Determination of the capacity of the two-lane acceleration lanes with a central island

A V Kostsov

Moscow Automobile and Road Construction State Technical University (MADI), 64, Leningradsky ave., Moscow, 125319, Russia

E-mail: kostsov_msfs@bk.ru

Abstract. Interconnection sections of exit ramps at different levels with motorways are one of the main sources of traffic hindrance, so special attention should be paid to ensuring the capacity of such areas. Dual-lane motorway connections are often made using two-lane acceleration lanes, with safety islands as a method of increasing their capacity. In order to develop recommendations for determining the capacity of such acceleration lanes, the author carried out experimental studies of the patterns of DLC maneuvers within the highways on the sections bordering the entrances. The studies were carried out by recording the trajectories of vehicles that perform a maneuver of exit from the entrance to the highway. On the basis of the carried out researches an improvement of a method of calculation of capacity of two-lane acceleration lanes is offered. The results of the studies are recommended for use in the design of highways and intersections at different levels of them, as well as for the reconstruction of the highway lanes in order to increase their capacity.

1. Introduction
Interconnection sections of exit ramps at different levels with motorways are one of the main sources of traffic hindrance [1], so special attention should be paid to ensuring the capacity of such areas. The significant amount of cars traffic performing the exit to the main direction of traffic leads to fluctuations in the speed of the traffic flow, i.e. the formation of road waves [2], which causes a drop in capacity and increases the risk of accidents [3]. One of the ways to reduce the negative impact of these processes when connecting exits by two-lane transition-speed lanes is the device of security islands (Fig. 1), which makes it possible to increase the distance between the areas of convergence of traffic flows.

![Figure 1. Schematic diagram of the interface area with the use of a two-lane acceleration lane and a central separating island: 1,2 – exit, 3,6 – traffic flow merger section, 4 – traffic island, 5 – maneuvering section ($L_m^d$), 7 – driving off section.](image)
In order to assess the capacity of two-lane acceleration lanes containing traffic islands, it is possible to apply the boundary interval theory, according to which the capacity of the merging area is determined by road conditions and traffic intensity of the conflicting traffic flow. In this case, to determine the capacity of the second (in the course of traffic) section of the interface, it is necessary to have the value of traffic intensity at least on the right lane of the motorway before the second section of the interface \( N_{a2} \), which can be found from (1):

\[
N_{a2} = N_{a1} + Q_r - N_{12}
\]

where

- \( N_{a1} \) – traffic intensity at the rightmost lane of the motorway before the first section of the interface, cars/h;
- \( Q_r \) – traffic intensity on the left lane of the exit, cars/h;
- \( N_{12} \) – traffic intensity of vehicles that have completed the transposition manoeuvre from the extreme right to the central motorway lane, cars/h.

The analysis of the dependence (1) shows that in order to determine the capacity of the second (in the course of traffic) merging section, it is necessary to assess the traffic intensity of vehicles that have made a transposition manoeuvre from the extreme right to the central lanes of the motorway. The study of the works performed on this subject has shown that up to now the characteristics of lane changes and their influencing factors on motorways have been studied mainly in terms of driver behavior [4] and road conditions [5, 6]. The most famous work is that of P. Gipps, who first proposed a traffic flow model that takes into account the lane-change of cars on a multi-lane road [7]. This model assumes that the main drivers' motives for changing lanes are:

- maintaining the desired speed;
- the need to be in a given lane to perform exit manoeuvres from the road or change direction.

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 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].

There is practically no empirical research into patterns of lane changes. Insufficient attention is paid to the search for patterns of execution of DLC maneuvers in the movement of vehicles from the exits to the highway. Despite the fact that this type of maneuvers has a significant impact on the capacity of the highway, in most of the existing movement models the patterns of DLC maneuvers at the exit are ignored or solved primitively. This is also noted in [14, 15]. This can be explained by the lack of technical capacity to carry out this type of research until recently, as it involves the need to observe the movement of vehicles over long distances, which prevents the use of traditional types and methods of research.

2. Research method

For experimental studying of regularities of the transport flows interaction following on the main lanes of the highway and making the maneuver of reorganisations from the rightmost to the central lanes of the highway, the author carried out researches of movement regularities of the cars moving from exit to the main transport flow. The traffic service level was identified as C as the one taken for calculations in the course of road design and complying with road economically feasible operation. Simultaneously with the registration of the load level in the measurement area, the laboratory car was used to study the trajectories of cars entering the main traffic flow from the exit. In the course of the measurements, the trajectories of the vehicles were studied by measuring the distance covered by the vehicle under study within the right lane of the multi-lane road at the exit of the vehicle from the motorway exit (L1, Fig. 2). The beginning of the report was the moment of entry to the motorway from the acceleration lane (the passage of the car's axis of the roadway marking line). 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. The covered distance data was registered by means of a studied car movement videotape and indicators of the covered distance and further processing of the videotape in office conditions.

Figure 2. Trajectory of vehicle movement in the studied section: 1 – laboratory car; 2 – leader car; 3 – trajectory of movement

3. The Results of the Study
On the basis of experimental data the curve of distribution of maneuvers of rearrangements of cars between lanes of movement in functional dependence on distances before the beginning of exit which is presented in fig. 3 is received.

Figure 3. Histogram and distribution curve of rearrangement maneuvers between lanes in functional dependence on the distances before the start of the exit

4. Design considerations for two-way acceleration lanes
Integrating the distribution curve obtained in the course of the studies, we obtain (2):

\[ N_{12} = \int_{0}^{L_m} f(L_m) dL. \]  

(2)
Substituting (2) in (1) we get:

\[ N_{a2} = N_{a1} + Q_r - \int_{0}^{L_{m}} f(L_{m})dL. \]  

(3)

Using the data in Fig. 3, the expression (3) allows carrying out a quantitative assessment of the traffic intensity at the rightmost lane of the motorway in front of the second section of the interface, and therefore of the entire interface section. The author's analysis of the capacity of the interface node shown in Fig. 1 with account of (3) has shown that the capacity of such a node at the introduction of central traffic islands of length from 100 to 700 m leads to an increase in its capacity by 4–18% (Table 1) in the presence of a reserve capacity of the highway. Thus, the arrangement of central traffic islands on two-lane acceleration lanes can be considered an effective measure to increase the capacity of the merging areas of intensive traffic flows, and the results of the studies are recommended for introduction into the design practice.

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