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The Issue of Probability of Traffic Road Accident on the Elements of the Transport Network

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Abstract

The uneven distribution of traffic on sections of the road network leads to the increase of intensity of traffic, which in turn exceeds the bandwidth of these areas. This leads to congestion and traffic jams, which significantly reduce the efficiency of functioning of the city's transport system, lead to an increase of mental and emotional stress of the driver and a temporary disruption of some of his physiological functions. The study is aimed at assessing the impact of the duration of traffic congestion on the level of fatigue and the reaction time of drivers of different ages and temperaments, as it largely determines the likelihood of traffic accidents in the transport network elements. To do this, the graphs, where there are considered the combined influence of age and the initial state of drivers with different temperaments at the level of fatigue of the driver in traffic jams and at the time of his reaction, are built. Developed non-linear model evaluates changes of reaction time of drivers of all temperaments in a traffic jam. Analysis of the graphs shows that for the drivers of all considered types of temperaments and ages (except phlegmatic temperament) with an initial normal state before the traffic congestion, further stay in the traffic jam leads to a deterioration of the functional state and to increase of their reaction time. Traffic congestion does not adversely affect driver-phlegmatic, but on the contrary, his condition gradually improves. The results can be applied in the development of measures for the improvement of road safety in the cities.

Keywords

Traffic Congestion, Functional State, Response Time, Traffic Accident, The Level of Fatigue, Temperament

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1. Introduction

The effectiveness of functioning of the city's transport system largely depends on the technology of organization of traffic management. It is necessary to know the laws of formation and management of traffic flows to develop this technology. The transport system is a complex, self-organizing system with its own features and characteristics [1].

The safety and reliability of the transport system depends on smooth, high-quality work of all its elements. In more than 70% of cases, faults and failures in the system occur because of the driver. Therefore, the design of transport system and traffic management should take into account psychophysiology of the driver and peculiarities of his activity.

Technology of organization of traffic in cities must provide the passage of vehicles without delay. However, multiple queues of vehicles are formed in many sections of the road network of cities. They lead to the appearance of congestion. Jams are formed because of the excess of intensity of traffic flow over the bandwidth of separate sections of the road network. Stay in traffic congestion has a negative impact on the driver's psychophysiology, it leads to a deterioration of its functional state, increase of reaction time and increase the likelihood of committing a road traffic accident (RTA) [2, 3].

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2. Literature Survey and Purpose Statement

A lot of researches work in the field of road safety and its management. Questions of the organization of traffic are considered in the work [2], taking into account the intensity, speed and road capacity. In the work [4] the effect of speed on the driver's reaction time is examined.

The association between traffic congestion, the occurrence of stress in the driver and his behavior is established by the authors of work [5, 6]. Such qualities as a driver's reaction time, work experience, temperament have been considered in their research by the authors of works [3, 7, 8]. The researchers took measurements of the reaction time of drivers in different situations with the help of different methods [9, 10].

Stay in congestion adversely affect physiological qualities of the driver. Growth of emotional tension leads to a temporary breakdown of some of his mental functions, increasing the reaction time [11–19]. The authors of works [20, 21] determined time of reaction of young and older drivers.

However, the impact of traffic congestion on the driver's reaction time and the likelihood of the traffic accident are not fully considered in the reviewed works. Thus, the study of changes in the probability of an accident in the agreed terms and conditions is pertinent.

3. Goals and Objectives of the Study

In this paper, research object is the process of emergence of traffic accidents on separate elements of the transport network. The objective of the study is to analyze the driver's activities as an element of the system, which creates the risk of an accident.

To achieve the objective of the study it is necessary to achieve the following results:

A. Set the dependency or its absence between the driver's reaction and the likelihood of an accident.

B. Develop a model for determining the time of driver's reaction in a traffic congestion.

C. Consider drivers with different types of temperament as the basis for change of the reaction time.

4. Data and Results of Research

4.1. Categories of Drivers and Equipment

Drivers of all ages and categories participated in experimental studies. To assess the impact of traffic congestion on the functional state of the driver, drivers of all age groups and types of the nervous system were involved. The most appropriate method from all the psychophysiological methods to solve this problem is the assessment of the functional state by recording an electrocardiogram. Electrocardiogram is the most studied indicator from all the psychophysiological indicators and methods of its measurement and analysis are the most perfect. This is because an electrocardiogram is widely used in clinical practice for the study of the cardiovascular system. In the psychophysiology electrocardiogram serves as the main indicator of a person's emotional state during physical and mental stress [3].

Electrocardiogram is fixed by portable electrocardiograph "Kardiosens", which is self-powered. For the determination of the driver's reaction, the device, consisting of a telescopic antenna, timer, pointer and switch of the light signal was used.

4.2. The Methodology of Experimental Research

Experimental studies are in fixing the electrocardiogram of the drivers at the entrance to the transport congestion, inside the traffic jam and on the way out of it. At the same time driver's reaction time was measured.

Driver's level of tension was estimated by the analysis of heart rate and determination of the level of fatigue (*Fl*) by the prof. Baievsky R. M. method [22]. It is calculated by an algorithm that takes into account five criteria:

A. The overall effect of regulation.

B. The total activity of regulatory mechanisms.

C. Vegetative balance.

D. The activity of the vasomotor center, regulating vascular tone.

E. The activity of cardiovascular subcortical nervous center.

F. l value are provided on a scale from 1 to 10. The following functional states based on the analysis of *Fl* values can be diagnosed:

A. State of optimal tension of regulatory systems (norm *Fl* = 1-2);

B. State of moderate tension of regulatory systems (*Fl* = 3-4);

C. State of expressed tension of regulatory systems (*Fl* = 4-6);

D. Overvoltage state of regulatory systems (*Fl* = 6-7);

E. State of exhaustion of regulatory systems (*Fl* = 7-8)

F. Breakdown state of adaptive mechanisms (*Fl* = 8-10).

Driver's reaction time was determined by the moment of driver's touch of the appropriate section with a special pointer, connected with telescopic antenna after the signal. At the time of the signal, the timer was switched on and was stopped after the touch of pointer to the antenna. In order to ensure road safety, certain moment to determine the reaction time was selected by the driver.

5. The Results of the Research

5.1. Model of the Impact of the Driver's Condition at the Time of His Reaction

In order to develop a mathematical model of the impact of traffic congestion on the functional state of the driver and his reaction relevant research was carried out. In the process of model development well-known statistical methods and regression analysis method were used [23, 24]. The developed model is as follows:

$$\Delta T_p = 0,029 + 0,022(Fl_2 - Fl_1)^2, \quad (1)$$

where ΔT_p – change of the driver's reaction time, c;

Fl_2 – when leaving the congestion, points;

Fl_1 – at the entrance to the transport congestion, points.

The calculation results of the model parameters are given in Table 1.

Table 1. Characteristics of the model of change of driver's reaction time depending on changes in its functional state after stay in traffic jams.

Parameters	Designation, dimension	The boundaries of measurement	Coefficient	Standard error	Student's criterion	
					Calculated	Tabular
Coefficient	–	–	0,029	0,001	30,6	2,0
Difference between fatigue level when leaving the congestion and at the entrance to congestion, squared	$(Fl_2 - Fl_1)^2$, points	0,01–13,69	0,022	0,0001	130,1	2,0

As shown in Table 1, in the developed mathematical model coefficient and the squared difference between *Vy* at the entrance and exit of the traffic congestion have proven to be influential. The fact of exceeding the calculated value over the tabular one shows their importance.

The average approximation error is 6.51%. This error is acceptable, and the developed model can be used to determine the change in the driver's reaction time after his stay in the traffic jam.

5.2. Change in the Time of Reaction of Drivers with Different Temperaments in the Traffic Congestion

Individual typological characteristics and temperament of the driver significantly affect his functional state and, therefore, time of his reactions.

To carry out studies on the evaluation of influence of traffic congestion on the reaction time, drivers with different temperaments were selected: choleric, sanguine and melancholic.

The results of some studies regarding the estimation of the impact of traffic congestion on the driver's reaction time are shown in Figure 1.

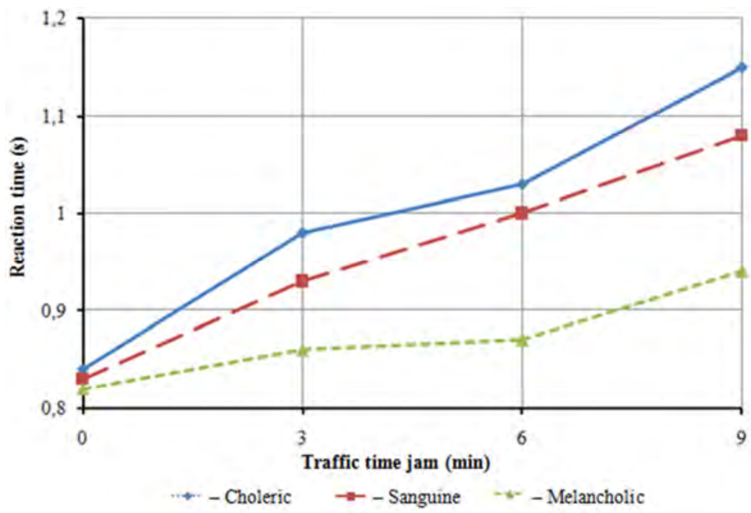

Figure 1. Change in the time of reaction of drivers with different temperaments in the traffic congestion.

As shown in Figure 1, staying in traffic congestion most of all increases the reaction time of the driver-choleric. The reaction time of the driver-melancholic changes the least.

Also, there was conducted a study on the definition of the reaction time of drivers with different temperaments during their stay in the traffic jam and after it. To assess the impact of traffic congestion on the driver's reaction time drivers with different temperaments were selected: choleric, sanguine and melancholic. The results are shown in Figure 2 [25].

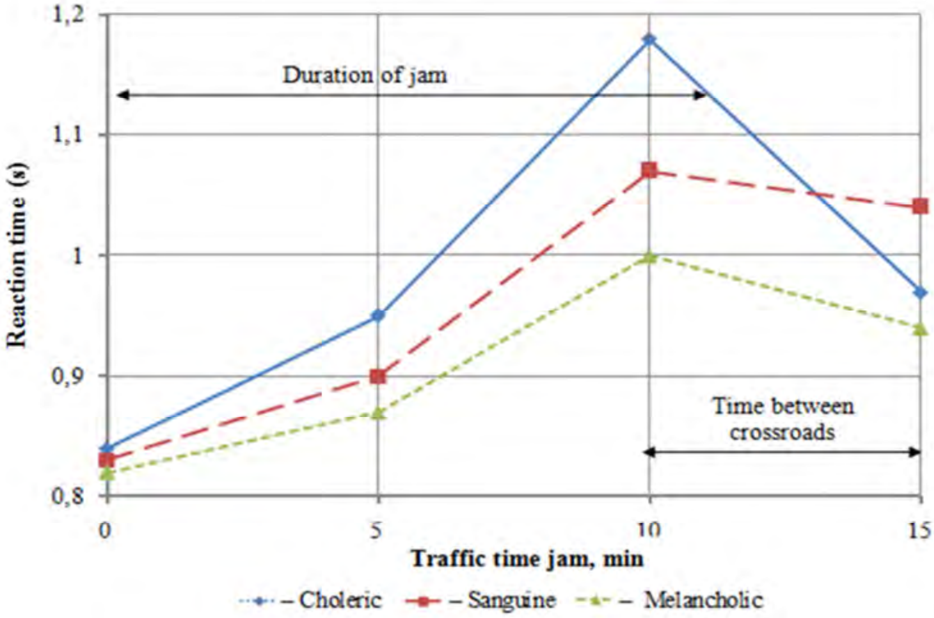

Figure 2. Change in the time of reaction of drivers with different temperaments in the traffic congestion.

To assess the impact of traffic congestion on the reaction times of drivers of different ages and temperaments regression models have been developed [19]. Figures 3-8 show the results of studies of changes in reaction time of drivers with different temperaments and age in traffic jams.

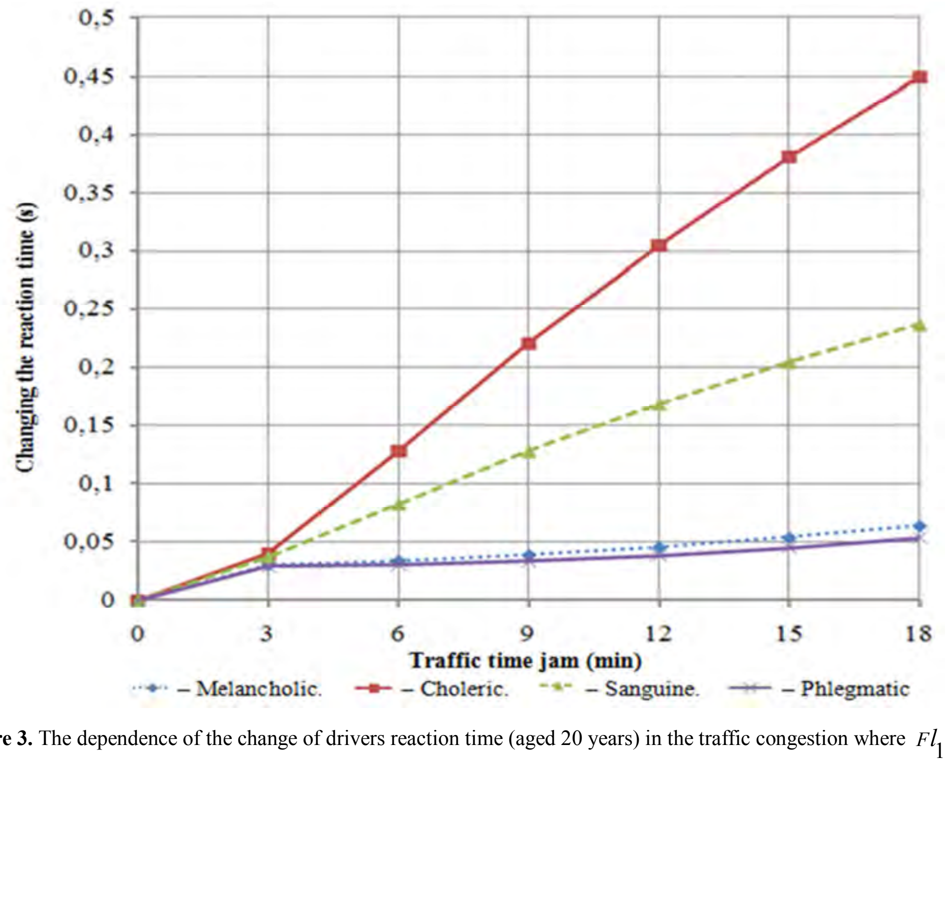

Figure 3. The dependence of the change of drivers reaction time (aged 20 years) in the traffic congestion where Fl_1 = 2.

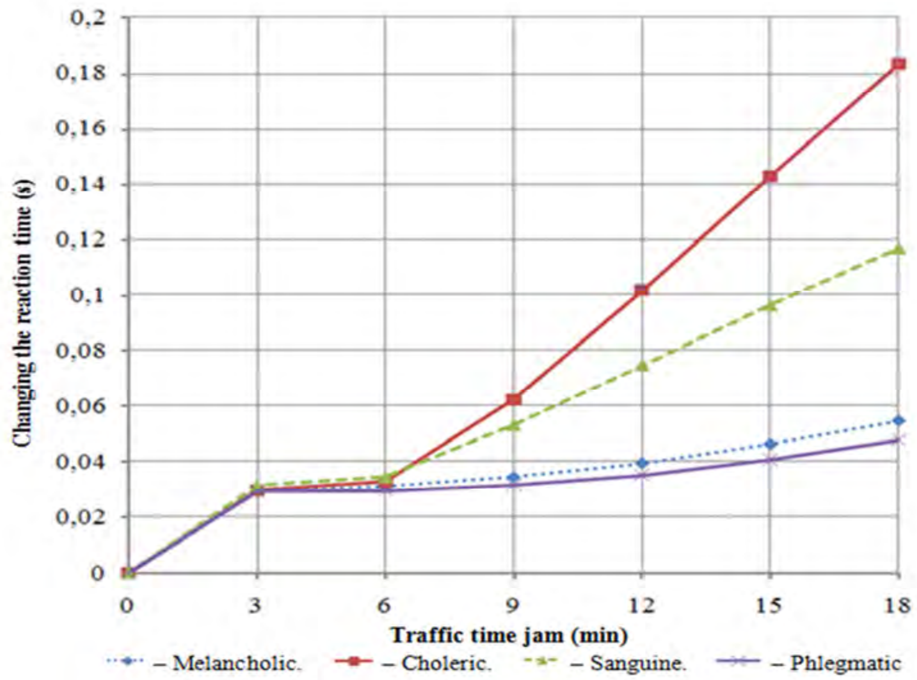

Figure 4. Change in the time of reaction of drivers (aged 20 years) in the traffic congestion where Fl_1 = 4.

At Fl_1 = 4 points reaction of twenty years old drivers with different temperaments changes as shown at Figure 4. Until the sixth minute of the traffic jam reaction time of drivers of all temperaments vary equally and insignificant. Further, it increases: for choleric - at 0.2 seconds, for sanguine – at 0.12 seconds, for the drivers of other temperaments – at 0.05 seconds.

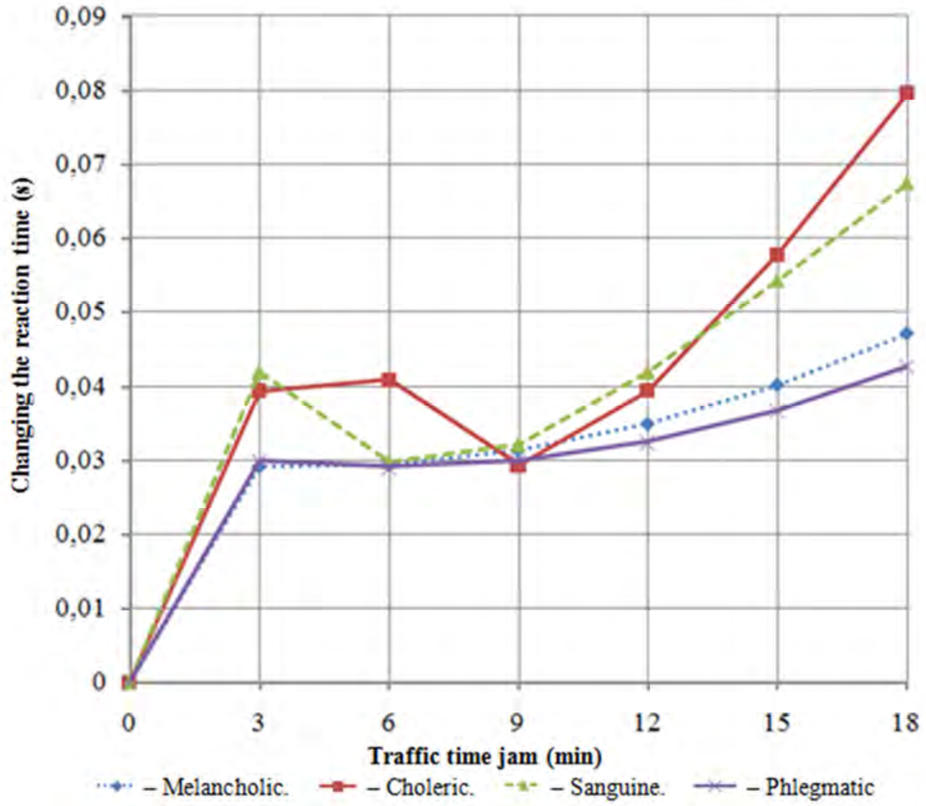

Figure 5. The dependence of the change of drivers reaction time (aged 20 years) in the traffic congestion where Fl_1 = 6.

Dynamics of changes in reaction time of young drivers of all temperaments in traffic congestion at Fl_1 = 6 points is shown in Figure 5.

In Figure 7 the corresponding reaction time is changed as follows: for choleric-driver it is 0.23 seconds, for the driver-sanguine - 0.15 seconds, for the driver-melancholic - 0.08 seconds and for the driver-phlegmatic - 0.05 seconds.

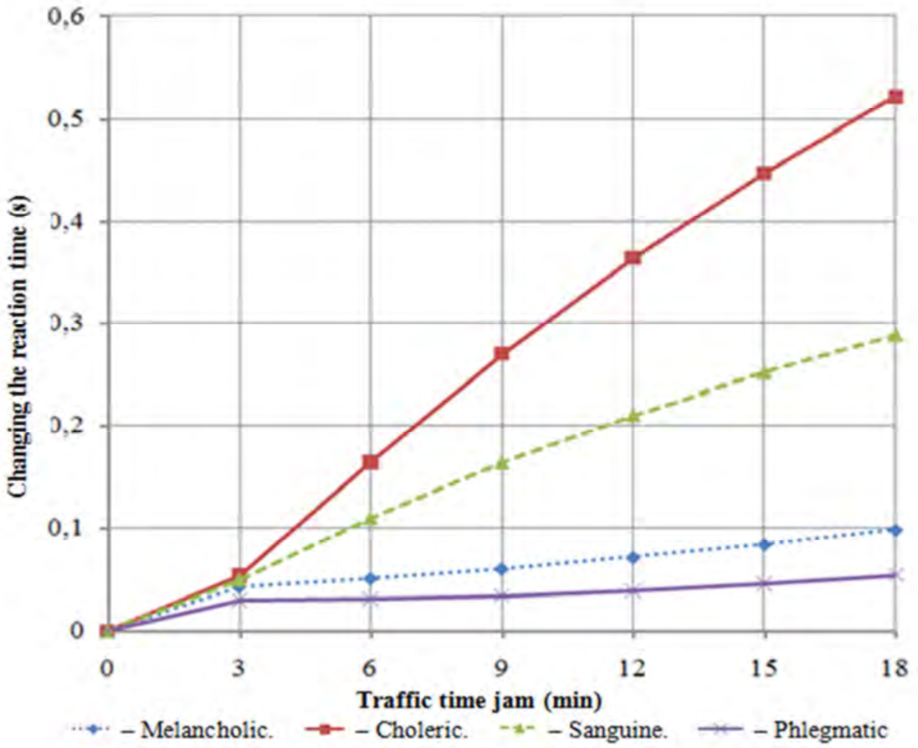

Figure 6. The dependence of the change of drivers reaction time (aged 60 years) in the traffic congestion where Fl_1 = 2.

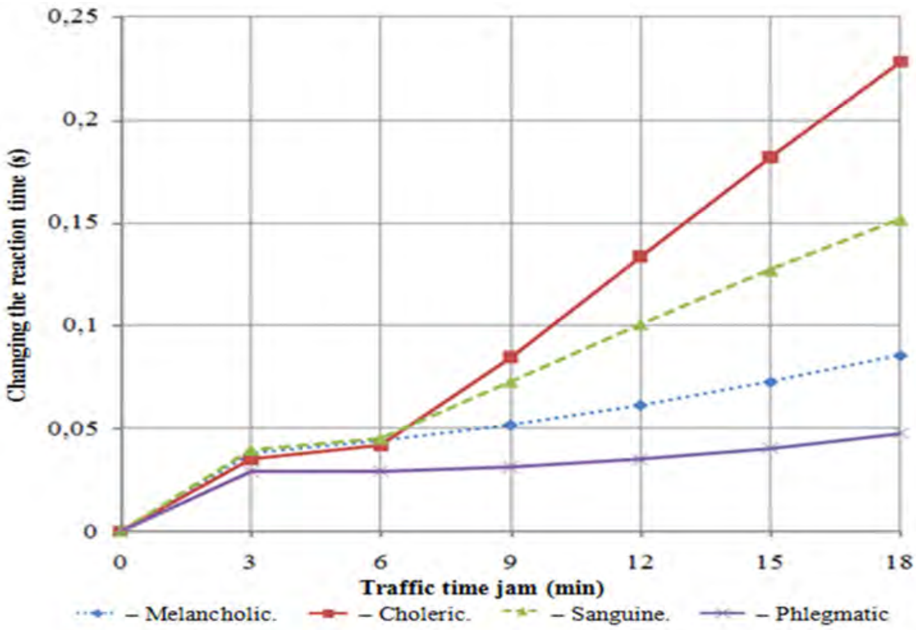

Figure 7. The dependence of the change of drivers reaction time (aged 60 years) in the traffic congestion where Fl_1 = 4.

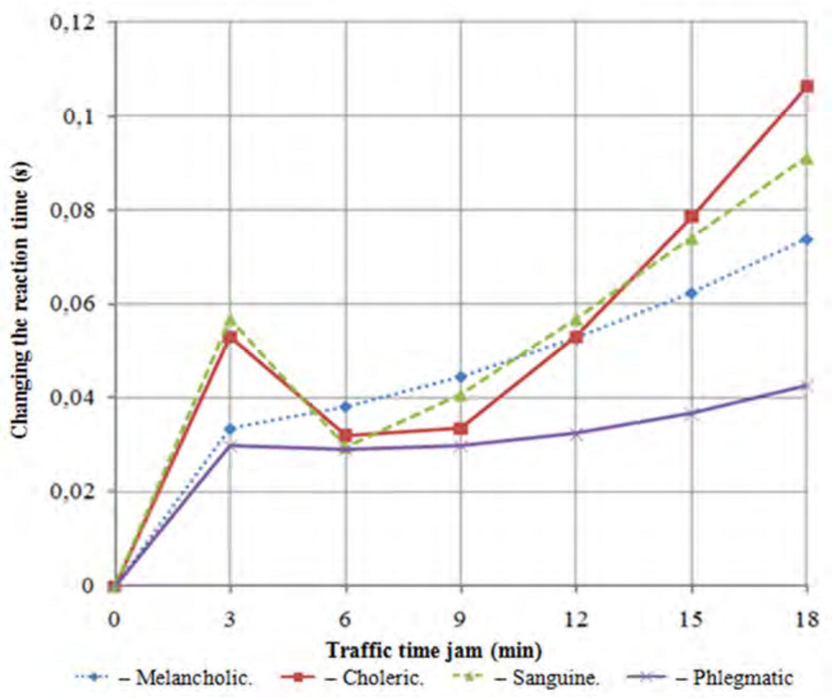

Figure 8. The dependence of the change of drivers reaction time (aged 60 years) in the traffic congestion where $Fl_1 = 6$.

In Figure 8 the reaction time of the driver-choleric and driver-sanguine is also rising up till the third minute of traffic jam, then it reduces to six minutes, then again increases, reaching at the end of the jam the meanings 0,092 seconds and 0,078 seconds respectively.

Until the twelfth minute of the jam corresponding change of reaction time of all drivers other than the phlegmatic, is aligned, reaching 0.055 seconds.

6. Discussion

As shown in Figure 2, the change of reaction time of the driver-choleric in traffic congestion is the biggest one, and of the driver-melancholic - the smallest. However, after the exit from the traffic jam, reaction time of the driver-choleric reduces much faster than for the other drivers.

Figure 2 shows that after the traffic congestion the first part of the trip is the most dangerous on the likelihood of an accident. At the first part of the trip after the traffic jam the probability of being in an accident is higher for the driver-choleric, and at the next part for the driver- sanguine.

As is clear from Figure 3, when $Fl_1 = 2$ points reaction time of drivers in traffic congestion increases for drivers of two temperaments - choleric and sanguine. Until the end of traffic congestion corresponding change in reaction time for the named drivers will be the following: for the driver-choleric - 0.45 seconds, for the driver-sanguine - 0.24 seconds. Therefore, traffic congestion has a negative impact on the functional state of the driver and increases his response time.

Change of the reaction time of the driver- melancholic and the driver-phlegmatic is negligible. Reaction time of drivers of all temperaments slightly increases until the third minute of the traffic jam, until the sixth minute reaction time of the driver-sanguine slightly reduces. Such reduction is observed in the driver-choleric from sixth to ninth minutes. Then reaction time of the drivers of all temperaments increases and the corresponding change of this time for the driver-choleric will be 0.08 seconds, and for the driver-sanguine - 0.07 seconds. The reaction time of the driver- melancholic and the driver-phlegmatic gradually increases, and the change of reaction time for them is equal to 0.04 seconds at the of end congestion.

At $Fl_1 = 2$ points, tendency of change of the reaction time of drivers of all temperaments in traffic congestion, shown in Figure 5.6, is similar to shown in Figure 3, and at Figure 7 (if the level of fatigue at the beginning of congestion is equal to 4 points) it is similar to changes in the Figure 4. In Figure 6 the reaction time of drivers of all temperaments except driver-phlegmatic, changes equally to the third minute of the traffic jam, and in Figure 7 (except phlegmatic) – to the sixth minute. Further, drivers' reaction time is growing, and at the end of the traffic jam these changes reach such values (Figure 6.): for the driver-choleric - 0.52 seconds, for the driver-sanguine - 0.29 seconds, for the driver-melancholic - 0.1 seconds and for the driver-phlegmatic - 0.05 seconds.

7. Conclusions

The likelihood of an accident largely depends from the driver's reaction time. With the help of the developed non-linear regression model, the reaction time of the driver of any temperament can be determined, both during his stay in the traffic jam, and after exit from it. To do this, one should know the initial and final value of fatigue level of the driver.

Experimental researches proved that driver's reaction time varies in different drivers with different types of the nervous system. In the case of identical initial values of the response time at the exit out of congestion, reaction time of the driver-choleric decreases faster than reaction time of the driver-sanguine.

In developing the technology of traffic management it is necessary to take into account the results of studies that determine the reaction time of the driver and traffic safety.

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