Road conditions and traffic speeds

P A Lushnikov¹, N A Lushnikov¹,², V A Kretov², A V Kostsov³

¹ ROSDORNI, 2, Smolnaya street, Moscow, 125493, Russia
² Russian university of transport, 9/9, Obraztsova Street, Moscow, 127994, Russia
³ Moscow Automobile and Road Construction State Technical University, 64, Lenin-grad Avenue, Moscow, 125319, Russia

E-mail: lab10@mail.ru, adaoif@bk.ru, kostsov_msfs@bk.ru

Abstract. The paper shows that from the point of view of energy consumption, the most optimal is the mode of movement with a constant speed among all possible speed modes of movement due to the fact that the average value of the mechanical energy of a moving car has a minimum value when driving at a constant speed. However, in real road conditions, certain sections of road do not allow moving at the selected speed and drivers are forced to change the mode of movement of the car for various reasons. The article discusses various methods for the assessment of the unevenness of the traffic flow speed, providing the use of forward accelerations, the coefficient of variation, as well as spatial and temporal speed. The study was carried out using the experimental analytical method. The paper shows that the forward accelerations of a car moving in a traffic flow have an oscillating character. Therefore, it is difficult to determine problem areas of the road that are the reasons for the decrease in speeds. It is also difficult to determine the areas where the speeds of movement change from the linear graph of the coefficient of variation, since this graph oscillates to a greater extent than the acceleration graph. As a result of the analysis and numerical calculations, it was proposed to assess road conditions by the ratio of temporal and spatial speed, which characterizes the unevenness of the speed of movement of vehicles. It is proposed to call this ratio the coefficient of speed unevenness of the traffic flow. It is shown that this indicator is more convenient for the determination of problem sections of the road. The graphs are based on the results of experimental measurements of driving speeds on specific highways. The coefficient of unevenness of speed better reveals problem road sections, since the dependence of this coefficient on the traveled distance has a much less oscillating character, which facilitates the selection of unfavorable sections of highways, in comparison with other existing indicators. The important result of this work is the proposal to use the coefficient of speed unevenness as one of the criteria for the assessment of road conditions, for example, when diagnosing highways.

1. Introduction

The modes of movement of vehicles are largely determined by road conditions: visibility distance, roadway condition, type of intersections with other roads, etc. The speed of traffic flow is one of the key factors in the driver-car-road system [1-4]. As a rule, the safest driving conditions and the shortest travel time are observed at a constant vehicle speed [2, 5]. In this mode, the mechanical impact of a car on the road is also minimal, as well as energy consumption for the transportation of goods [1-4]. In this regard, there is the problem of eliminating sections on the road with uneven traffic of cars by developing measures to improve traffic conditions in such sections and equalize the speed of movement throughout the road.
The paper discusses the use for this purpose of the coefficient of speed unevenness of movement $k$:

$$k = \frac{v_t}{v_s}$$

where

$v_t$ – temporary average speed of a car;

$v_s$ – spatial average speed of movement of a car [4].

It is necessary to note that the authors did have the purpose to provide the comprehensive survey of existing methods for the assessment of the unevenness of movement with a detailed analysis of their advantages and disadvantages. For comparison they used only some approaches to solve the problem of leveling the speed of movement based on the use of the values of the linear speeds and accelerations, the coefficient of variation of speeds and the coefficient of speed unevenness, with the purpose of possible further use of this coefficient as an estimated indicator of the state of road conditions.

2. Problem statement

It seems reasonable to find the optimal speed of movement according to the criterion of minimum energy consumption. Let us suppose that the car moves along a straight and horizontal section of the road with a length $L$ for time $T$. Then the average mechanical energy of movement $E$ can be determined by the following expression:

$$E = \frac{\int_{0}^{T} mx^2 dt}{2T},$$

where

$m$ – mass of a car;

$x(t)$ – movement along the studied road section, $x(0)=0, x(T)=L$;

$t$ – current time.

In order to determine the minimum of $E$ for all possible laws of motion $x(t)$, $x(0)=0, x(T)=L$, we need to solve the Euler equation [6]:

$$\frac{\partial L}{\partial x} - \frac{d}{dt} \frac{\partial L}{\partial \dot{x}} = 0,$$

where

$$L(x, \dot{x}, t) = \frac{mx^2}{2}.$$  

Taking into account (3) the equations (2) is:

$$m\ddot{x} = 0$$

or

$$\dot{x} = \text{const}.$$  

That is, the average value of the mechanical energy of a moving car has a minimum value when driving at a constant speed. This means that in the studied case from the point of view of energy consumption the most optimal is the mode of movement with a constant speed among all possible high-speed modes of movement.

As it was already noted such a movement is optimal in other cases. Therefore, the issue of the determination of areas with uneven movement speeds is very relevant. In order to solve this problem, we use the concepts of temporal and spatial average speeds [4]. These speeds are defined as follows.
3. Research method

Let us suppose that a car moves during time $T$ along a section of the road of length $L$. Let us conditionally divide this section into $n$ equal segments with uniform traffic conditions, each of which has length $h$: $L = nh$. Then temporal $v_t$ and spatial velocity $v_s$ are determined as follows:

$$v_t = \frac{L}{T}; \quad (5)$$

$$v_s = \frac{\sum_{k=1}^{n} v_k}{n}, \quad (6)$$

where

$$v_k = \frac{h}{t_k},$$

$t_k$ – time of movement of the car along the $k^{th}$ segment of the considered road section.

Thus, the temporary speed is determined by the ratio of the length of the road section to the time of movement along it and the spatial speed is determined as the average value of the speeds on its parts. After the transformation of the equation (5) we get:

$$v_i = \frac{1}{T} \sum_{i=1}^{n} \frac{h}{t_i} = \frac{nh}{\sum_{i=1}^{n} t_i} = \frac{nh}{\sum_{i=1}^{n} \frac{1}{v_i}}. \quad (7)$$

Thus, the average temporal speed (7) on the considered section of the road is the average harmonic value on its parts and the average spatial speed (6) is the arithmetic mean of the speed. Therefore, the inequation [7] is as follows:

$$v_t \leq v_s. \quad (8)$$

Moreover, the equality sign takes place only in the case when $v_k = \text{const}$, $k = 1, ..., n$ i.e. in the case of movement at a constant speed. In this regard, the ratio of temporary and spatial speeds $k = v_t/v_s$ can be used as a quantitative measure of the movement unevenness. Taking into account the expression (8), the inequation $0 \leq k \leq 1$ takes place and $k = 1$ is only on sections with a constant speed of movement.

4. Results of calculations

Let us illustrate the above mentioned case with the examples in which segments of length $h = 5$ m were used to determine the speed $v_s$.

As an example, Figure 1 shows the graphs of the spatial and temporary speeds of a car moving in a traffic flow on a section of the ring highway around St. Petersburg. It is possible to notice a sharp decrease in speed at 36 km. As a result of the study of the reasons for the decrease in speed, it was found that a road accident occurred on this section.
Figure 1. Dependence of spatial and temporary speeds of a car movement from the distance traveled on the ring highway section

Figures 2 and 3 show the values of indicators that can be used to assess the movement steadiness: the coefficient $k = \frac{v_t}{v_s}$ and the forward acceleration of a car averaged over kilometers on the same section of the ring highway. Both graphs allow highlighting an unfavorable (from the point of view of traffic steadiness) section, but the value of the forward acceleration is determined by significantly larger oscillations, which makes the determination of road sections with uneven traffic more difficult.

Figure 2. Dependence of the forward acceleration of a car from the distance traveled on the ring highway section

Figure 3. Dependence of coefficient $k = \frac{v_t}{v_s}$ from distance traveled on the section of the ring highway
Figures 4-6 show the results of speed measurements on a section of another road - the Small Moscow Ring (SMR) from the highway M-9 “Baliya” in the direction of Zvenigorod. The values of $v_t$ and $v_s$ were determined after 100 m. The large value of the necessary coefficient of speed unevenness in a section with a length of 1 to 2 km (Fig. 4) is explained by the presence of the intersection with traffic light regulation.

Figures 5 and 6 graphically show the change in the coefficient $k$ and the coefficient of variation of speed depending on the path along the sections 100 m long. The dependence of the coefficient $k$ on the distance traveled, in comparison with the analogous dependence for the coefficient of variation (Fig. 6), has a much less oscillating character, which makes it easier to determine the areas with uneven movement.
5. Conclusion

Thus, the research results allow drawing the following conclusions:

1. The movement of traffic flows at a constant speed is optimal from the point of view of traffic safety, minimum mechanical impact of a car on the road and energy consumption when a car is moving, as well as in other cases (for example, when a driver does not move). Therefore, the task of the determination of road sections on which traffic steadiness is not ensured is urgent.

2. In order to determine unfavorable areas with uneven movement, along with forward acceleration, linear speed of a car and coefficient of variation of speeds, the coefficient of unevenness of speed \( k = \frac{v_t}{v_s} \) can be used, which better determined problem areas of the road, since the dependence of the coefficient \( k \) on the distance traveled has a significant less oscillating character, which makes it easier to determine unfavorable road sections, compared with other existing indicators.

3. It is proposed to use the coefficient of speed unevenness of movement as one of the criteria for the assessment of road conditions

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