AUTOMATED REGULATION OF INTERVALS FOR BUS RAPID TRANSIT ROUTES

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Abstract: *In this article, the issue of improving the quality of passenger service of urban passenger transport in large cities and megacities on the routes, operating on the Bus Rapid Transit technology, is considered. Quality improvement is achieved by automatic regulation of the movement of each passenger vehicle during the movement on the route after disturbing influences in order to ensure the movement of each vehicle on schedule. As a mechanism for regulating Autonomous traffic, an advanced bus driver assistance system is proposed. In contrast to the existing advanced driver assistance systems that improve traffic safety, the main purpose of the proposed system is to automatically maintain the route movement of the vehicle in accordance with a given schedule. The question of centralized automatic control of the movement of a group of vehicles on the route with a significant deviation from the specified schedule of one of the vehicles is considered. The result is a developed criterion of efficiency of regulation of movement of a group of vehicles on the route.*

Keywords: *urban passenger transport movement schedule, quality of passenger service, passenger transport movement regulation, automated system of dispatching control of passenger transportation.*

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I. INTRODUCTION

Urban passenger transport must play an important role in improving the difficult transport situation of modern large cities and megacities. It is planned to achieve this by offering public transport services of high quality for the majority of the urban population. In this case means of public transport is supposed, will sharply shorten the usage of private cars [4,8,11,13].

In accordance with the regulatory documents of the leading Western countries and Russia, the main criteria for the quality of public transport is the degree of vehicle occupancy and the regularity of the movement of vehicles on the route [9,12].

In this article, we will consider only systems in which the movement of public transport passenger vehicles is organized on dedicated lanes. Examples of such systems are Bus Rapid Transit systems operating in many of the largest cities in South and North America, and Select Bus Service system operating on similar principles in the city of New-York [3,5,6,7]. The reason for our choice is the firm belief that the most important criterion when choosing a means of transportation in addition to the mentioned above criteria of quality, is a significantly higher average speed of communication on the route compared to the average speed of traffic flow on the same route. This can be achieved only by the organization of dedicated lanes on the main routes of urban passenger transport.

Traditional technologies of automated dispatching control of the movement of passenger vehicles assume that the control and regulation of the traffic interval is carried out in accordance with the traffic schedule. This regulation is carried out by controlling the time of departure of the next vehicle to the route from the starting point of the flight (point A). However, the regulation of the intervals of movement of passenger vehicles on the route is not applied [13]. In our opinion, the main reason for this is the lack of physical capacity for the driver to simultaneously ensure the safety of the vehicle and monitoring the planned schedule. It follows from this that the task of regulating the interval of traffic should be transferred to an automatic system that will regulate the speed of the vehicle on the route in order to comply with the specified schedule. Obviously, the main task of this system must be regulation of the longitudinal movement of the passenger vehicle on the route according the schedule. An objective necessity of such traffic regulation has place even for BRT routes.

In accordance with the conceptual provisions on the organization of the movement of passenger vehicles in BRT system described above, the vehicles move along dedicated lines only. Therefore, the main factor (general traffic flow), which affects the violation of the intervals of movement, is excluded. However, the second factor–passenger flow–remains. Since the passenger traffic intensity is a random variable, high diversity of passenger flow may appear sharply during periods of “rush hour”.

The organization of movement at a given interval should be stable with respect to sudden, unpredictable bursts of passenger traffic intensity at stops. It should be noted that it is impossible to predict a short-term surge in passenger flow at a stop in advance. This proves the lack of modern dispatch control algorithms based on the regulation of the movement of passenger vehicles at one point on the route – the starting point of the flight (point A).

This article proposes to solve this problem through the introduction of a new advanced specialized bus driver assistance system.

As part of modern advanced driver assistance systems, there are several systems whose task is to regulate the speed of the longitudinal movement of the vehicle in order to improve traffic safety [1,2,10]. However, the main difference of the proposed system is that it should help the driver to adjust the traffic modes in order to comply with the specified traffic schedule and thus ensure high quality of the transportation process for this indicator. By analogy, we call such a system "advanced bus driver assistance system" (ABDAS).

II. BASIC MANAGEMENT STRATEGY OF ADVANCED BUS DRIVER ASSISTANCE SYSTEM

With the practical implementation of the ABDAS system the bus driver can operate in two modes:

- in manual mode;

- in automated mode.

Manual mode should be used for auxiliary technological movements of the vehicle, as well as in case of emergency situations on the route.

Automatic driving mode should be activated by the command of the driver only at the beginning of the movement from each stop of the route. In automatic mode, the system provides automatic implementation of all phases of movement on the route (acceleration, steady motion, braking). Responsibility for traffic safety remains with the driver. The driver must control the lateral movement on the route and the execution of all maneuvers. If necessary, driver can at any time interfere with the regulation of longitudinal movement. This will disable the automatic mode. When the vehicle is stopped at a bus stop, the automatic mode should be disabled. State diagram of advanced bus driver assistance system (ABDAS) is shown in figure 1.

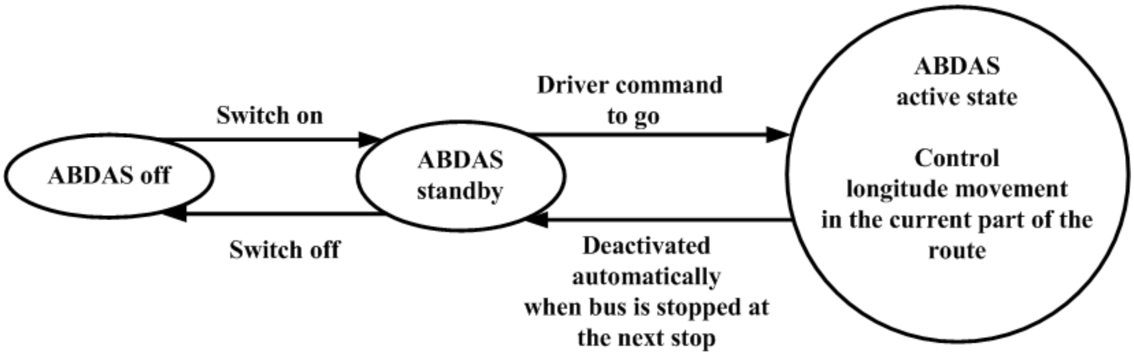

***Figure 1**. State diagram of advanced bus driver assistance system (ABDAS)*

III. AUTONOMOUS REGULATION OF THE MOVEMENT OF A PASSENGER VEHICLE ON THE ROUTE

Autonomous regulation of the movement of a passenger vehicle on the route means the implementation of the planned movement on the route in accordance with the schedule, using only the means of the vehicle itself and its control system, modified with advanced bus driver assistance system.

To ensure the autonomous regulation of movement, in memory of the control system of the vehicle must be loaded:

- Digital model of a route.
- Operational schedule of the vehicle on the route for the current trip, including arrival/departure times for each bus stop.
- Traffic dynamics modeling on the stretches between stops.

Digital model of the route includes [13]:

* Spatial description of the route as a piecewise broken line;

* Position and name of bus stops on the route.

A schema of the operational timetable of a trip is presented as shown in figure 2.

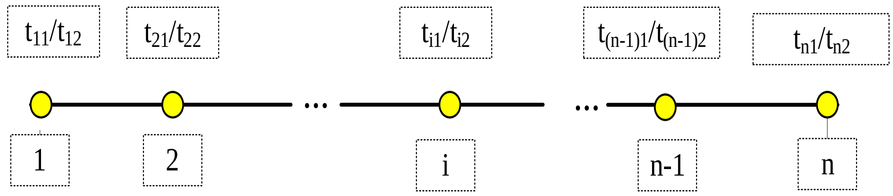

Figure 2. *Schema of the operational timetable of a trip*
t_{i1} - scheduled time of arrival of the vehicle at the i-th stop for boarding / alighting passengers; t_{i2} - planned time of departure of the vehicle from the i-th stop, i=1,2, …,n.

IV. NECESSARY CONDITIONS AND REGULATING THE TIMETABLES OF PASSENGER VEHICLES ON THE ROUTE IN AUTONOMOUS MODE

The first prerequisite is to receive on-line data on incoming and outgoing passengers at stops and calculated data on the occupation ratio of the vehicle compartment after each stop. The second prerequisite is:

• Determination of the actual time of departure for each stop of the route/

• Comparison of the planned time of departure and actual time of departure for each stop of the route and calculating difference between planned and actual time of departure (Δt).

The third prerequisite is the use of technology for regulating the movement of vehicles on the route in order to reduce the discrepancy between the planned and actual time of departure for each stop.

Currently, the first and second prerequisite can be implemented by means of on-board controllers. However, the technology for regulating the movement of vehicles on the route in order to reduce the discrepancy between the planned and actual situation is not implemented. Below we consider a possible solution to this problem.

The theoretical basis for solving this problem is the theory of vehicle dynamics, which describes the behavior of the vehicle during acceleration, braking and when driving at a constant speed. Input parameters for the analytical description of the motion model passenger vehicles are the data of the vehicle design and the parameters of the environment, characteristics of the road section and download the passenger compartment [3].

The necessary technical and technological prerequisites for solving this problem is scientific, software and technical support for collecting and processing data on the parameters of vehicle occupancy in real time, the results of which allow us to begin to solve this problem [3].

If all conditions are met, the onboard advanced bus driver assistance system (ABDAS), having received the values of the initial parameters of the calculation, will calculate the model of the vehicle movement on the next section of the route. Schematically, this model is shown in figure 3.

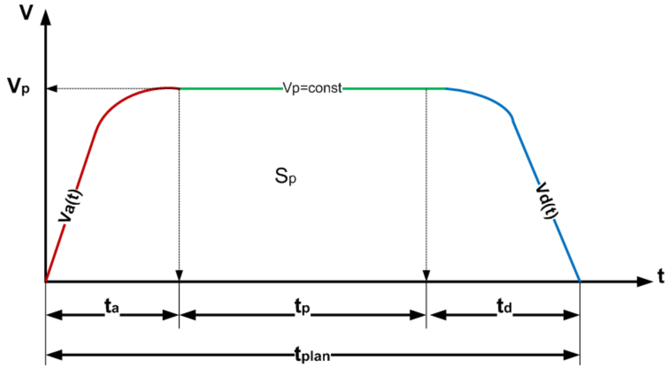

Figure 3. *Dynamic model of the vehicle movement between stops on the route*
t_a,$v_a(t)$ – time and speed of acceleration; t_p,v_p – time and speed of steady state; t_d,v_d – time and speed of deceleration; S_p – distance of the part of the route between stops.

There are equalities:

$$\int_0^{t_p} V_a(t)dt + \int_0^{t_p} V_p dt + \int_0^{t_d} V_d(t)dt = S_p \quad (1)$$

$$t_a + t_p + t_d = t_{plan} \quad (2)$$

Before the start of the movement on the next section of the route in automatic mode advanced bus driver assistance system must compare planned time of departure and actual time of departure and calculate difference (Δt) between planned time and actual time of departure. If Δt value would considered as essential, the system must recalculate the mode of movement for this section of route and execute the movement along this section in the new mode to eliminate discovered difference (Δt) autonomously. Let's consider a case, when Δt means a time lag from the schedule. In this case, the average speed on the site should be higher than the scheduled speed. The graph of the recalculated mode of movement on the section should have the form shown in figure 4.

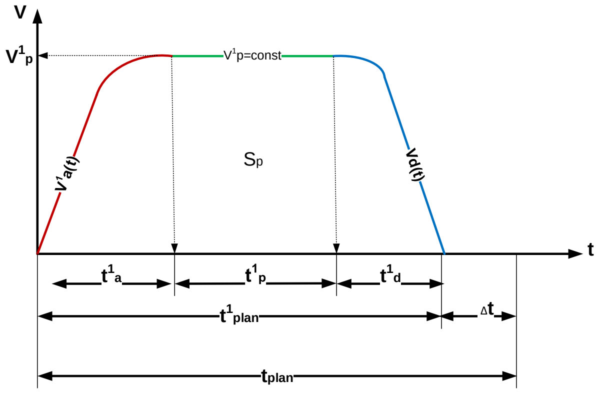

Figure 4. *Recalculated dynamic model of the vehicle movement between stops on the route*
t^1a,$v^1a(t)$ – time and speed of acceleration after regulation; t^1_p,v^1_p – time and speed of steady state after regulation; t^1_d,v^1_d – time and speed of deceleration after regulation; S_p – distance of the part of the route between stops

There are equalities:

$$\int_0^{t_a^1} v_a^1(t)dt + \int_0^{t_p^1} v_p^1 dt + \int_0^{t_d^1} v_d^1(t)dt = S_p \quad (3)$$

$$v_p^1 > v_p \quad (4)$$

$$t_a^1 + t_p^1 + t_d^1 = t_{plan}^1 = t_{plan} - \Delta t \quad (5)$$

V. CENTRALIZED REGULATING THE TIMETABLES OF PASSENGER VEHICLES ON THE ROUTE WHEN ABNORMAL DEVIATIONS FROM SCHEDULE OCCUR

If abnormal deviations from schedule occur then the limited capabilities of the vehicle control system are not enough to compensate for the time lag from the schedule. For example, a large group of students appear at a bus stop and board into the first vehicle that approaches the stop. As a result, the boarding/alighting time at the stop increases significantly. In this case interval of movement is violated as follows. A vehicle moving before the bus in question on the same route that has passed the considered stop without additional delay continues to move and increases the interval of movement. A vehicle moving along the same route after the vehicle in question shortens the interval of movement. Schematically, the situation is shown in Figure 5.

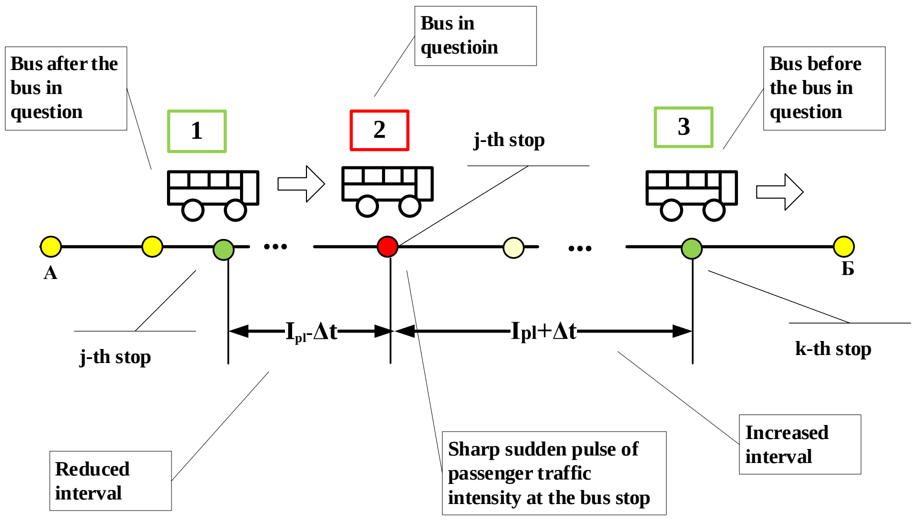

Figure 5. *Scheme of situation of interval violation on the BRT route*

The vehicle indicated by number 2 is delayed at the stop due to a sharp, short-term increase in the number of passengers at the stop. The vehicle, indicated by number 3, moves on schedule without additional delay and increases the interval of movement in relation to the next vehicle 2. The vehicle, indicated by number 1, moves according to a schedule without additional delay and reduces the interval of movement in relation to the vehicle 2 in front of it.

At "rush hour" the number of passengers boarding / alighting at stops positively correlates with the size of the interval. As a result, the situation described above can develop as follows. Vehicle 2, moving with an extended interval, spends more time boarding and disembarking passengers compared to vehicle 3, as a result of which vehicle 2 continues to lag and increase the interval of movement with respect to vehicle 3. This process can go on increasing. Vehicle 1, moving on a schedule, begins to “catch up” vehicle 2 for two reasons:

1) The vehicle 2 continues to lag behind the schedule due to the ever-increasing number of passengers at stops;

2) The vehicle 1 spends less and less time for boarding and alighting passengers due to the reduced interval of movement and it become close to the vehicle 2.

It is impossible to correct the evolving situation on the route in the traditional dispatch control system of public transport due to objective reason of its origin. Therefore, such a picture often occurs: one vehicle comes to a bus stop with an extended interval and with an overflow of the passenger compartment. Behind him with a small (less than planned) interval moves another vehicle, with compartment current occupancy much less than the one of first vehicle. Often, when planned interval of movement is small, these vehicles begin to move directly one after another in "platoon mode". This is a problem situation for traditional dispatch systems.

The described situation causes public disappointment and passenger’s complaints about the work of the dispatch system and public transport itself. Therefore, the elimination of this situation and its causes is an important social task.

In order to rectify the situation and return the intervals to the given planned value, it is necessary to correct the schedule of vehicles 1 and 2 slowing down their movement by the value -Δt. This maneuver must be fulfilled by on-board ABDAS system of each vehicle. When adjustment will be completed, the intervals have planned value as shown in figure 6.

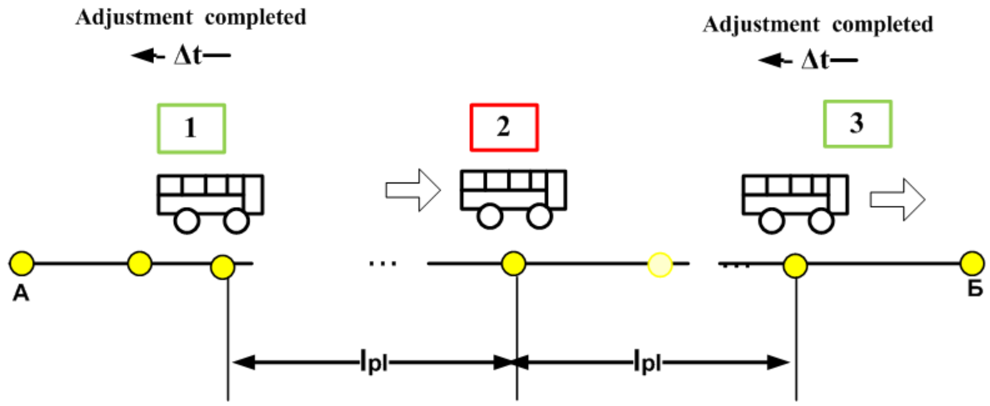

Figure 6. *Regulation for recovering interval is completed*

VI. CONCLUSION

Developed advance bus driver assistance system (ABDAS) is specified system to help bus driver fulfill scheduled bus movement on the route which is the most complicated task for the bus driver. The acceleration, constant speed movement and deceleration phases of scheduled movement between stops would be executed automatically after driver's command to go.

Offered regulation methods can be fulfilled in autonomous or centralized modes. The centralized mode regulation is possible if there is another vehicles in front and behind of the lagging vehicle on the route. We considered the case when there are three vehicles on the route. However, such a maneuver can be performed in a more general case, when more than three vehicles are on the route. In this case, the dispatch system should give a command to the control units of all unmanned vehicles on the route, except to synchronously slow down for the one behind the schedule, by the $-\Delta t$ value.

Therefore, it is necessary to recalculate the forecast of vehicle occupancy at a critical stop. And if, according to the forecast, the overflow of the vehicle interior with number 3 does not happen, then can be perform the maneuver. Since the maneuver should be carried out synchronously, the command for its execution should be given by the dispatch center. For this purpose, the dispatch center should have all the information about the movement of vehicles on the route and the factual data and forecast of vehicle occupancy.

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