Studying impact of on-ramp from multi-lane highways on the basis of experimental studies of traffic flows

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Abstract. Lane-change manoeuvres are the main sources of traffic hindrance in multi-lane highways, so solving the issues of traffic capacity provision in such sections of highways should be performed with consideration of traffic flows interaction patterns. The analysis carried out in this area indicates lack of attention towards the issues of traffic capacity estimation in sections of highways adjacent to on-ramps. The article contains the results of experimental studies of the patterns of DLC manoeuvres on highways in sections adjacent to on-ramps, which provides the basis for elaboration of the methods of estimating the vehicle density impact on traffic capacity of adjacent sections of highways. The results of the studies are recommended to be applied in the course of highways design and their multi-level interchanges.

1. Introduction

Contemporary motor highways are objects of transport infrastructure which provide drivers with a high class of transport services, that's why both the studies aiming at further increase of traffic safety in highways and the studies aiming at provision of motor-car traffic with high level of convenience are definitely sought-after.

The studies of sources of traffic convenience level falling lower than acceptable values on multi-lane highways and of the causes of it show that formation of such sources significantly depends on lane-change manoeuvres [1,2]. The lane-change manoeuvres also cause adverse effect on traffic safety indicators [3].

Up to the present day, the characteristics of lane-change and factors influencing it have been studies mostly in terms of driver behaviour [4] and road conditions [5,6]. In these and many other studies, the lane-change manoeuvres are usually categorised as Mandatory Lane Change (MLC) and Discretionary Lane Change (DLC). In 1986, P. Gipps presented the first model of lane change with consideration of MLC and DLC manoeuvres for the conditions of city road traffic [7]. The model developed by P. Gipps was further developed in works [8,9] where its applicability to highway conditions was proved. K. I. Ahmed [10] applied the DLC model in conditions of high levels of vehicle density ($Z>0.8$). Further studies of the process of lane change are based on risk-oriented models [11] and also use intellectual algorithms such as neural networks [12] and methods of fuzzy interference [13-14].

There are almost no experimental studies of DLC manoeuvre patterns in sections of highways adjacent to on-ramps, which can be explained by lack of capability to carry out such studies until
present day as such studies are linked with necessity to track motor-car traffic at a large distance, which does not allow to use conventional types and methods of studies. Development of duplex global positioning systems (NAVSTAR and GLONASS), drone systems (unmanned aerial systems) as well as measurement devices and video recording devices allowed to develop the method of studies proposed below and to achieve required accuracy in the course of the studies.

This study contains the results of experimental studies of DLC manoeuvre patterns in highway sections adjacent to on-ramps, which allows to estimate the impact of incoming traffic flow on traffic capacity of adjacent sections of highways.

2. Experimental Study Methodology

For studying of DLC manoeuvres patterns in highway sections adjacent to on-ramps, the author studied the trajectories of movement of motor-cars entering the highway from different levels of an intersection. According to preliminary studies data, the length of the DLC manoeuvre section was equal to 2.0 km. The start point of the section length was taken in the beginning of the acceleration lane of a multi-level intersection (figure 1).

The studies were carried out in sections of multi-lane motor-roads of the Moscow region (Moscow, Moscow region) with the number of lanes of three to five providing permanent traffic mode. The traffic service level was identified as C as the one taken for calculations in the course of road design and complying with their economically feasible operation. Hence, the acceptable vehicle density ratio was within the range of $0.45 < Z < 0.7$. For determination of the vehicle density ratio, the traffic video capturing method was used by means of DJI Phantom 4 unmanned aerial system. The recording resolution was $1920 \times 1080$, the height of the drone flight was about 200 to 300 m and accuracy of measurements was at least $\pm 0.3$ m [15]. Alongside with the level of vehicle density registration, the trajectories of movement of cars leaving the main traffic flow to an off-ramp of the multi-level intersection were studied by means of a laboratory car. The scheme of measurements is shown in figure 2.
In the course of measurements, the trajectories of car movement were studied by measuring the distances covered by a studied car within each lane of a multi-lane road after this car left the on-ramp (L₁, L₂, L₃, .. Lₙ). The zero point was taken at the moment of change of the acceleration lane to the outer lane (crossing the lane stripe by a car axis). After each further change of lane the distance covered by a car within the lane was determined (L₁, L₂, L₃, .. Lₙ). Distances covered were measured by means of Garmin Mobile PC (V5.00.60g) software package which determines the distance covered by a car using the data of NAVSTAR and GLONASS global positioning systems. The error of mobile laboratory longitudinal and latitudinal location coordinates determination in the course of above mentioned measurements did not exceed 1.5 to 3.0 m [16]. The covered distance data was registered by means of a videotape of a studied car movement and indicators of the covered distance and further processing of the videotape in office conditions [17] (figure 3).

Figure 3. Scheme: 1 – the studied car; 2 – the mobile laboratory; 3 – the source of satellite navigation signal of NAVSTAR and GLONASS; 4 – processing of NAVSTAR and GLONASS signals using the software package.

3. The Results of the Study
Statistical processing of the gathered data allowed to gain probability distributions of DLC manoeuvres presented in figure 4. Adjustment of gathered data was carried out using the lognormal law.

Figure 4. The distribution (a) and cumulative frequency (b) curves of probability of lane change by a car entering the highway from the on-ramp as a function of distance to the on-ramp (L).
4. Conclusions
On the basis of the study carried out, the patterns of DLC manoeuvres distribution as a function of distance to the on-ramp (L) which are presented in fig. 4 were obtained. The results of MLC manoeuvres patterns presented in the article may be recommended to be used for justification of distances between on-ramps, location of road signs and may be also used for calculation of traffic capacity of multi-lane highways.

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