Functions of the interlocking system on mixed traffic lines

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Abstract. These days, automated rail traffic control systems help to lessen the need for human intervention in train traffic management. On the other hand, the various algorithms used by interlocking systems to coordinate the movement of trains belonging to distinct categories result in longer wait times for technological procedures at the station. The possibility of timely routes for trains of multiple categories occurs by employing the method of automatic route preparation by interlocking systems in the organization of the movement of trains of different categories. In interlocking systems, automatic route preparation can be achieved by continuously monitoring train characteristics, train traffic graphs of various train classes, and the condition of equipment involved in the function's development. Nonetheless, it is predicated on the creation of many models to arrange the specifications of various train classes and train movements inside a single schedule type. In order to prepare the routes ahead of time for the station tracks based on the algorithms for the operation of interlocking systems for various kinds of trains, the paper analyzes the reliance of the traffic composition characteristics.

1 Introduction

Different route preparation operating modes are currently available for interlocking systems, based on the elements’ usage and system structure.

Systems of stations with up to 30 point machines employ the interlocking system’s operating mode. In this instance, the station’s railway switch that enters the route is configured to the desired position in accordance with the route. Subsequently, the railway switch control button is depressed to verify if the arrows have traversed the concerned path. The route-specific traffic light button is pressed if the railway switch is positioned in accordance with the route. The EC-9 system is one of the relay interlocking systems that uses this kind of route preparation mode. In interlocking systems at stations, where several technological operations are carried out and a significant number of railway switches are present, routing control of routes is employed. When establishing a route using this kind of interlocking system, one just presses the buttons on the beginning and finishing traffic lights that enter the route. When a

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railway switch enters a route, it will automatically adjust its position based on the route’s
direction. MRC and BMRC systems are examples of relay interlocking systems that use
this kind of route preparation mode [1–33].

By pressing the route’s start button, the intelligent routing system of the interlocking
system determines the options for route preparation to the station. The station attendant can
then receive the route at the station by assessing the conditions of the tracks, railway
switches, hostile and opposing routes, and the station itself. The system then assigns the
route to one of these options. This makes receiving feasible. This reduces the amount of
mistakes the station attendant can make when determining routes.

Nonetheless, the implementation of the aforementioned interlocking system operating
modes is subject to specific time restrictions when planning routes for various train
classifications. Longer wait times at the station are the result of this technological
processes. The types of interlocking systems at railway stations in the JSC “Uzbekistan
Railways” high-speed train traffic sections “Tashkent-Samarkand”, "Samarkand-Kitob,”
and "Samarkand-Bukhara" are depicted in Figure 1.

2 Analysis of methods for automatic installation of routes on
railway sections, where the movement of trains of different
categories is organized

In Japanese railways, the automatic route preparation method for interlocking systems is
regarded as the primary train traffic control system in railway transportation. The linkages
between the electric centralization systems’ automatic route preparation method and the
other rail traffic control systems' components are depicted in Figure 1. The following lists
the primary responsibilities of the automatic route preparation approach for interlocking
systems[34-35]:

a) automatically prepare the path when a traffic light is about to turn: Where tracks
branch or trains may change direction, interlocking systems’ automatic route preparation
mechanism chooses and establishes the appropriate paths for each train. Interlocking
systems that use automatic route preparation often prepare routes using schedule data. On
the other hand, in certain intricate systems, the automated route planning technique of
interlocking systems automatically reroutes trains to alternative routes in the event that an
issue arises with the intended route.

b) timely issuing of route preparation commands: when a train approaches a traffic
signal, the automatic route preparation method transmits commands to interlocking systems
for route preparation[34]. Although trains may not arrive at traffic signals on time owing to
equipment issues and passenger flow, the route preparation time is, in theory, indicated in
the train schedule. Station attendants may occasionally manually set itineraries that diverge
from the intended train route. Therefore, utilizing real-time data on train descriptions and
device statuses, an automatic route preparation approach should decide when to assign a
route.

c) there are only a few locations where trains can cross paths while arranging their
movement in a railway transport system. These locations are used to resolve conflicting
routes in opposing directions and determine train priority. As a result, the autonomous route
planning method makes it possible to plan and postpone train movements at various points
along the track. Reducing the human factor is conceivable with this strategy, particularly in
major stops at the intersection of routes with complex layouts or single-track lines.
Fig. 1. Types of interlocking systems at railway stations in the sections “Tashkent – Samarkand”, “Samarkand-Kitab” and “Samarkand-Bukhara”, where the movement of high-speed trains of JSC “Uzbekistan Railways” was established.

To put the automatic route preparation approach into practice, devices and systems must be designed with the following criteria in mind:

- The rail chain must be extended to a minimum length of 300 meters in order to facilitate the running of high-speed trains;
- Digital communication methods and interconnection with the automated signaling systems of contemporary locomotives that allow for the capability of locating the rolling stock should be guaranteed;
- Rail chain lengths should be split into virtual rail chains no longer than 50 meters, accounting for typical train usage;
- The station’s interlocking systems need to have either an all-electronic or relay-based computer interlocking system installed;
- Maintaining a regular schedule for the movement of trains.

3 Modelling the process of automatic preparation of routes in the interlocking system

The arrangement of trains according to train category reduces the amount of time lost at the station and in between trains, which helps to ensure safety and save time in technological operations at the station[36-38].

The following sub-multiples often make up the parts of the model of the item to be represented, or system S, and can be visualized as values that depict the operation of the real system:

- A compilation of data regarding the arrival of several kinds of trains at the EC system
  \[ x_i \in X, i = 1, n_x \];
- A collection of EC system commands
  \[ v_i \in V, l = 1, n_v \];
- A group of command signals that EC systems get
  \[ v'_i \in V', l = 1, n_{v'} \];
- An internal collection of the EC system’s parameters
\[ h_k \in H, \quad k = 1, n_H \];

- a group of EC system output specifications

\[ y_j \in Y, \quad j = 1, n_y \].

The variables on the list can also be categorized as controlled or uncontrollable. The non-intersecting (non-joining) elements of the subsets, \( x_i, v_l, h_k, \) and \( y_j \), generally have both deterministic and stochastic components.

In modeling the EC system, the input effects, the external environment and the internal parameters of the system are independent (exogenous) variables, in the form of vectors \( x(t) = (x_1(t), x_2(t), \ldots, x_n(t)) \), have the corresponding form, the system and output descriptions are dependent (endogenous) variables and have the form of a vector \( y(t) = (y_1(t), y_2(t), \ldots, y_n(t)) \).

The operator \( F_s \), which generally converts exogenous variables into endogenous ones in accordance with the relations of the form, describes the operation process of the system \( S \) in time.

The set of time dependences \( y(t) \) for all types of output characteristics \( j = 1, n_y \) of the system is called the output trajectory \( y(t) \). Dependence (1) is called the law of operation of system \( C \) and is denoted by \( F_s \). In general, the law of operation of the \( F_s \) system can be given in the form of function, functional, logical conditions, algorithmic, table, or oral correspondence rules.

In the research and study of the \( S \) system, the concept of the operation algorithm is very important, \( x(t) \) and it is understood as a method of obtaining the output characteristics, \( y(t) \) taking into account the input effect, the effect of the external environment, \( h(t) \) and the internal parameters of the system. Obviously, the same working \( F_s \) law of the \( S \) system can be implemented in different ways, that is, with the help of different working algorithms of \( S \) system. Interaction (1) is a mathematical description of the behaviour of the modelling object (system) in time \( t \); that is, it reflects its dynamic properties. Therefore, these types of models are usually called dynamic models (systems).

The depiction of the real object in the form of two objects—the controller and the controlled (control object)—is typically followed while explaining automatic control operations. Fig. 2 depicts the endogenous variables and the overall multivariate automatic control system’s structure.

- \( x(t) = \tilde{x}(t) = \tilde{x}'(t) \) - influence the vector of parameters of trains approaching the station;
- \( \tilde{v}(t) \) - effect vector of external commands on EC systems;
- \( \tilde{v}'(t) \) - effect vector of control signals in EC systems;
- \( \tilde{v}''(t) \) - Effect vector of commands given to signaling system devices and systems;
- \( \tilde{h}''(t) \) - effect vector of control command of signaling system and nims systems of EC system;
- \( \tilde{h}'''(t) \) - effect vector of the control signal in signaling system and NIM systems according to the EC control command;
- \( \tilde{h}''''(t) \) - effect vector of interdependence of signaling system and NIM systems in the EM system;
\( \vec{y}(t) \) - effect vector of control signals of signaling system and nimsystems, usually 
\[ y(t) = \vec{\phi}''(t). \]

A modern control system is a set of software and technical tools that ensure the achievement of a certain goal by the control object. It is possible to estimate how precisely the control object achieved the given goal for a one-dimensional system by the position of the coordinate \( y(t) \). The difference between the given \( y_{\text{mon}}(t) \) and the actual \( y(t) \) of the controlled variable is the control error \( h'(t) = y_{\text{mon}}(t) - y(t) \). If the specified change of the controlled quantity corresponds to the specified change law of the input (main) motion, i.e., \( x(t) = y_{\text{mon}}(t) \), then \( h'(t) = x(t) - y(t) \).

Systems that always control errors \( h'(t) = 0 \) are called ideal. In practice, ideal systems cannot be implemented. Thus, the error \( h'(t) \) is a necessary substrate for automatic control based on the principle of negative feedback, since the deviation (difference) between their values is used to adjust the output variable \( u(t) \) to its specified value. The task of the automatic control system is to change the variable \( y(t) \) according to a certain law with a certain accuracy (with a fixed error). When designing and using automatic control systems, it is necessary to choose the parameters that ensure the required control accuracy of the S system as well as the stability of the system in the transient process.

If the system is stable, then the maximum deviation of the adjustable variable \( y(t) \) during the transition, the behaviour of the system during the transition time, etc., is of practical interest.

The static and dynamic properties of the system S entirely dictate the order of values of differential equations and their coefficients. \( x^m \) and \( y^n \) are n- and m-order time derivatives of functions \( x \) and \( y \), respectively. Suppose that the SA system described by equation (2) works in a certain mode described by the functions \( x_0(t) \) and \( y_0(t) \). We write \( x(t) \) from \( x_0(t) \) to \( \Delta x(t) \) and \( y(t) \) from \( y_0(t) \) to \( \Delta y(t) \), i.e., \( x(t) = x_0(t) + \Delta x(t) \), and we denote small deviations by \( y(t) = y_0(t) + \Delta y(t) \).

Then putting equation (2) into the Taylor series function \( F(y_m, y_n, ..., y, x_m, x_n, ..., x) \) and its linear \( a' \) with respect to the increments of \( x \) and \( \Delta \) can be drawn by limiting the i.e.

The resulting equation (2) provides a rough description of the process under consideration, thus the derivatives are computed for a set of fixed values of the variables it contains. This yields a system with constant coefficients.

Furthermore, the equations exhibit linearity about \( \Delta x \), \( \Delta u \), and their respective derivatives. This is significant because, in comparison to generic systems, linear systems may be solved and studied using considerably more straightforward and in-depth approaches.

To make equation (3) simple, it is assumed that the system’s input and the disturbances’ points of application match. The operator approach, for instance, can be used to substitute an algebraic equation for the differential equation in order to solve (3). In other words, the trains’ features are used to prepare the routes, utilizing the expression found in [4, 5]. In this scenario, determining the distance and duration that are not less than the trains’ braking distance is necessary to guarantee movement safety while the trains are moving.

\[
\vec{y}(t) = F_{\vec{\phi}M}(x, \vec{v}, \vec{\phi}, \vec{h}, \vec{h}', \vec{h}'', \vec{m}, t) 
\]

\[
\frac{\partial F}{\partial y_0} \Delta y'' + \frac{\partial F}{\partial y^{n-1}_0} \Delta y^{n-1} + ... + \frac{\partial F}{\partial y_0} \Delta y + y = \frac{\partial F}{\partial x_0} \Delta x'' + 
\]

\[
+ \frac{\partial F}{\partial x^{m-1}_0} \Delta x^{m-1} + ... + \frac{\partial F}{\partial x_0} \Delta x + \Delta x
\]

(2)
\begin{align*}
    a_0 \frac{d^n y}{dt^n} + a_1 \frac{d^{n-1} y}{dt^{n-1}} + \ldots + a_n y &= \\
    = b_0 \frac{d^m x}{dt^m} + b_1 \frac{d^{m-1} x}{dt^{m-1}} + \ldots + b_m x
\end{align*}

(3)

4 Time indicators for automatic preparation of routes for trains of different categories

Every station has many pairs of control points installed on the approach section. It is found that the intervals between these locations correspond to the electrical centering system’s mode entry times [1–15]. When the rolling stock approaches the station, the first of the two control points notifies the interlocking system. The following information is sent to the second control point regarding the routing of traffic that is heading toward the station:

- The vehicle will keep traveling at the predetermined speed if information regarding the route’s preparation is received at the second control point.
- The train’s operating stop distance, which is incorporated to guarantee train movement safety, is from the second control point to the entrance traffic signal.

2. a - For high-speed trains, the following expressions (4), (5), (6), and (7) are used to calculate the distance between the first and second control points in the figure as well as the rolling stock's time of movement. High-speed train braking times are expressed as follows: (4) for high-speed train braking times between 0 and 108 km/h, (5) for high-speed train braking times between 108 and 350 km/h, and (6) and (7) when braking is an expression of the path [15–24].

Fig. 2. Model for automatically creating routes for various class trains.

When a traffic structure approaches a station from an odd headland in Figure 3, the interlocking system enters the “Normal movement” mode if the “High-speed” mode is not active.

If the electric centering system for the traffic approaching the station is not set to the “High-speed” or “Normal movement” modes. The entry traffic light is where vehicles that are approaching the station stop. After that, the “Manual” mode is used to prepare the train's path at the station.

2, a - For high-speed trains, the following expressions (4), (5), (6), and (7) are used to calculate the distance between the first and second control points in the figure as well as the rolling stock's time of movement. High-speed train braking times are expressed as follows: (4) for high-speed train braking times between 0 and 108 km/h, (5) for high-speed train braking times between 108 and 350 km/h, and (6) and (7) when braking is an expression of the path [15–24].
(4) – The braking time of high-speed trains at speeds of 0-108 km/h is calculated using the expression.

\[
t = \int_0^{v''} \frac{m \cdot f \cdot p \cdot v}{v' \cdot P - ((n_0 + F_G) + \eta \cdot v + r_2 \cdot v^2)} \, dv
\]  

(5) – The braking time of high-speed trains at speeds of 108-350 km/h is calculated using the expression.

\[
t = \int_0^{v''} \frac{m \cdot f \cdot p \cdot v}{v' \cdot P - ((n_0 + F_G) + \eta \cdot v + r_2 \cdot v^2)} \, dv
\]  

(6) – Braking path of high-speed trains with speeds of 0-108 km/h is calculated using the expression.

\[
S = \int_0^{v''} \frac{m \cdot f \cdot p \cdot v}{v' \cdot P - ((n_0 + F_G) + \eta \cdot v + r_2 \cdot v^2)} \, dv
\]  

(7) – Using the expression, the braking path of high-speed trains with speeds of 108-350 km/h is considered.

\[
S = \int_0^{v''} \frac{m \cdot f \cdot p \cdot v}{v' \cdot P - ((n_0 + F_G) + \eta \cdot v + r_2 \cdot v^2)} \, dv
\]  

When creating train routes to stations, interlocking systems’ automated style of route preparation minimizes the amount of time needed for technological procedures at the station.

Routes are prepared automatically based on the kind and speed of the trains that are approaching, accounting for the previously mentioned brake times:

- The time required to use the expression to prepare routes for high-speed trains traveling at 0-108 km/h is (8).

When preparing routes for trains to stations, preparation of routes through the automatic mode of interlocking systems reduces time consumption in technological processes at the station.

Routes are prepared automatically based on the kind and speed of the trains that are approaching, accounting for the previously mentioned brake times:

(8) – The equation is used to determine the route preparation time for high-speed trains traveling at 0–108 km/h.

\[
T_{m.t.1} = \left[ \frac{v''}{v'} \int_0^{v''} \frac{m \cdot f \cdot p \cdot v}{v' \cdot P - ((n_0 + F_G) + \eta \cdot v + r_2 \cdot v^2)} \, dv \right] \cdot K_k
\] 

(9) – Using the expression is the time to prepare routes for high-speed trains with speeds of 108-350 km/h.

\[
T_{m.t.2} = \left[ \frac{v''}{v'} \int_0^{v''} \frac{m \cdot f \cdot p \cdot v}{v' \cdot P - ((n_0 + F_G) + \eta \cdot v + r_2 \cdot v^2)} \, dv \right] \cdot K_k
\]
The length of the approach section to prepare routes for high-speed trains with speeds of 0-108 km/h in straight traffic is calculated using the following expression (10).

\[ L_{NnUP} = v_{maks} \cdot T_{m.t.1} \]  

(10)

The length of the approach section for the preparation of routes for high-speed trains with speeds of 0-108 km/h in flat accelerating motion is calculated using the following expression (11).

\[ L_{NnUP} = v_{maks} \cdot T_{m.t.1} + \frac{a(T_{m.t.1})^2}{2} \]  

(11)

The length of the approach section to prepare routes for high-speed trains with speeds of 108-350 km/h in straight traffic is calculated using the following expression (12).

\[ L_{NnUP} = v_{maks} \cdot T_{m.t.2} \]  

(12)

The length of the approach section is calculated using the following expression (13) to prepare routes for high-speed trains with speeds of 108-350 km/h in flat accelerating motion.

\[ L_{NnUP} = v_{maks} \cdot T_{m.t.2} + \frac{a(T_{m.t.2})^2}{2} \]  

(13)

where: fp is the weight coefficient in rotation; a - speed-related acceleration [m/s^2]; FG - resistance force [kN]; P - power of all engines [kW]; r0 is the coefficient of mechanical resistance depending on the mass [kN]; r1 - coefficient of dependence of weight on mechanical resistance [kN*(s/m)]; r2 - coefficient of aerodynamic resistance [kN*(s^2/m^2)]; S - braking distance [m]; v - speed [m/s]; v' - initial speed [m/s]; v'' - final speed [m/s]; t - time [s]; m - train mass [t]; Tm.t. - the time it takes to prepare routes; ts. mash. kab. - the time when the driver receives the traffic light indicator; Tm.t.1. (Tm.t.2.) - the time it takes to prepare the route; t man.mash.am. - the time required to perform shunting routes (llok. - locomotive length; lmarsh. - route length; vlok. - locomotive speed; tsek.aj. - section separation time; K to'g. - correction coefficient); t t.x. - time to finish technological processes in the shortest time interval; Kk. - additional coefficient.

By using expressions (8) and (9), it is possible to calculate the route preparation for different categories of trains. Reducing the time of the regulatory mode of preparation of routes for high-speed trains mentioned above can be achieved by determining the length of the sections based on the speed of the trains in the approximation using expressions (10), (11), (12) and (13) (3a, b - picture).

The scheme of the route preparation mode for high-speed trains in the electric centralization system will have to be changed for each station, as shown in Figure 3. This will make it possible to reduce the time spent preparing routes for trains of different categories.
5 Conclusion

In order to organize the movement of trains of various categories at the stations, additional modes are added in the routing planning for interlocking systems. These modes require all stations to halt technological operations for ten to fifteen minutes when trains approach the station in order to plan routes (Fig. 3a, b). By using the approach described in the article, it is feasible to minimize the amount of time that technological operations take at the stations, all the while assuring the safety of train movement and preparing the routes in the interlocking systems’ working modes.

By measuring the length of the approach section where the mode can be entered based on the speed of the trains on the section and operational indicators, the scheme of route preparation for the electric centralization system modes at the station is completed. As a result, each station's power centering system requires a different amount of time for the approach section and route preparation than what is required by the regulatory regimes of the power centering systems that are now in operation.

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