AMERICAN Journal of Engineering, Mechanics and Architecture
Volume 3, Issue 5, 2025 ISSN (E): 2993-2637

Algorithm for Optimizing Train Operation Modes Based on Timetable Parameters

Lesov A., Adilov N., Miryakubov A., Usmonov K.
Tashkent State Transport University (Tashkent, Uzbekistan)

Abstract: The article focuses on developing an algorithm to optimize the switching points of train movement modes, taking into account scheduled time, movement resistance, gradients, and rolling stock characteristics. The primary emphasis is on modeling the movement process, calculating speed and time increments, and considering the impact of gradients on train movement. The developed mathematical model and algorithm aim to minimize deviations from the planned arrival time and optimize train movement modes. The methodology described in the article can be applied to enhance railway transportation efficiency, improve travel time calculation accuracy, and reduce energy consumption during train operation.

Keywords: rolling stock, movement optimization, scheduled time, traction modes, switching algorithm, energy efficiency, adaptive algorithm.

Introduction. Optimizing train movement is a key aspect of increasing railway transport efficiency, especially in conditions of tight schedules and the need for precise adherence to arrival times. One of the crucial stages in this process is accurately identifying the points for changing movement modes such as traction, coasting, and braking, as these directly impact travel time and energy efficiency [6,9,10].

The aim of this scientific work is to develop an algorithm that enables optimization of the change points based on the graphical time of train modes, taking into account possible track parameters and deviations. The study examines methods for calculating speed, time, and distance increases at each stage, as well as the operational characteristics of the regenerative braking and coasting systems.

The article is based on theoretical methods of modeling train movement, considering the actual track parameters and acting forces. This allows for proposing a more precise and effective approach to calculating traffic schedules and minimizing deviations from planned arrival times. The applied approach helps to increase the accuracy of train movement time prediction and reduce schedule deviations.

Model description. The mathematical model of train movement is based on a system of equations describing the dynamics of electric rolling stock. The fundamental equation of dynamics expresses the change in velocity over time by dividing the difference between the tractive force and the resistance to motion by the mass of the train composition. This equation takes into account the interaction of various factors, such as resistance to motion and traction characteristics, which allows for a more accurate modeling of the movement process [1,2,8].

The fundamental equation of dynamics is written as follows:

$$\frac{dV}{dt} = \frac{F_u(V) - W(V,S)}{(P+Q)},$$

here, $F_u(V)$ is the traction characteristic depending on speed, and *W(V,S)* is the total resistance, which includes all types of resistances dependent on road conditions and external factors, such as air resistance, rolling resistance, and other elements. The mass of the train *(P+Q)* is taken into account to ensure the accuracy of calculations, as it directly affects the acceleration and braking characteristics.

To account for the specific characteristics of electric rolling stock, the concept of specific accelerating force is introduced [8]. It is calculated using the following formula, which takes into account the maximum traction force, adhesion coefficients, and gravitational factors:

$$f_{t\,max} = \frac{1000 \cdot F_{u\,max}}{(P+Q) \cdot g} - w_m - w_a,$$

here, w_m represents the main resistance dependent on speed and other factors, while w_a represents the additional resistance that accounts for the road's specific characteristics such as slopes and unevenness.

According to this model, velocity changes are calculated for each step of train movement, depending on the current and set speeds. These changes are influenced by both the current and set speeds. In this process, the following conditions are taken into account:

$$\Delta V = \begin{cases} if\ V_c < V_{ss} \Rightarrow \Delta V > 0 \\ if\ V_c > V_{ss} \Rightarrow \Delta V < 0 \\ if\ V_c \le V_l \Rightarrow \Delta V = 10\ km/s \\ if\ V_c > V_l \Rightarrow \Delta V = 5\ km/s \end{cases}$$

where V_c is the current train speed, V_{ss} is the steady-state speed, V_l is the limit value for changing the speed by 5 km/h, and ΔV is the speed increment for the current step.

It is noteworthy that for more accurate calculations at closer values, the speed change increment can be reduced to 1 km/h [4].

Slope and its impact on train movement

To calculate more accurately the time required to traverse the sloped sections of the track, a correction coefficient k_{cor} is introduced. Slope affects resistance to movement and traction, therefore it is necessary to take this into account when planning the movement regime. The train expends more effort to overcome resistance at points of ascent, while at points of descent, conversely, the resistance decreases, but problems with speed control may arise.

The formula for calculating the time required to traverse the sloped section of the track is as follows:

$$t_b = k_{cor} \cdot \frac{S_i}{S} \cdot t_{norm},$$

where t_b is the boundary time on the sloping section of the road, k_{cor} is the slope correction coefficient, S_i is the length of the road section with a slope, S is the total length of the route, and t_{norm} is the designated time to cover a section of the road without accounting for the slope.

This approach helps to calculate more accurately the travel time on inclined sections of the road, as well as to adjust the points of mode changes (traction, idling, braking) based on the variations in resistance to movement on such sections.

Basic steps of the algorithm

The algorithm begins by calculating the maximum specific accelerating force $f_{u\,max}$, taking into account the forces of resistance to motion:

$$f_{t\,max} = f_{u\,max} - w_m - w_a.$$

After that, the increase in time and distance is calculated. The time for each step is determined using the following formula:

$$\Delta t_i = \left| \frac{\Delta V_i}{2 \cdot f_{t\,max\,i}} \right|.$$

After calculating the time for each step, the total time ti is determined as follows:

$$t_i = t_j + \Delta t_i,$$

where t_j is the time from the previous step.

Path gain in current step:

$$\Delta S_i = 16{,}7 \cdot \left(V_c + \frac{\Delta V_i}{2} \right) \cdot \Delta t_i\,,$$

$$S_i = S_j + \Delta S_i.$$

Given the length of the section S_i and the travel time t_{tr} along the section, we obtain the following relationship:

$t_{tr\,i}(S) = 0{,}001 \cdot S_i\,,$

$\varDelta t_{tr\,i} = t_{gr\,i} - t_{b\,i},$

At this stage, the condition of equality between the travel time t_{tr} in the section and the time t_i at the current step is checked. Due to the discrete nature of calculations, it may be impossible to achieve exact equality. Therefore, an allowable ϵ is applied, and the condition is verified as follows:

$t_i = t_{tr} \pm \epsilon.$

If the difference between t_i and t_{tr} is within the \epsilon boundary, it is possible to proceed to the next step. However, if the travel time on the section $t_{tr} < t_i$ is smaller than the time at the current step by more than ϵ, it is necessary to adjust parameters such as speed or tractive force to eliminate the deviation and bring the calculations to optimal accuracy.

To correctly account for time and distance, the condition $\varDelta S$ must remain unchanged. To ensure that the distance traveled corresponds to the given speed and time, the new increase in speed, $\varDelta V$, is recalculated as follows.

$$\Delta V_i = \frac{\Delta S_i - 16{,}7 \cdot V_{c\,i} \cdot \Delta t_{tr\,i}}{8{,}35 \cdot \Delta t_{tr\,i}}.$$

The specific accelerating traction force f_u is recalculated, taking into account all resistances and motion characteristics that ensure the necessary dynamics for train movement.

$$f_{u\,i} = \frac{\Delta S_i - 16{,}7 \cdot V_{c\,i} \cdot \Delta t_{tr\,i}}{16{,}7 \cdot \Delta t_{tr\,i}^2}.$$

A block diagram is presented in Figure 1 to visualize the computational stages and the algorithm for switching modes. This diagram illustrates the main steps, including the calculation of the specific accelerating force, as well as the increase in velocity and time.

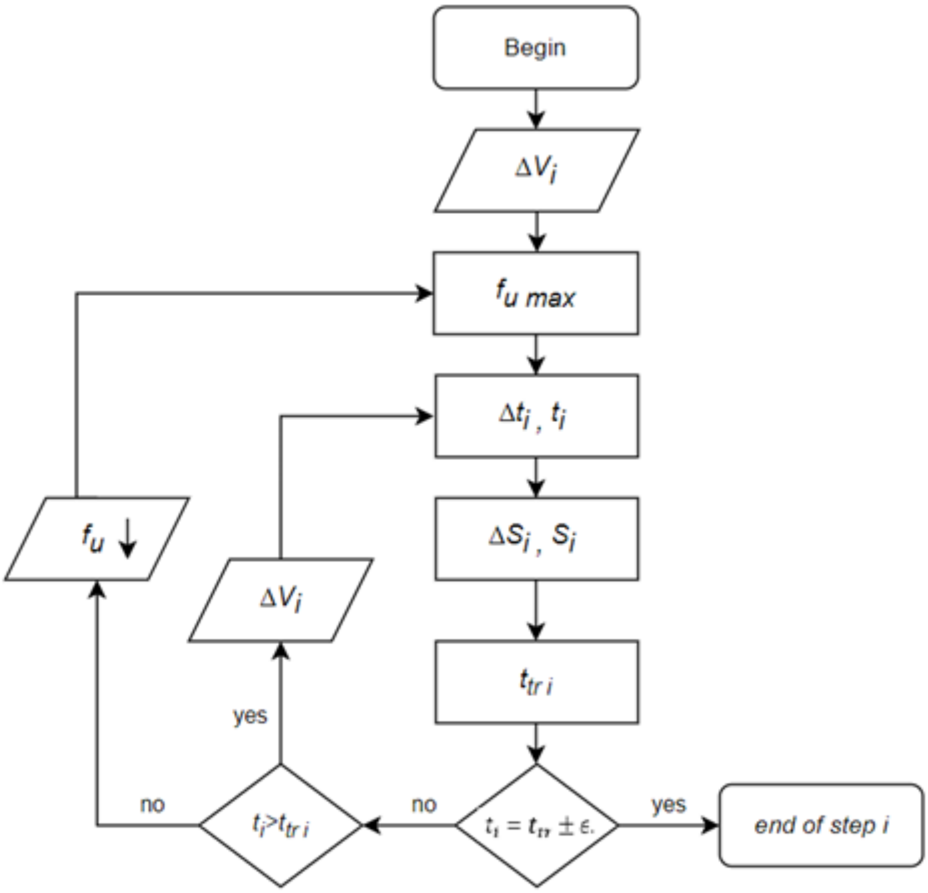

Figure 1. Adaptive algorithm for switching train modes based on a time schedule

The main stages of the flowchart include:

The initial calculation is to determine the maximum specific accelerating force $f_{t\ max}$.

Calculation of velocity and time increases - based on current and steady-state velocity and resistance to motion.

Switching between modes - the algorithm automatically switches traffic modes depending on the value of the specific power and speed of the train.

Limit time - calculation of the limit time and adjustment of the mode switching points, taking into account the slopes on the road.

Train movement modes

Traction mode

During the traction mode phase, the train's speed increases, and the time increment is calculated taking into account the traction force and resistance to movement.

Coasting mode

When the accelerating force becomes zero ($f_t \le 0$), the train switches to coasting mode. In this state, the force acting on the train is defined as the sum of the resistances to motion:

$$f_t = w_m + w_a.$$

In this mode, the train moves at a constant speed, and the time at this stage is calculated using the following formula:

$$\Delta t = \frac{\Delta S}{16{,}7 \cdot V_{ss}}.$$

Recuperative braking mode

When using recuperative braking, the tractive force $f_{r\,u}$ is determined as follows:

$$f_{r\,u} = 0{,}8 \cdot f_u(V),$$

where $f_u(V)$ is the traction characteristic of the electric locomotive [7]. In calculations, the motion resistances w_m and w_a are also taken into account.

Mechanical braking

When the train speed reaches a certain limit, mechanical braking is applied. Calculation of time and path increments is carried out in the same way as in previous modes [3,5].

Conclusion. In this article, an algorithm for optimizing the switching points of train modes based on the time of the graph is proposed. Various factors influencing traffic dynamics, such as road slopes and resistance, were taken into account. The described calculation methods allow for more accurate modeling of the train movement process and reduce deviations from the established arrival time. For accurate adjustment of time indicators in sections where the road profile changes, the use of the slope correction coefficient is of great importance. The mathematical model, based on the system of equations of motion dynamics, allows for the calculation of specific accelerating forces, changes in speed and time. This, in turn, serves to increase the accuracy of train traffic management.

The proposed algorithm can be effectively used to optimize traffic schedules, increase energy efficiency, and reduce travel time. As a result, railway transport operates more stably.

References

1. Baranov L.A., Yerofeyev Y.V., Melyoshin I.S., Chin L.M. Optimizatsiya upravleniya dvijeniyem poyezdov. Uchebnoye posobiye/ pod redaksiyey doktora texnicheskix nauk, professora L.A. Baranova. - M.:MIIT, 2011. – 164 s.
2. Klimovich A.V. Optimizatsiya upravleniya dvijeniya poyezda po minimumu zatrat energoresursov na tyagu. M.: Kompaniya Sputnik+. 2008. – 263 s.
3. Lesov A. T., Ivashenko V. O. Optimizatsiya krivoy dvijeniya poyezda dlya minimizatsii energopotrebleniya na baze j. d. Uzbekistana // Byulleten rezultatov nauchnix issledovaniy. — 2022. — Vip. 1. — S. 68–79. DOI: 10.20295/2223-9987-2022-1-68-79
4. Lesov A.T. K obosnovaniyu optimalnogo rejima upravleniya dvijeniyem gruzovogo poyezda na uchastke Kokand – Andijan Uzbekskoy jeleznoy dorogi / O.S. Ablyalimov, A.T. Lesov // Universum: Texnicheskiye nauki: elektron. nauchn. jurn. – 2022. - № 11(104) – S. 30 – 35.
5. Lesov A. T. Energooptimizatsiya rejimov dvijeniya poyezda na yazike programmi C#/ A. T. Lesov, V. O. Ivashenko // Izvestiya Peterburgskogo universiteta putey soobsheniy. – SPb.: PGUPS, 2021. – T. 18, vip. 4. – S. 480–490.
6. Muginshteyn L.A., Ilyutovich A.Y., Yabko I.A. Energooptimalniye metodi upravleniya dvijeniyem poyezdov // Sb. nauchn. tr. OAO «VNIIJT». M.: Intekst, 2012. 80 s.
7. Nazirkhonov, T.M., Evaluation of the efficiency of a 4q-S converter of an alternating current electric locomotive of the O'Z-ELR series using a computer simulation model / Nazirkhonov, T.M., Radjibaev, D.O. // AIP Conference Proceedings, 2023, 2476, 020055. DOI10.1063/5.0103507.
8. Rozenfeld V. Y. Teoriya elektricheskoy tyagi / V. Y. Rozenfeld, I. P. Isayev, N. N. Sidorov, M. I. Ozerov; M.: Transport, 1995. – 294 s.
9. Nilam R. Dongre1. "Optimization of Energy Consumption In Electric Traction System By Using Interior Point Method." IOSR Journal of Electrical and Electronics Engineering (IOSRJEEE) 13.2 (2018): 09–15.

10. R. Chen, L. Liu and J. Guo, "Optimization of High-Speed Train Control Strategy for Traction Energy Saving Using an Improved Genetic Algorithm", Journal of Traffic and Transportation Engineering. 1, 12 (2012)