Improved Method and Algorithm of Railway Crossing Automatic Signaling System

Sohibjamol Valiyev, Qamara Kosimova, Sunnatillo Boltayev, and Bekhruz Ergashov

Abstract Currently, the most important issues at JSC "Uzbekistan Railways" are: full electrification of railway sections, reliable provision of train safety. To do this, large-scale work is being carried out on the gradual modernization of automation and telemechanics systems to electrify railway sections and ensure the safety of train traffic. The solution of these problems will serve to increase the speed of rail transport and increase the number of passenger and freight operations. This, in turn, has a direct impact on the operation of the automatic railway crossing signaling of the railway crossing, i.e. leads to an increase in the length of the approach section to the intersection, which signals the approach of trains to the railway crossing. The scientific article proposes a new method using modern technologies aimed at ensuring safety at railway crossings and reducing the waiting time for road transport participants at the intersection and avoiding congestion. Two sensors were used to send the train approaching message, one to check and back each other, and one to open the intersection, and radio modules were used instead of cables to transmit messages. According to this method, at the same time, the algorithm of the principle of operation of the guarded railway crossing in JSC "Uzbekistan Railways" integrated version with the automatic railway crossing alarm system is presented.

Keywords Crossing automatic signaling · System · Sensor · Alarm · Roadblock · Barrier device · Stoplight · Wireless communication

1 Introduction

Today, due to the obsolescence of most of the railway automation and telemechanics systems that ensure the safety of trains in railway transport, these systems cannot meet the requirements of the present time. This is because the internal production capacity of these systems does not allow it, or to do so will require major changes to

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the existing system. These changes are not economically justified in the first place, and they cannot be a long-term solution [1–11].

However, at a time when the economy of the Republic of Uzbekistan is developing rapidly, JSC "Uzbekistan Railways" is trying not to lag behind in this development process and not to lose its place in the economy of Uzbekistan [1, 2]. In order to do this, they have set themselves a number of important issues, taking into account modern requirements. The most important of these:

- Full electrification of all railway sections within JSC "Uzbekistan Railways";
- Construction and electrification of new railway sections;
- Upgrading of automation and telemechanics systems to ensure the safety of train traffic;
- Establishment of its own logistics center.

The solution of these issues will serve to strengthen the position of JSC "Uzbekistan Railways" in the economy of Uzbekistan. In other words, by reducing the consumption of fuel by electrifying all railway sections of JSC "Uzbekistan Railways", reducing the cost of transportation of goods by rail, attracting new customers by building new ones, creating convenience for its customers and users of this service by opening its own logistics center and by upgrading automation and telemechanics systems, will be able to increase the safety of trains and fully control the movement of workers involved in the organization of train traffic. All this together serves to increase the speed of passenger and freight traffic, to ensure the safety of trains and the timely safe and quality delivery of passengers and cargo to their destinations [1, 2].

In the modernization of automation and telemechanics systems, which serve to organize and manage the movement of trains on railway sections and ensure their safety, it is important to take into account the current trends in the development of machinery and technology.

Updates on railway transport, in turn, will lead to an increase in the speed of trains on the railway. This, in turn, leads to a change in the category of the railway crossing and, as a result, the lengthening of the section approaching the railway crossing and the increase in the waiting time of road transport participants at the intersection. Among railway facilities, the railway crossing is the most high-risk facility. This is because railways and highways intersect at the same level. Because of the large number of human factors here, traffic safety at railway crossings remains a pressing issue even today [12–17]. In addition to ensuring traffic safety at the railway crossing, the reduction of waiting times for road transport participants in front of the railway crossing and the prevention of congestion is also the contribution of railway automation and telemechanics systems.

2 An Improved Method of Transmitting Data to a Railway Crossing Signaling System

As a solution to the above-mentioned problems, a new way of operating the automatic railway crossing automatic signaling (CAS) system using modern technologies to reduce the waiting time of road transport participants at the haul and prevent possible congestion and ensure train safety (Fig. 1) and its processing algorithm (Fig. 2) are proposed.

In the proposed method for the operation of the CAS system, modern axle count sensors were used instead of rail chains, and radio modules were used instead of cables to send a message about the approach of the train to the intersection to the CAS system. Today, the internal power of the elements of radio control systems allows us to transmit data over long distances reliably and securely via wireless communication. Using these modern technologies, we will be able to avoid labor-intensive and expensive cables and improve the quality of service in the process of upgrading or improving the automation and telemechanics systems of railway transport.

Depending on the category of railway crossing, it can be equipped with sound and traffic light signaling, auto-barrier, barrier device (UZP), barrier traffic light, road signs and video surveillance systems. Currently, rail chains are used to transmit the approach of trains to the approach section of the railway crossing.

Rail chains are made up of many elements, and these elements are sensitive to external influences. Every simple failure that occurs in these elements will result in the operation of the CAS system of the railway crossing and the closure of the intersection, as well as artificial congestion in front of the intersection. Therefore, it is the most appropriate decision to use axle count sensors instead of rail chains.

Here, sensors 1, 3, and 2, 4 detect that a train is approaching a railway intersection on an odd or even side, while sensors 5 and 6 serve to open the intersection for motor vehicles once the train has left the intersection completely. In addition, sensors 1, 3 and 2, 4 monitor each other's operating status.

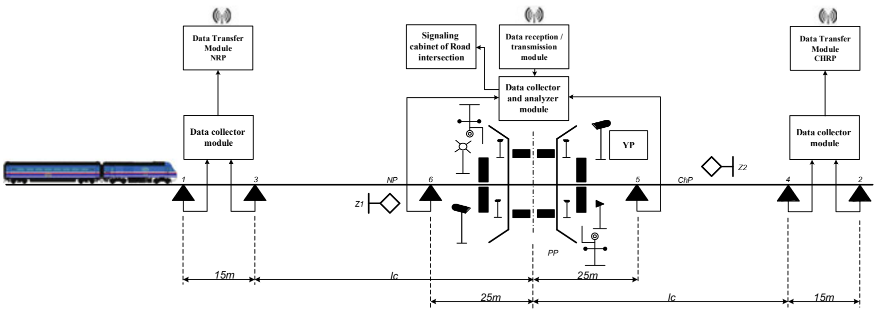


Fig. 1 Method of installation of sensors.
Where: l_c is the calculated length of the section approaching the intersection

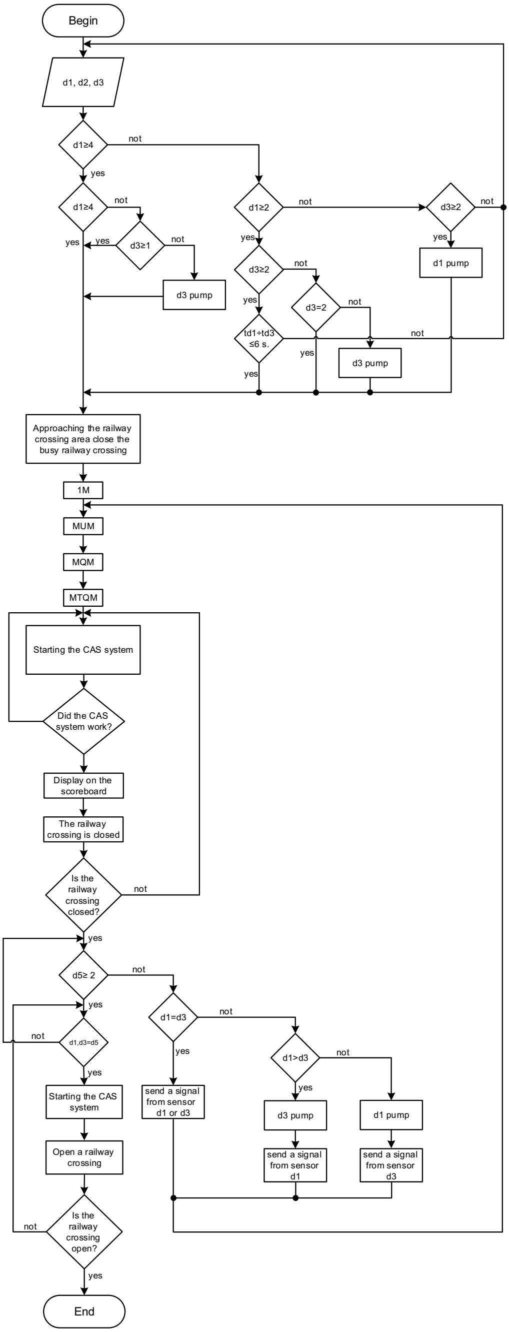


Fig. 2 Algorithm of operation of the railway crossing according to the proposed method

Radio modules that transmit commands from sensors transmit the command when there is a command, and constantly monitor the configuration of radio modules and data transmission channels when there is no command by transmitting discrete data.

3 Algorithm of Operation of Railway Crossing on the Improved Method of Data Transmission to the Railway Crossing Signaling System

The operating algorithm of the railway crossing according to the proposed method is given for the current state of the railway crossing integrated with the relay CAS system. This is due to the fact that this may be an optimal solution at a time when the process of upgrading safety devices and systems in railway transport is underway [11, 14–17].

In this method, the normal condition of a rail crossing is that the sensors and modules that count all axes are in working condition and the rail crossing is open. All the circumstances that may occur in the issuance of the order to close the railway crossing, i.e. the full rolling stock, single rolling stock (motor vehicles, trolleys, motor cars, etc.) and two-axle carts of road workers are also taken into account [1–11].

Before entering the approach section of the railway crossing, a protective block section "ZP" was established by installing sensors "d1" and "d3" at a distance of 15 m from each other. The function of this protection block is to detect moving content. The mounting locations of the sensors are shown in Fig. 1.

According to the proposed method, the railway crossing works in the following order:

There are two different modes of transmission of the closing command at a railway crossing, these are:

- normal, there are signals on sensors "d1" and "d3";
- fault condition, fault condition of one of the sensors "d1" and "d3".

The normal case is also considered for two different situations, respectively:

In the first case, the sensors "d1" and "d3" begin to count the arrows when the moving long-acting unit enters the defensive block "ZP". If $d1 \geq 4$ ва $d3 \geq 4$ the order to close the railway crossing if the conditions are satisfied in series 1M (signal receiver module) from the module to the MUM (data transfer module) module;

In the second case, the sensors "d1" and "d3" begin to count the arrows when the moving autotris or trolley (two-axle) enters the protective block section "ZP". If the conditions $d1 = 2$ and $d3 = 2$ are satisfied in series and the time difference of the signals received from the sensors in order to distinguish the autotris or dresina from the two-axle cart of the road workers $td1 \div td3 \leq 6c$ condition is entered and if this condition is met, the command to close the railway crossing is given from module 1M to module MUM.

In both cases, the MUM module is transmitted wirelessly via an attached radio channel at an open frequency of 410–441 MHz to the MQM (data receiving module) module located at the railway crossing.

The defective condition is also considered for several situations in turn:

In the first case, the sensors “d1” and “d3” begin to count the arrows when the moving long-acting unit enters the defensive block “ZP”. If d1 $\geq$ 4 condition fulfilled d3 $\geq$ 4 if the condition is not met, d3 $\geq$ 1 condition is checked. If this condition is not met, the sensor “d3” is considered faulty, and the command “sensor d3” is given as faulty, together with the command to close the railway crossing, from module 1M (signal receiving module) to module MUM (data transmission module);

In the second case, the sensors “d1” and “d3” begin to count the arrows when the moving autotris or trolley (two-axle) enters the protective block section “ZP”. If condition d1 = 2 is satisfied and condition d3 = 2 is not satisfied, then the condition d3 > 1 is checked. If this condition is also not met, the sensor “d3” is considered to be faulty, and the command “sensor d3” is faulty, together with the command to close the railway crossing, from module 1M to module MUM;

In the third case, the fault condition of the sensor “d1” is checked, i.e. if the condition d1 $\geq$ 4 is not fulfilled, then the condition d1 = 2 is checked. If this condition is not satisfied, the condition d3 $\geq$ 2 is checked for the presence of a signal on the sensor “d3”. If this condition is met, the sensor “d1” is considered to be faulty, and the command “sensor d1” is given as faulty from module 1M to module MUM together with the command to close the railway crossing.

If the condition d3 $\geq$ 2 in the third state of the fault condition is not met, then it returns to the variables, i.e., “d1” and “d3”. This indicates that there is no moving content in the ZP protection block, and this will be repeated until the moving content appears in the ZP protection block. In this order, the working condition of sensors “d1” and “d3” is constantly checked.

In all cases of both normal and faulty conditions, the commands transmitted from the MUM module via the attached radio channels are received by the MQM (data receiving module) module located at the railway crossing and transmitted to the correct MTQM (data analysis module) module. The MTQM module analyzes the command to close the railway crossing from the sensor “d1” or “d3” and gives the command to close the intersection to the CAS (automatic railway crossing signaling) system to start it and close the intersection. Then the activation condition of the CAS system (operation of audible and stoplight alarm V, open position of the PV relay) is checked. If the condition is met, the intersection board will turn on an indicator indicating that the train is approaching the intersection in an odd direction and will give an audible message. If a fault in one of the sensors “d1” or “d3” is noted, it changes the indication of the operation control of the sensors located on the intersection board from green to red. This indicates that the sensor is faulty.

In the next step, the MTQM module checks whether the intersection is closed (the current status of the zU relay controlling the barrier closure). If the condition is not satisfied, then the CAS system returns to the condition that it starts. If the condition is satisfied, then the presence of a signal on the sensor “d5”, which serves to open the railway crossing, is checked for the condition d5 $\geq$ 2. If this condition is not satisfied, then the condition d1 = d3 is checked. Fulfillment of this condition means that the moving content has passed through sensors "d1" and "d3" and the data of sensor "d1" or "d3" is passed from module 1M to MUM module as a command to open the railway crossing. If the condition d1 = d3 is not met, it means that one of the sensors is faulty and the condition d1 > d3 is checked. Fulfillment of this condition means that the sensor "d3" is faulty and the data of the sensor "d1" is faulty, if not, the sensor "d1" is faulty and the data of the sensor "d3" is transferred from module 1M to the module MUM. The MUM module, in turn, transmits this command to the MQM module located.

At the intersection via the attached radio channel. The MQM module receives the transmitted command and transmits it to the MTQM module, and this loop to d1; continues until the condition d3 = d5 is satisfied. If the condition d1; d3 = d5 is met, it means that the rolling stock has vacated the railway crossing. The MTQM module gives the command to open the intersection to the CAS system and checks whether the intersection is open (non-toxic state of the zU relay controlling the opening of the barrier). This cycle continues until the zU relay is de-energized. Upon fulfillment of the condition, the railway crossing will be fully open for the movement of motor vehicles and the system will return to its normal operating mode.

4 Modeling of the Method of Control of Approach Sections of Railway Crossings

Today, the rapid development of techniques and technologies in the field of wireless communication has brought the process of data acquisition and transmission to a new level. As a result, as in other areas, the use of wireless communications in some directions of railway transport has begun, and this is justifying itself. The development of these technologies allows the use of wireless means in the process of receiving and transmitting data, even in railway safety systems [3, 4, 8, 9, 16, 17].

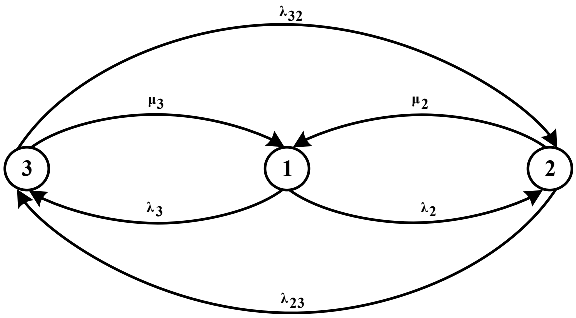
In the CAS system, which provides security at a railway crossing, it is important to know their reliability and safety when using wireless radios during data acquisition and transmission. Therefore, in order to ensure safety at the railway crossing and increase the reliability of CAS devices, we consider the proposed method of controlling the approach sections of railway crossings and mathematical modeling of potential hazards in their operation in close connection with CAS devices.

In studying the safety of wireless transmission of information about the approach of trains to railway crossings to CAS systems, it is possible to check several crossing cases with Markov chains [16, 17]. Theoretically, train motion can be represented by a stochastic process.

It will be necessary to include several cases in accordance with the process of sending the message of approach of trains to railway crossings (Fig. 3):

1. In the CAS system, information about the approach of trains is sent wirelessly to the CAS system.

Fig. 3 Approach model of approaching trains to railway crossings



2. In the case of the CAS system, information about the approach of trains will not be sent to the CAS system without your connection.
3. If the CAS system is faulty, information about the approach of trains will not be sent to the CAS system wirelessly.

In accordance with the processes of sending the message of approach of trains to railway crossings, we can determine the indicators of the processes that connect several cases. We, as indicators of connecting processes, vary the speed of trains on the maximum section and the distance of data transmission depending on the maximum and shortest distances, and accept the following notation:

λ_2 Intensity of switching the wireless device to fault mode;
μ_2 The average time it takes for a wireless device to be restored to its original state;
λ_3 Intensity of transition of CAS system to failure mode;
μ_3 The average time it takes for the CAS system to recover to its default state;
λ_{23} Intensity of transition from CAS system configuration and wireless device failure to CAS system failure and wireless device configuration;
λ_{32} Intensity of transition from CAS system fault and wireless device failure to CAS system word and wireless device failure.

We create the Fokker–Planck (Kolmogorov) equation by writing the semi-Markov processes using differential equations in accordance with the connections between the cases of wireless data transmission to the CAS system:

$$\begin{cases} \frac{dP_1(t)}{dt} = -\lambda_2 \cdot P_1(t) + \mu_2 \cdot P_2(t) - \lambda_3 \cdot P_1(t) + \mu_3 \cdot P_3(t) \\ \frac{dP_2(t)}{dt} = \lambda_2 \cdot P_1(t) + \lambda_{32} \cdot P_3(t) - \lambda_{23} \cdot P_2(t) - \mu_2 \cdot P_2(t) \\ \frac{dP_3(t)}{dt} = \lambda_{23} \cdot P_2(t) - \lambda_{32} \cdot P_3(t) - \mu_3 \cdot P_3(t) + \lambda_3 \cdot P_1(t) \end{cases} \tag{1}$$

$$\mathrm{P}_1(\mathrm{t}) + \mathrm{P}_2(\mathrm{t}) + \mathrm{P}_3(\mathrm{t}) = 1$$

where: P1, P2, P3—Probabilities of occurrence of 1, 2, 3 cases.

By changing the expression of Eq. (1) above to the Laplace equation, we obtain the following expression.

$$\begin{cases} s \cdot P_1 - 1 = \mu_2 \cdot P_2 - \lambda_2 \cdot P_1 - \lambda_3 \cdot P_1 + \mu_3 \cdot P_3 \\ s \cdot P_2 = \lambda_2 \cdot P_1 + \lambda_{32} \cdot P_3 - \lambda_{23} \cdot P_2 - \mu_2 \cdot P_2 \\ s \cdot P_3 = \lambda_{23} \cdot P_2 - \lambda_{32} \cdot P_3 - \mu_3 \cdot P_3 + \lambda_3 \cdot P_1 \end{cases} \tag{2}$$

This means that if we change the expression of Eq. (2) to the Laplace table $F(s) = 1/s \rightarrow f(t) = 1$ we get the following expression:

$$\begin{cases} \lambda_2 P_1 + \lambda_3 P_1 - \mu_2 P_2 - \mu_3 P_3 = 1 \\ \lambda_2 P_1 - \lambda_{23} P_2 - \mu_2 P_2 + \lambda_{32} P_3 = 0 \\ \lambda_3 P_1 + \lambda_{23} P_2 - \lambda_{32} P_3 - \mu_3 P_3 = 0 \end{cases} \tag{3}$$

We calculate the system of equations using the Krammer method to express the resulting equations (3). The following boundary condition in the mathematical calculation of the probability of occurrence of cases in the resulting expressions $P_i(t)|t \rightarrow \infty$ we put (4) as a solution:

$$\begin{gathered} P_1 = P_1(t)|_{t\rightarrow\infty} = \\ \frac{\lambda_{23}\mu_3+\lambda_{32}\mu_2+\mu_2\mu_3}{(\lambda_2+\lambda_3)(\lambda_{23}+\mu_2)(\lambda_{32}-\mu_3)-\lambda_3\lambda_{32}\mu_2-\lambda_2\lambda_{23}\mu_3-\lambda_3\mu_3(\lambda_{23}+\mu_2)-\lambda_{23}\lambda_{32}(\lambda_2+\lambda_3)-\lambda_2\mu_2(\lambda_{32}+\mu_3)} \\ P_2 = P_2(t)|_{t\rightarrow\infty} = \\ \frac{\lambda_3\lambda_{32}+\lambda_2\lambda_{32}+\lambda_2\mu_3}{(\lambda_2+\lambda_3)(\lambda_{23}+\mu_2)(\lambda_{32}-\mu_3)-\lambda_3\lambda_{32}\mu_2-\lambda_2\lambda_{23}\mu_3-\lambda_3\mu_3(\lambda_{23}+\mu_2)-\lambda_{23}\lambda_{32}(\lambda_2+\lambda_3)-\lambda_2\mu_2(\lambda_{32}+\mu_3)} \\ P_3 = P_3(t)|_{t\rightarrow\infty} = \\ \frac{\lambda_3\lambda_{23}+\lambda_3\lambda_{23}+\lambda_3\mu_2}{(\lambda_2+\lambda_3)(\lambda_{23}+\mu_2)(\lambda_{32}-\mu_3)-\lambda_3\lambda_{32}\mu_2-\lambda_2\lambda_{23}\mu_3-\lambda_3\mu_3(\lambda_{23}+\mu_2)-\lambda_{23}\lambda_{32}(\lambda_2+\lambda_3)-\lambda_2\mu_2(\lambda_{32}+\mu_3)} \end{gathered} \tag{4}$$

5 Conclusion

It is no secret that today, as a result of the increase in the number of freight and passenger transportation and organization works and road transport in railway transport, security at railway crossings is becoming a topical issue. Ensuring security at railway crossings and shortening the waiting time for road transport participants requires railway transport workers to take a new approach to solving these problems.

In this article, using the currently advanced technology, the application of the proposed method at the railway crossing will help to solve the above-mentioned problems. In determining rolling stock, using a modern axis counting system instead of rail chains and transmitting a message that a train is approaching the crossing to the CAS system of the intersection using a protected wireless type of communication instead of cables will increase the reliability of data acquisition and transmission.

The scientific article presents the algorithm of operation of the CAS system and devices of the intersection according to the proposed method. When the CAS system of the intersection works with this algorithm, the microcontroller transmits the message of the approach of the train to the intersection, at least 4 signals from the sensor when the long train is moving and 2 signals when the individual motor is moving. This method, unlike the operation of other types of alternative CAS systems at the railway crossing, prevents false operation when a single signal is received from the sensor and eliminates the occurrence of excessive congestion.

The advantage of the proposed method is that it can be integrated with the existing relay control systems of the existing railway crossing, as well as to determine the speed of the rolling stock by comparing the time of signals from sensors "d1" and "d3" and is the ability to send a train approaching message to the intersection. It is more cost-effective, both in terms of energy consumption and in terms of maintenance and improvement of working conditions.

The reliability of the proposed method is theoretically considered using the Markov chain, its safety and resistance to damage.

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