Complex Fundamental Diagram of Traffic Flow in the Deep Lefortovo Tunnel (Moscow)

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Summary. The fundamental diagram for tunnel traffic is constructed based on the empirical data collected during the last two years in the deep long branch of the Lefortovo tunnel located on the 3rd circular highway of Moscow. This tunnel of length 3 km is equipped with a dense system of stationary radiodetectors distributed uniformly along it checkerwise at spacing of 60 m. The data were averaged over 30 s. Each detector measures three characteristics of the vehicle ensemble; the flow rate, the car velocity, and the occupancy for three lanes individually. The conducted analysis reveals an original complex structure of the fundamental diagram.

1 Traffic Flow in Long Tunnels

The properties of traffic flow in long highway tunnels has been under individual consideration since the middle of the last century (see, e.g., Refs [1, 2]). Interest to this problem is caused by several reasons. The first and, may be, main one is safety. Jams in long tunnels are rather dangerous and detecting the critical states of vehicle flow leading to the jam formation is of the prime importance for the tunnel operation. Second, the tunnel traffic in its own right is an attractive object for studying the basic properties of vehicle ensembles on highways. On one hand, it is due to the individual car motion being more controllable inside tunnels with respect to velocity limits and lane changing. On the other hand, long tunnels typically are equipped with a dense system of detectors, which provides a unique opportunity to receive a detailed information about the spacial-temporal structures of traffic flow.

The present work continues the investigation of tunnel traffic properties reported previously [3]. The analysis is based on empirical data collected during the last time in the Lefortovo tunnel located on the 3rd circular highway of Moscow (Fig. 1). It comprises two branches and the upper one is a deep linear three lane tunnel of length about 3 km. Exactly in this branch the analyzed data were collected. The tunnel is equipped with a dense system of stationary radiodetectors (Remote Traffic Microwave Sensor, X model) distributed
uniformly along it chequerwise at spacing of 60 m. Because of the technical features of the detectors traffic flow on the left and right lanes is measured at spacing of 120 m whereas on the middle lane the spacial resolution is 60 m. The data were averaged over 30 s.

Each detector measures three characteristics of vehicle ensemble; the flow rate \( q \), the car velocity \( v \), and the occupancy \( k \) for three lanes individually. The occupancy is analog to the vehicle density and is defined as the total relative time during witch vehicles were visible in the view region of a given detector within the averaging interval. It is measured in percent. The detectors themselves and their records were analyzed initially to justify the reliability of the collected data.

2 Fundamental Diagram

The fundamental diagram under consideration was constructed as follows. The phase space \( \{k, v, q\} \) was divided into cells of size about \( 1\% \times 1 \text{ km/h} \times 0.01 \text{ car/s} \). Each 30 seconds a detector contributes unity to one of the cells. Taking into account a certain rather long time interval of traffic flow observation, all the detectors, and then dividing the result by the total number of records we obtain the three-dimensional distribution \( P(k, v, q) \) of fixed traffic flow states over this phase space. In order to elucidate the obtained result we present the projection of \( P(k, v, q) \) on three phase planes \( \{kq\}, \{kv\}, \) and \( \{vq\} \). Besides, in projecting onto the given phase planes some layers can be singled out, for example, the expression

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P_{DV}(k, q) \propto \int_{v \in DV} dv \, P(k, v, q)
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