THE MOTIVES OF DRIVERS' BEHAVIOR WHEN CHANGING LANES

Yakimov, Mikhail R., *Perm National Research Polytechnic University, Perm, Russia.*

ABSTRACT

In the context of psycho-physiological model of the car driver's behavior a place of behavioral situation «lane change» is considered within a common set of factors affecting the duration of transport correspondence. The definition of required lane change maneuver by own vehicle is given. With the help of mathematical calculations and full-scale video surveillance change in movement of other vehicles when changing lanes on a multilane highway is investigated.

Keywords: car, road, driver's behavior, manner of driving, psychophysiological model, traffic flow, lane change.

Background. *Movement is a mandatory component in the life of any human being, but movement in large cities in XXI century cannot be imagined without transport – so large distances we began to develop. Moreover, movement scale is such that any of the vehicle users faces different driving situations.*

Objective. *The objective of the author is to consider lane change maneuver and driver's behavior in this situation.*

Methods. *The author uses general scientific methods, simulation, comparative analysis.*

Results.

Typical in individual

Transport correspondence is made by a modern man almost every day, and we cannot say that their duration is always the same. However, there are several key factors that influence the choice of one or another variant.

Before determining factors it should be noted that the traffic consists of movements of individual vehicles and traffic flows, and is a result of interaction of the elements of the complex «car–driver–road–environment» («CDRE») [1]. Consequently, the factors can be divided into three groups corresponding to the elements of the complex:

1. Features of a passed section of the road network (distance between start and end points, the number of lanes on the roadway, the presence of regulated and non-regulated intersections, road surface condition, and others.);

2. Technical characteristics of a vehicle. It is worth noting that the inevitable modification of the fleet makes to conduct and maintain a constant monitoring of changing characteristics of the traffic flow.

3. Features in the driving style of a driver.

Indeed, the driver's behavior in different situations can be put on a par with other factors which, at first glance, have a greater impact on the same duration of the transport communication. An active human role in the transport correspondence manifests itself in planning, decision-making, exit from a particular traffic situation and, more often, in rapid processing of a variety of information in a limited time. It is he who in this case assesses the risk and ensures safety while driving [2].

A lot of research on influence of character features of the driver to drive a car was conducted. Thus, A. A. Makenov [3] identifies the relationship between the manner of driving of the car and the person belonging to different groups of psychological type. As a result of selective testing of drivers it was highlighted that psychological group – cholerics, which is most prone to risk driving. A. A. Oseev [4] examines the relationship between personality traits of the driver (courage, elevated moral standards, equability of mind, creative imagination) and his features of a car driving.

Generally those people are most prone to aggressive driving who are under the influence of constant psychological stress, as well as those who are feeling the strong pressure of emotions. Sometimes this leads to a splash of negative emotions on others, often a nervous man, and not wanting that, is unable to control his emotions [5], which manifests itself in neglecting safety distance with respect to the vehicle ahead, ignoring warning traffic signals at controlled crossings, abrupt lane changing.

All features of the behavior behind the wheel have a huge impact on duration of the transport correspondence and are unified by a psycho-physiological model of driver's behavior.

The psychophysiological model can be viewed as a set of standard behavioral situations:

1) The behavior of the driver црут following the vehicle ahead.

2) The behavior of the vehicle driver when changing lanes.

3) The behavior of the driver with respect to the vehicle, located next to him.

4) The reaction of the driver to changing traffic light signals.

In this case, our aim is not to examine each of these model types, our interest concerns primarily the behavior of the driver when lane change maneuvering and accompanying changes in the movement of other vehicles. The reason is clear: lane change is characterized by interaction of several road users and features of drivers' behavior in such a tense situation manifest themselves most clearly. In comparison, for example, with keeping safety distance with respect to the vehicle ahead.

«Priority» of six seconds

The tasks of the study include:

– Determining the required lane change maneuver;

– Study of the maneuver conditions (their detection and calculation);

– The study of interaction of the vehicle drivers when lane changing (form, options and calculation at the section of the road network at the time moment).

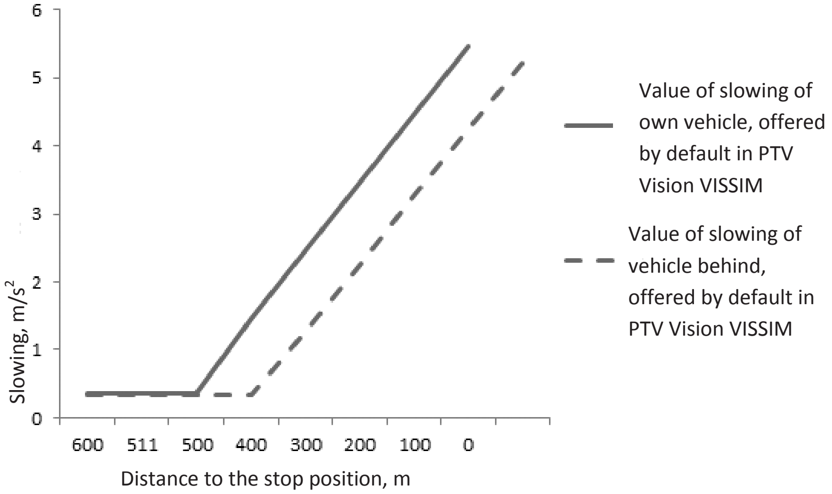
In the analysis of lane change process, the following basic terms are used:

Lane change maneuver – exit of the vehicle from the occupied lane while preserving the original traffic direction.

Own vehicle – a vehicle which driver has committed to the lane change maneuver.

Vehicle ahead – a vehicle moving in front of own vehicle on the same lane.

Vehicle behind – a vehicle moving behind own vehicle on the same lane.



Pic. 1. Graph of slowing function when performing required lane change maneuver with calculated values of parameters.

The first vehicle of the interval on the lane – a vehicle moving the first in the interval on the desired lane, in which the driver of own vehicle has an intention to integrate while performing lane change maneuver.

The second vehicle of the vehicle on the lane – a vehicle moving the second in the interval on the desired lane, in which the driver of own vehicle has an intention to integrate while performing lane change maneuver.

Desired lane – driving lane, which the driver of own vehicle has an intention to take while performing lane change maneuver.

Position of forced stop – a point on the occupied lane, where the drive of own vehicle will be forced to stop if he fails to perform lane change maneuver.

Interval on the lane – distance between vehicles moving one after another in the desired lane.

Suitable interval on the lane – distance between vehicles moving one after another in the desired lane, which will allow own vehicle to perform lane change maneuver

It is worth noting that the reason why the driver of the vehicle makes a decision about the upcoming maneuver is also important. Depending on this reason lane change can be classified in two ways:

1. An arbitrary lane change – lane change maneuver carried out by the vehicle driver for more freedom of movement and a higher speed.

2. Required lane change – lane change maneuver carried out by the vehicle driver with a view to further make the maneuver to change traffic direction.

In both cases, when the driver decides to make a lane change maneuver, the main condition for this becomes adequate time interval – suitable interval on the desired lane. Check for a suitable interval occurs usually occurs while slowing own vehicle. Wherein:

1. There is a consistent slowing of own vehicle up to the position of forced stop.

2. Vehicle behind own vehicle at this time is watching the maneuver and starts braking process [6].

In aggregate, behavior of drivers when changing lanes can be represented as a graph containing the function of slowing of own and behind vehicles, depending on the distance to the position of forced stop (Pic. 1).

Recall that convergence of two transport flows is possible with the presence of a suitable interval on the

Table 1

Distribution of intervals between vehicles on the lane, seconds

№ vehicle / № min	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1,8	1,9	1,9	1,7	2,8	1	1,3	2	1,4	0,9	1,1	0,9	2,3	1,8	1,3	1,8	1,7	1,5	1	0,9
2	2,5	1,7	8,7	1,4	0,8	2,9	3,2	1,2	1,1	1,6	1,7	1,9	1,7	1,8	1,8	1,2	1,6	1,1	1,2	1,1
3	1,3	0,6	1,9	2,5	1,1	1,2	2,9	1,3	0,6	1,9	1,5	1,9	9,6	1,5	1,2	1,3	9,7	2,5	2,3	2,1
4	1,9	1,6	1,8	1,2	2	1,2	1,1	1,8	1,5	2,5	1,4	2	3,1	2	1,5	3,5	8,6	3,5	2,9	1,7

№ vehicle / № min	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
1	0,9	1,7	1,4	1,5	0,7	1,6	1,3	1,4	2,5	1,9	1,9	1,3	1	2,3	1,3	1,2	2,2	2,1	0,3
2	1,5	1,4	1,6	1,8	1	1,7	1	1,9	2,5	1,1	1,2	2,9	-	-	-	-	-	-	-
3	1	2,5	1,4	1,2	2,4	2,1	1,5	-	-	-	-	-	-	-	-	-	-	-	-
4	9,5	2,9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2

Calculated values of the function of change in deceleration when making required lane change maneuver

Distance to the position of forced stop, m	Calculated value of own vehicle	Calculated value of the vehicle behind
600	0,35	0,33
500	0,35	0,33
400	1,46	1,25
300	2,46	2,25
200	3,46	3,25
100	4,46	4,25
0	5,43	5,25

desired lane. However, not every interval on the lane will be suitable. For example, at a maximum intensity of the vehicle movement on one lane (600 vehicles / h), the average interval on the lane is about 6 seconds.

Presumably, 6 seconds are perhaps insufficient to perform lane change maneuver. However, due to the fact that the transport flow is uneven (because of traffic signalization, pedestrian traffic across the roadways, etc.), the size of intervals on the lane can either decrease or increase. Practice shows that even under high traffic density there are suitable time intervals for lane change maneuver.

Check on the roads

The author and his colleagues made a special study of the distribution of intervals on the lane at the 4-minute time range for one of the streets of Perm. The survey was conducted with records from CCTV cameras included in ATCS (Automated Traffic Control System).

The study was conducted as follows:

1. Time (sec.) was noted since the beginning of the video clip to the moment of entry of the first vehicle into the zone of visibility.

2. Time (sec.) was fixed from the moment of entry of the first vehicle into the zone of visibility until the entry of the second vehicle into the zone of visibility, that is time, which also characterizes the interval between vehicles on the lane. The operation was repeated for 5 minutes.

In parallel with the study of distribution of intervals on the lane the average speed of traffic flow was taken into account.

As a result, values of time were obtained, which are observed between the moments of vehicles' entry into the zone of visibility (Table 1). These figures relate to the transport flow, moving at a speed of 45.5 km / h. The table shows that generally the duration of intervals between vehicles on the lane is not more than 3 seconds, but there are also intervals of 9 seconds.

The next step was to determine the value of a suitable interval on the lane between vehicles on the desired lane. Interval size should be such that enables own vehicle to perform lane change maneuver.

Before proceeding to the calculation, it should be noted that the interaction of vehicles in the zone of traffic flow convergence is as follows: own vehicle (0) moves in anticipation of a suitable interval (Δd) (on the main (desired) lane, on which car traffic moves at a speed of V_t. And it is necessary to make lane change maneuver so as not to create obstacles to the vehicles moving on the desired lane. That is, they should not slow down, giving way to own vehicle, but the collision should not occur.

The duration of a suitable interval on the lane can be represented using a sum of two quantities:

$\Delta d = d_1 + d_2$, (1)

where Δd is a duration of a suitable interval on the lane (sec.);

d_1 is a duration of the interval between the first vehicle of the suitable interval and own vehicle (sec.);

d_2 is a duration of the interval between the second vehicle of the suitable interval and own vehicle (sec.).

In turn, d_1 can again be divided into several components:

1. The duration of reaction of the driver of own vehicle (T_{reac_0}) and duration of the actuation of the braking system (T_{brak_0}). In sum, these two indicators – one second.

2. Static external dimension of own vehicle (g_{veh_0}) and a minimum safety clearance between vehicles ($g_{veh_{1-0}}$). The sum of two figures was accepted as 4,5 m.

3. The difference in braking distances of the first car at the suitable interval on the lane and own vehicle $(l_{veh_0} - l_{veh_1})$. This difference was calculated based on coefficients of operating conditions of braking of front and rear vehicles (1,8), traffic speeds on the main lane and coefficients of coupling weight (0,5), tire traction (0,7), road resistance (0,425) and visibility (1,8). As a result, the difference in braking distances is 1,5 seconds.

Accordingly, by adding the components the duration of the interval d_1 was obtained:

$d_1 = 1 + 4.5 + 1.5 = 7$ sec. (2)

To obtain Δd it is necessary also to calculate the interval d_2, which includes:

1. The duration of reaction of the driver of own vehicle (T_{reac_0}) and duration of the actuation of the braking system (T_{brak_0}). In sum, these two indicators – one second.

2. The minimum safety clearance between vehicles in relation to the average traffic flow speed on the desired band. As a result of the calculation the value was set as 0.004.

3. The difference in braking distances of the first car at the suitable interval on the lane and own vehicle $(l_{veh_2} - l_{veh_0})$. This difference was calculated based on coefficients of operating conditions of braking of front and rear vehicles (1,8), coefficients of coupling weight (0,5), tire traction (0,7), road resistance (0,425) and visibility (1,8). As a result, the difference in braking distances is 1,5 seconds.

Accordingly, by adding the components the duration of the interval d_2 was obtained:

$d_2 = 1 + 0.04 + 1.5 = 2,54$ sec. (3)

Recall that a suitable interval is a sum of intervals d_1 and d_2. Then:

$\Delta d = 7 + 2,54 = 9,54$ sec. (4)

Waiting for maneuver

It should be noted that some of the indicators included in the suitable interval is constant regardless of the speed *of movement of the vehicle and the road surface condition, and a part changes based on traction and speed characteristics of the vehicle. Constant indicators include safety distance, vehicle external dimensions. Variables (acceleration time, stopping distance) depend on power characteristics of the engine, braking system efficiency, taking into account wear of working elements and the road surface condition [7].*

When comparing the obtained value of the suitable interval Δd of 9,54 seconds with distribution of the intervals, shown in Table 1, five suitable intervals were identified. At their waiting times are significantly different from each other – waiting time of the first suitable interval cannot be determined, waiting time of the second – 74, of the third – 13,7, of the fourth – 57,5, of the fifth – 16,6 seconds. From these values the average waiting time was derived, which is equal to 40,55 seconds.

We should not forget that while waiting for a suitable interval on the lane for lane change maneuver own vehicle does not stand still, but is moving along the roadway. To get the distance that it covers in anticipation of a suitable interval, it is necessary to multiply the average waiting time by the speed of the vehicle:

$$S = V \cdot t = 40{,}55 \cdot 12{,}6 = 510{,}93 \approx 510 \text{ m}. \quad (5)$$

However, only distance value is not sufficient to fully characterize the lane change maneuver. It is necessary to know the value of a suitable deceleration.

In our case, it was found through studies of decelerations for different speeds. However, we were primarily interested in the slowing observed at a speed of 45,5 km / h, established under the terms of the study of suitable intervals on the lane. This value is 0,35 m / s^2.

Maximum deceleration was obtained from the study of technically feasible mode. At a speed of 45,5 km / h, it is 5,43 m / s^2.

In addition, in the graph of changes of deceleration when making required lane change maneuver a slowing function of the vehicle behind is also taken into account. If the vehicle ahead is braking, then the vehicle behind should also brake. At the same time deceleration of the vehicle behind can be carried out not at the same distance, as slowing of own vehicle. So, if slowing of own vehicle occurred along 510 meters, then for the vehicle behind at a distance of

$$S_{behind} = S_{own} - d, \quad (6)$$

where S_{behind} is a distance at which slowing of the vehicle behind will occur;

S_{own} is a distance at which slowing of own vehicle occurs while lane changing (taken as 510 m);

d is an interval on the lane between S_{behind} and S_{own} (taken as 20 m).

It was found that the distance, which will be covered by the vehicle behind during slowing, is equal to 490 m.

The maximum deceleration and suitable deceleration of the vehicle behind should also be slightly different from the values of own vehicle. They were calculated using the relationship of S_{behind} to S_{own}:

$$S_{behind} = 0{,}96 \cdot S_{own}. \quad (7)$$

On the basis of maximum and suitable deceleration, which were taken as limiting, and the distance that own vehicle will cover while waiting for suitable interval on the lane, were obtained the values of change in deceleration when making required lane change maneuver (Table 2).

Conclusions. *In the course of studies calculation of conditions was carried out for lane change maneuver, changes in the movement of own vehicle and the vehicle behind. The obtained results can be used to determine the capacity of a vehicle at any section of the road network, as well as in modeling traffic flows, carrying out comprehensive research on the driver's behavior.*

REFERENCES

1. Sergeev, S. A. Influence of traffic flow parameters on increase in the level of road safety [*Vlijanie parametrov transportnogo potoka na povyshenie urovnja bezopasnosti dorozhnogo dvizhenija*]. *Nauka i tehnika transporta*, 2004, Iss. 4, pp. 30–35.

2. Dolya, V. K., Volobueva, T. V. Mathematical model of driver's behavior in stressful situations [*Matematicheskaja model' povedenija voditelja v stressovyh situacijah*]. *Vestnik Doneckoj akademii avtomobil'nogo transporta*, 2008, Iss. 1, pp. 4–14.

3. Makenov, A. A. Decision-making by a car driver, taking into account his psychological type [*Prinjatie reshenija voditelem transportnogo sredstva s uchetom ego psihologicheskogo tipa*]. *Vestnik MADI*, 2013, Iss. 2, pp. 92–96.

4. Oseev, A. A. The role of the driver's character in reducing the accident rate in road transport [*Rol' haraktera voditelja v snizhenii avarijnosti na avtomobil'nom transporte*]. *Bulletin of Moscow University. Series 18: Sociology and Political Science*, 2005, Iss. 3, pp. 151–169.

5. Trofimov, A. V., Pulyaevskaya, O. V. Influence of traffic congestion on the driver' behavior [*Vlijanie transportnyh zatorov na povedenie voditelej*]. *Aktual'nye problemy gumanitarnyh i estestvennyh nauk*, 2015, Iss. 6/2, pp. 187–188.

6. Koryagin, M. E., Pozdnyakov, V. V., Protodyakonov, A. V. Socio-economic model of lane change as part of traffic flows simulation system [*Social'no-ekonomicheskaja model' smeny polosy kak chast' sistemy imitacionnogo modelirovanija transportnyh potokov*]. *Vestnik Kuzbasskogo gosudarstvennogo tehnicheskogo universiteta*, 2011, Iss. 6, pp. 96–97.

7. Tsvetkov, G. A., Khlyupin, A. S., Shevchenko, A. E. Technique of determination of safety interval of automotive assistance system in the course of lane changing evolution [*Metodika opredelenija intervala bezopasnosti avtomobil'noj sistemy pomoshhi pri perestroenii*]. *Bulletin of Perm National Research Polytechnic University: Safety and risk management*, 2015, Iss. 2, pp. 67–72.

8. Yakimov, M. R., Arepieva, A. A. Definition of technical characteristics: weight and power of vehicles belonging to transport flows of major cities illustrated by the example of the city of Perm [*Opredelenie tehnicheskih harakteristik: massa i moshhnost' transportnyh sredstv, vhodjashhih v sostav transportnyh potokov krupnyh gorodov na primere g. Permi*]. *Obrazovanie i nauka v sovremennyh uslovijah*, 2015, Iss. 4 pp. 229–232.

Information about the author:
Yakimov, Mikhail R. – D.Sc. (Eng.), professor of Perm National Research Polytechnic University, Perm, Russia, auto@perm.ru.

Article received 25.01.2016, accepted 20.04.2016.

Уважаемые читатели!

Оформить подписку на журнал «Мир транспорта» можно в любом отделении почтовой связи:

- в каталоге «Газеты. Журналы» Роспечати – подписной индекс 80812.

Журнал выходит шесть раз в год

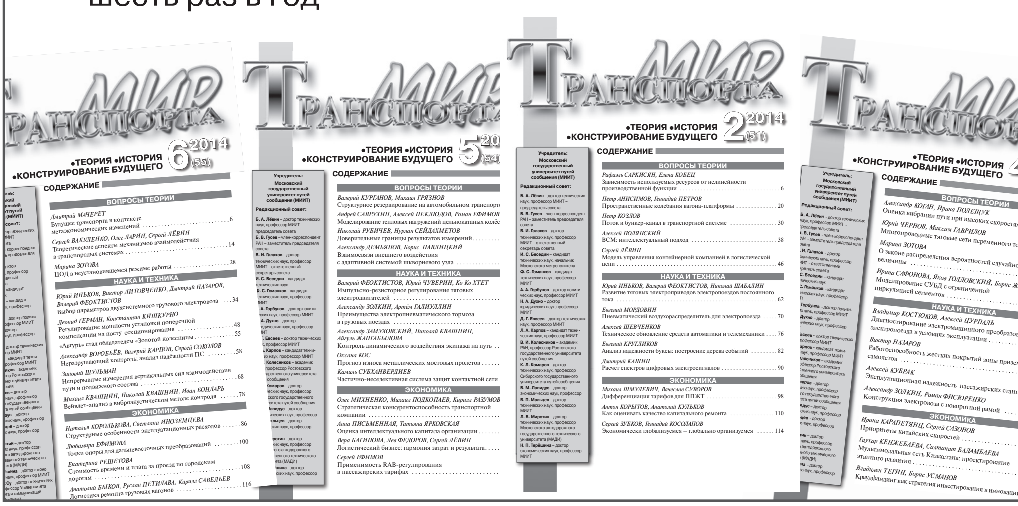
Dear Readers,

In Russia and CIS countries you can subscribe to the journal Mir Transporta (World of Transport and Transportation) at any post office using Rospechat JSC catalogues:

- «Newspapers. Journals» with subscription index 80812.

If you want to receive our journal in other countries please send a letter to the editorial board to e-mail addresses indicated on the back cover, we'll try to consider possible variants.

Published bimonthly



Журнал «МТ» получают транспортные и ведущие технические вузы, областные, научные и технические библиотеки большинства регионов Российской Федерации, а также библиотечные центры ряда стран СНГ.

The journal is delivered by the editor to leading Russian technical and transport universities, national and regional technical libraries of most Russian regions, transport government and public bodies, and companies, as well as to libraries of CIS and other foreign countries.