Modeling dynamic speed changes on highways

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Abstract. The article provides an analysis of the dynamic speed control systems’ use in various countries. It is established that as a result of such systems’ use, traffic capacity increases, a stable speed is maintained, and traffic safety is increased. In accordance with spatiotemporal features, three types of control algorithms are described. The features of these algorithms’ implementation are shown. The role of modeling traffic flows in the choice of control methods is substantiated. Based on the simulation results, the performance parameters are given.

Introduction
In modern automated traffic control systems and intelligent transport systems, various speed control methods are widely used. One of the current trends in this area is flexible speed control known in foreign practice as Variable Speed Limit [1, 2, 3, 4]. Although in literal translation this method can be interpreted as a variety of approaches to speed limiting, in fact, the functional properties of this method are the speed modes’ flexible control in difficult conditions and are aimed at eliminating the unstable speed modes. Dynamic speed control is carried out in a rapidly changing environment to maintain a uniform driving style in order to improve road safety, eliminate traffic jams, reduce emissions. Dynamic speed control systems use information about the traffic load on the connected sections of the road, speed, weather conditions to determine the optimal speed at which drivers should move both on the control section and on the approaches to it. This is achieved, among other things, by introducing a speed limit in a certain area in order to limit the cars access to a bottleneck. In this case, higher traffic capacity can be achieved due to the transport stream stability. Adaptive management is based on real-time traffic flow data and real-time driver information.

Improving road safety with the introduction of this control method occurs by reducing the difference in speed between the sequentially moving vehicles. This reduction in velocity dispersion synchronizes driver behavior thereby reducing the collisions probability. Also, when traffic intensity approaches capacity, any disturbance in traffic flow can lead to traffic congestion. Due to the speed dynamic control, it is possible to restore the situation, reducing the movement intensity at the entrance to the bottleneck. Together, this leads to lower fuel consumption and lower emissions.

In general, as a result of the existing experience analysis in the high-speed modes’ flexible control application on highways, the following conclusions can be drawn about the effectiveness of this control method [5, 6, 7, 8]:
- increase in traffic congestion for 7-10%;
- traffic capacity increase by 5-22%;
- decrease in traffic accidents by 5-30%;
- stabilization of speed modes, elimination of sharp fluctuations in speed.

Flexible speed control methods
Despite this experience of using the dynamic speed control systems on highways, there are certain problems with their implementation. One of the main problems is the ambiguity of possible solutions, when there is no single answer, and for almost any situation a solution to a certain problem is required. It is required to provide a compromise between travel time, capacity, the ability to monitor the decision implementation while ensuring road safety.

It is difficult to solve the problems of assessing the flexible speed limits’ impact on changing the traffic conditions and it is difficult to select the optimal control parameters based on the actual data available before implementing these control algorithms. This is a typical problem when investigating traffic flows for such changing situations. In real conditions, it is quite difficult to provide the conditions for a controlled experiment with given values of the traffic flows’ parameters.

The use of various types of traffic modeling provides new opportunities in the development of various algorithms for dynamic speed control on highways, the design of automated traffic control systems, and the prediction of the traffic flow state in the process of implementing flexible speed control [9, 10, 11]. It is especially important that it is possible to expand the capabilities of speed control in the conditions of intelligent transport systems [12, 13].

The existing decision-making methods when choosing the speed modes in dynamic speed control systems on highways can be divided into the following:
- the method of selecting the speed by the operator on the actual data basis on traffic conditions and previously developed solutions for certain types of situations;
- active control methods, in which the traffic flow state is predicted, the bottlenecks are identified and according to this information, the control system assigns the optimal speed modes.

Based on the previously developed solutions, the approaches should be reliable and require experienced professionals. But in any case, these approaches are effective only for complex situations that constantly arise in a given place. Dynamic speed limits are set in accordance with the boundary values of intensity, employment, speed in real time. The effectiveness of such methods depends on the traffic flow state forecasting models’ reliability [14, 15].

In the case when speed control is carried out by transmitting information simultaneously to all the cars in the control section, all cars simultaneously respond to recommendations on changing the speed and implementing the control strategy quickly and effectively. Naturally, the implementation of such control algorithms should be supported by technologies of intelligent transport systems v2v (car-to-car) and v2i (car-infrastructure) [16]. The use of autonomous cars provides a constant information exchange both with the road infrastructure and with other vehicles and this will lead to a more deterministic interaction of ITS with vehicles. Speed limit requirements can be sent to each individual autonomous vehicle, and they will be forced to move within the limits of the restrictions. Dynamic speed control is also used to limit traffic on approaches to bottlenecks in the event of congestion. It is for these conditions that the efficiency of the control method is manifested to the greatest extent, in which the change in the speed mode occurs simultaneously on the entire road.

Dynamic Speed Simulation
The study of various dynamic speed control algorithms was carried out using simulation. An approximate design scheme for modeling is shown in Figure 1.
Figure 1. Fragment of a road section for modeling

Based on Figure 1, the high-speed modes’ dynamic control essence in difficult conditions is to control the parameters of the traffic flow to a narrow section of the road and apply the appropriate control algorithms in order to avoid reducing traffic capacity and blocking entries / exits. The control targets are the traffic intensity optimization in a bottleneck and ensuring the high-speed mode stability to improve road safety. It is also necessary to consider the possibility of reducing travel time with the high-speed modes’ dynamic control introduction on highways.

However, the use of an approach focused only on minimizing the travel time can lead to an unreasonable decrease in the traffic flow density and, accordingly, a decrease in the intensity, and one of the dynamic speed control goals is to maintain traffic intensity in the area close to the carrying capacity. In order to avoid this situation, it is necessary to use a complex objective function which parameters are determined during modeling:

\[
F = T \sum_{j=1}^{N_p-1} \sum_{l=1}^{M} l i s_i [\alpha_T k_i(t + j) - \alpha_D k_i(t + j) v_i(t + j)],
\]

where \(F\) – is the target function;
\(\alpha_T, \alpha_D\) – are the weights for travel time and traffic intensity respectively;
\(k\) – is the traffic density;
\(v\) – is the traffic speed;
\(l\) – is the number of lanes;
\(s\) – is the road length;
\(i\) – is the road section number;
\(t\) – is the moment of time;
\(j\) – is the forecast horizon.

When using this approach, it is also necessary to take into account the restrictions on the difference in the recommended speed in the road neighboring sections and the time for making a decision to switch to a new speed mode.

This method was used for micro-modeling in the AIMSUN software package. The high-speed modes’ dynamic control introduction effectiveness on the highway was assessed by the comparative values of the traffic flows’ characteristics for a section of the road 5 km long, divided into the separate sections with a length of 300 to 500 m. For the entire section of the road, the changes in traffic intensity, traffic stream speed and delay time were analyzed. Figure 2 shows the change in travel time according to the simulation results.
Figure 2. Change travel time in difficult conditions using dynamic speed control

The traffic flows’ characteristics (intensity, total driving time, number of stops, speed variation coefficient) obtained as a result of modeling confirm the speed modes’ dynamic control effectiveness. These characteristics are shown in Table 1.

The dynamic speed control simulation results’ reliability on highways obtained by modeling is confirmed by comparison with the data obtained by other researchers. So, in [12] it is indicated that as a result of applying dynamic speed control, the total movement time decreased by 22%, and the traffic intensity increased by 2%. Therefore, the results obtained are comparable with other studies and can be used to analyze various dynamic speed control algorithms.

Table 1. Evaluation of the dynamic speed control effectiveness.

| Characteristics of traffic flows                  | No dynamic regulation | With dynamic speed control | Difference, [%] |
|-------------------------------------------------|-----------------------|---------------------------|----------------|
| Traffic intensity, [vehicle / h]                | 2530                  | 2590                      | +2,3           |
| Total time of movement, [hour]                  | 332,1                 | 275,2                     | -17,2          |
| Number of stops, [vehicle / km]                 | 0,11                  | 0,08                      | -27,3          |
| Speed variation coefficient, [km/h]             | 0,42                  | 0,36                      | -28,6          |

Summary

Thus, the dynamic control of high-speed modes in difficult traffic conditions on highways is one of the most important conditions for reducing the consequences of traffic jams and improving the road safety. The variety and complexity of possible situations require the mandatory use of modeling in justifying and choosing the control algorithms. The simulation results show that such control methods help stabilize the speed mode, reduce the number of stops and delay time.

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