 can be estimated at different points in the collision warning of vehicles. The same approach can be used for this purpose as in [12, 13].

3. Statistical modeling of vehicles collisions

The collision probability of the vehicles in question can be determined by statistical simulation using the Monte Carlo method. To do this, it is necessary to conduct a series of experiments with the obtained model (3), forming random values of the parameters in accordance with the given distribution laws. As a result of each experiment, we will fix two outcomes: the presence or absence of a collision of cars AM1 and AM2. Then the probability P_{col} of collisions will be determined as the ratio of number N_{col} collisions in N experiments to the total number of experiments N :

$$P_{col} = \frac{N_{col}}{N}. \quad (4)$$

The check of sufficiency of number N of the conducted experiments for the given error ε and confidence probability Q is estimated by the formula

$$N_{min} = \frac{P_{col} (1 - P_{col})}{\varepsilon^2} (F^{-1}(Q))^2, \quad (5)$$

where F^{-1} is the inverse Laplace function.

Let's set the error value $\varepsilon = 0.01$ and confidence probability $Q = 0.99$. At these values $F^{-1}(Q = 0.99) = 2.58$.

Random values of the model parameters will be generated according to uniform distribution laws in the following specified ranges: $V_1 = [60; 100]$ km/h, $V_2 = [40; 80]$ km/h, $D_0 = [60; 120]$ m, $t_r = [0.4; 1.0]$ m, $t_b = [0.1; 0.5]$ sec. The time interval value is $\Delta t = 0.25$ sec.

We perform a series of experiments $N = 20000$ at $G = 1.5$, the results of which we determine N_{col} and according to the formula (4) we calculate the P_{col} . We get $P_{col} = 0.307$. According to the formula (5) we determine the sufficiency of the number of experiments. We get $N_{min} = 14162$. Accordingly, the number of experiments is sufficient to estimate the obtained value of the collision probability with a given error and confidence probability.

We perform series of experiments at $N = 20000$ for each set and its value G , varying from 1 to 2 in steps of 0.01. The obtained dependence of $P_{col}(G)$ is presented on graph 3. From this figure it is seen that the collision probability is extremely small at $G < 1.4$, and then begins to increase with increasing G . At $G > 1.56$ collisions occur more often than in half of the cases. However, a small value of G corresponds to an early alarm, which is bad, because according to [7] it can lead to incorrect actions of the driver. In general, using this graph and other similar dependencies, we can conclude on optimal or trade-off values of G .

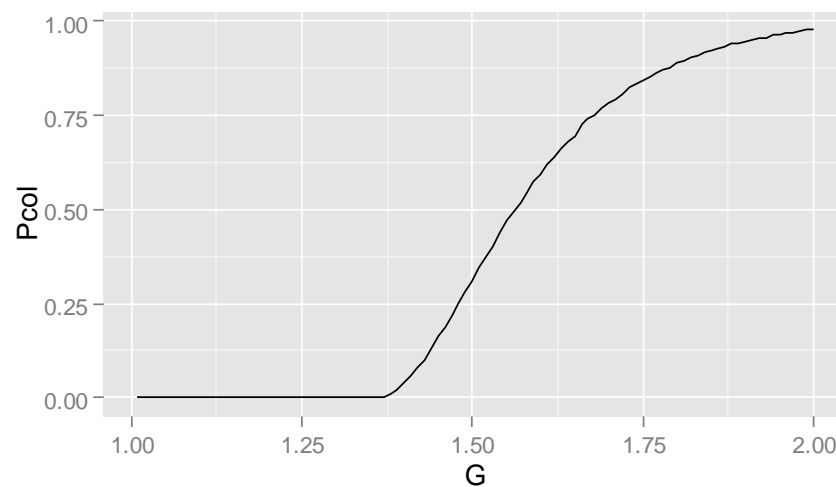


Figure 3. Graph of dependence of $P_{col}(G)$.

Similarly, we construct the dependence of $P_{col}(t_r)$ at $G = 1.5$. In this case, the values of the time t_r of the driver's reaction in each series of the experiment will set a constant from 0.4 seconds to 1.2 seconds. The obtained dependence of $P_{col}(t_r)$ is presented on graph 4. From this figure it is seen that if the driver's reaction time is less than 0.61 seconds, the probability of collisions is extremely small. With increasing reaction time, the probability of collisions increases and with a reaction time of about 1.1 seconds, a collision in the system under consideration with the given parameters is almost inevitable.

In general, the joint analysis of the obtained dependences will lead to the conclusion about the optimal setting of the parameters of the driver's alarm about a possible collision, taking into account the indicators of the road system, the car and the driver. Thus it will be possible to evaluate not only the optimal values of Δt , G , but also to draw a conclusion about the necessity of changing the speed of the car.

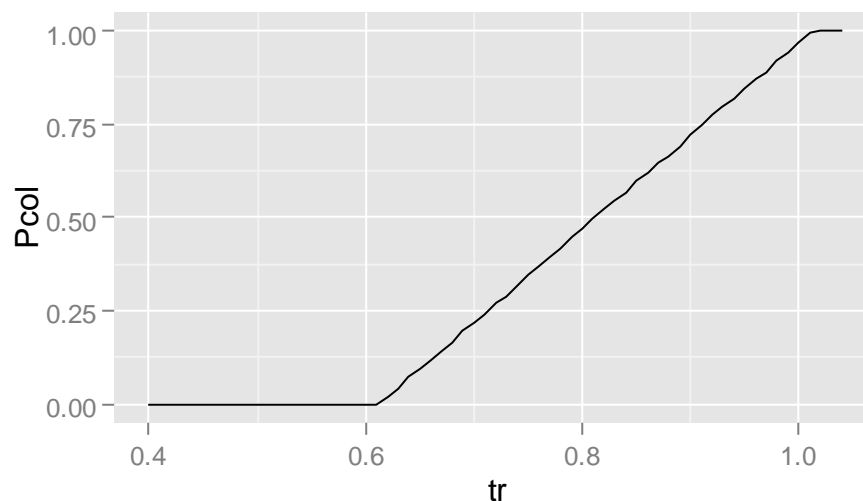


Figure 4. Graph of dependence of $P_{col}(t_r)$.

4. Conclusion

In this paper, the statistical modeling of vehicle collision during maneuver with the vehicle exit to the oncoming lane is carried out. In this case, the car that went to the oncoming lane, is considered

equipped with a video recorder with the function of warning of a possible collision with another vehicle. Using the Monte Carlo method, the probability of collision of vehicles is estimated at the given parameters of the road system under consideration.

As a result of this simulation, a series of dependencies on the collision probability of different parameters of the alarm algorithm, the car, the driver and the car movement is received. Based on the obtained dependences, it will be possible to conclude about the optimal setting of the parameters of the driver's alarm about the possibility of a collision, taking into account the status and performance of the road system, the car and the driver.

In the future it is planned to include other parameters and indicators in the considered model of movement and maneuver of vehicles, as well as to consider the effectiveness of signaling in other maneuvers of vehicles.

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