

ENGINEER



international scientific journal

ISSUE 3, 2026 Vol. 4

E-ISSN

3030-3893

ISSN

3060-5172



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ENGINEER

A bridge between science and innovation

E-ISSN: 3030-3893

ISSN: 3060-5172

VOLUME 4, ISSUE 3

SEPTEMBER, 2026



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TASHKENT STATE TRANSPORT UNIVERSITY

ENGINEER

INTERNATIONAL SCIENTIFIC JOURNAL
VOLUME 4, ISSUE 3 SEPTEMBER, 2026

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The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

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Tashkent State Transport University had the opportunity to publish the international scientific journal “Engineer” based on the **Certificate No. 1183** of the Information and Mass Communications Agency under the Administration of the President of the Republic of Uzbekistan. **E-ISSN: 3030-3893, ISSN: 3060-5172.** Articles in the journal are published in English language.

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Digital national microprocessor-based semi-automatic interlocking system for improving the throughput capacity of Uzbekistan Railways

E.G. Khujamkulov¹^a

¹Tashkent state transport university, Tashkent, Uzbekistan

Abstract:

This paper examines pressing operational challenges arising at railway stations as a result of equipment deterioration, increasing traffic loads, and a growing number of emergency incidents. An analysis of the technical condition of signalling, interlocking, and centralization systems revealed that their physical wear significantly exceeds the permissible normative thresholds, posing risks to train traffic safety and adversely affecting the throughput capacity of railway sections.

Furthermore, the widespread use of outdated and poorly integrated systems, combined with a high degree of dependency on foreign equipment suppliers, necessitates the development of domestic railway automation and telemechanics (RAT) solutions. Accordingly, the design and implementation of nationally developed RAT systems are regarded as a priority direction for ensuring technological independence, enhancing operational efficiency, and achieving sustainable sectoral development.

The paper presents an analysis of the key performance indicators of railway automation equipment operating on the network of JSC 'Uzbekistan Railways', as well as a comparative assessment of the total length of train interval control systems and semi-automatic interlocking devices currently in service on the main railway network of the Republic of Uzbekistan. The study also introduces the architectural design of the national digital microprocessor-based semi-automatic interlocking (MSAI) system under development, along with the results of throughput capacity calculations.

The findings indicate that, given adequate track infrastructure conditions, the proposed national digital MSAI system is capable of increasing train operating speeds on inter-station sections up to 200 km/h.

Keywords:

railway automation; telemechanics and communication systems; interval train traffic control; microprocessor-based semi-automatic interlocking; throughput capacity

1. Introduction

Railway transport constitutes one of the key sectors of Uzbekistan's national economy. In alignment with the 'Uzbekistan-2030' development strategy, the sector is currently undergoing a phase of infrastructure modernisation and the adoption of advanced innovative technologies.

At present, a sustained growth in freight and passenger traffic volumes is observed both along international transport corridors and in suburban zones surrounding major urban centres. According to expert projections, the demand for transport services will continue to increase in the foreseeable future. However, the existing throughput capacity of numerous railway sections has virtually reached its operational limits. Consequently, the development of economically efficient methods for increasing the transportation and throughput capacity of the main railway network under the new economic, technological, and organisational conditions represents an urgent scientific and practical challenge.

Train traffic management systems not only ensure the safety of the transportation process but also exert a considerable influence on its principal technological parameters, thereby determining the overall operational efficiency of the transportation system. Throughout the history of railway transport development, traffic management systems have been continuously improved with

the aim of increasing transportation volumes and enhancing operational efficiency.

In particular, the need to augment the carrying capacity of railway lines has driven the expansion of the functional capabilities of interval train traffic control systems. New technologies enabling the reduction of inter-train time and distance intervals were subsequently introduced. Notably, rod-based control systems were replaced by semi-automatic interlocking (SAI) systems, which allowed for the postponement of additional parallel line construction on sections experiencing increasing traffic volumes and facilitated more effective utilisation of existing infrastructure.

In the Republic of Uzbekistan, the condition of railway automation and telemechanics (RAT) systems is primarily characterised by the following key infrastructure indicators. The RAT complex of JSC 'Uzbekistan Railways', which performs the functions of managing and monitoring train movements, encompasses the following principal subsystems:

- electric centralisation systems (ECS);
- inter-station train traffic control systems (ITTCS);
- automatic level crossing signalling devices;
- dispatcher centralisation (DC) and dispatcher supervision (DS) systems.

The following systems are primarily employed for monitoring and controlling rolling stock movements on inter-station sections:

- automatic block signalling (ABS);

^a <https://orcid.org/0009-0004-4556-0746>



- semi-automatic interlocking (SAI).

Semi-automatic interlocking (SAI) is a system designed to regulate the interval-based movement of trains on single- and double-track sections. It is applied on sections adjacent to stations equipped with signalling, centralisation, and block (SCB) devices, where the tracks are provided with electric centralisation (ECS) systems and signal devices of any type [1-3].

2. Research methodology

The total operational length of the main railway network currently amounts to 4,892.37 km, comprising a total of 279 railway stations. The main network and its stations are equipped with automation, telemechanics, and computing systems designed to ensure the safe and uninterrupted movement of trains within the specified parameters of throughput and processing capacity.

As of the present, 279 stations are operational on the railway sections belonging to JSC 'Uzbekistan Railways'. Of these, 185 are equipped with electric centralisation (ECS), 66 with microprocessor-based centralisation systems, and 28 with route control devices. The inter-station sections connecting these stations, with a total length of 4,892.37 km, are equipped with the following systems:

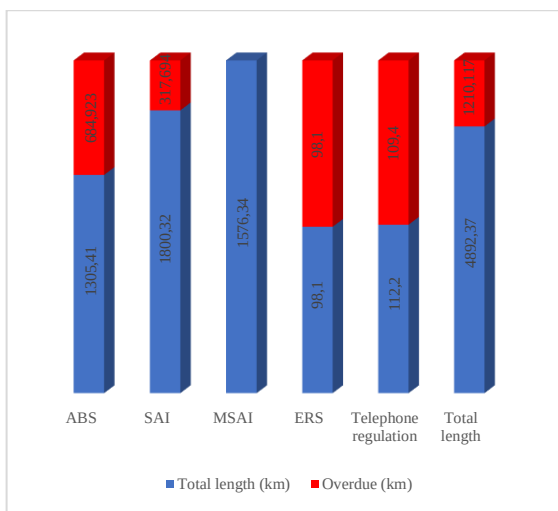


Fig. 1. Systems installed on railway inter-station sections in the Republic of Uzbekistan

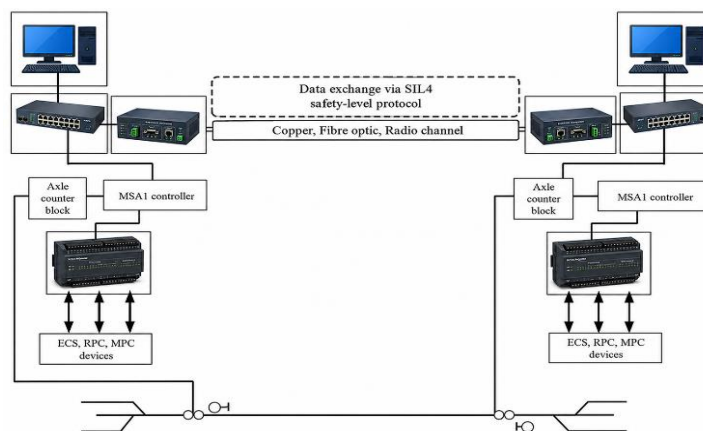


Fig. 2. Architectural structure of the national digital microprocessor-based semi-automatic interlocking (MSAI) system under development

Track blocking systems are currently in operation on the main railway network under the jurisdiction of JSC 'Uzbekistan Railways'. Based on the available statistical data (Figure 1), it can be concluded that technical equipment that has been in service for 35 years or more — a period considered critically hazardous — accounts for 3,316.03 km. Of this total, interval control devices covering 2,010.62 km have exceeded 40 years of service life. Certain specialised technical sections, commissioned in the 1960s, have now been in continuous operation for over 50 years.

A comprehensive analysis of the current condition of RAT systems indicates that the degree of physical and functional deterioration of infrastructure equipment has exceeded 70%. In the absence of systematic modernisation measures, this adverse indicator is projected to surpass 85% by 2030.

The microprocessor-based semi-automatic interlocking (MSAI) system consists of two identical control blocks housed in the relay rooms of adjacent stations. At automatic control posts, the equipment is installed in standard signalling cabinets or portable modules. No additional communication cable is required for system installation. This solution enables the transition of the semi-automatic interlocking to a modern component base, improves train traffic safety and system reliability, simplifies maintenance procedures, and reduces both construction and operational costs.

In the course of system development, the established operational procedures of the station duty officer during train reception and dispatch were fully preserved. The MSAI hardware and software operate on a unified platform utilising standard blocks and modules.

The interaction of the MSAI system with external signalling, centralisation, and block (SCB) devices is achieved through the reception of control signals and the transmission of corresponding commands to executive relays.

The deployment of the MSAI system on inter-station sections significantly reduces the costs associated with complex construction works, the installation of post equipment, and subsequent maintenance activities.

As a communication medium, the digital MSAI system may utilise radio communication channels in cases where wired communication infrastructure is unavailable or where its construction is not economically viable.

The utilisation of fibre-optic communication lines and radio channel data transmission technologies contributes to the reduction of operational expenditure by decreasing reliance on conventional cable and overhead communication networks, thereby mitigating losses associated with the theft of copper-containing materials.

In addition, the MSAI system enables the integration of equipped sections into a centralised dispatcher management system, thereby further enhancing the efficiency and safety of train traffic control.

The throughput capacity of a railway section is defined as the maximum number of freight trains (train pairs) of a specified length and weight that can pass through the section within a 24-hour period, subject to the section's technical characteristics and the applied method of traffic organization [4-6].

The throughput capacity of a single-track railway section is, to a significant extent, dependent on the technical capabilities of the signalling, centralisation, and block devices, as these devices directly affect the values of inter-train and inter-station intervals.

Under parallel train scheduling, the maximum throughput capacity of a single-track limiting section is determined using the following formula:

$$N_{max} = \frac{(1440 - t_{mex}) \cdot \alpha_n}{t_x + \Sigma \tau} \quad (1)$$

where: t_x = net travel time of a train pair (bidirectional) over the limiting section; t_{mex} = planned duration of daily time allocated for construction and maintenance works, min.

With existing mechanisation equipment and work technology, the value of t_{mex} used for productivity calculations is taken as 75 minutes for single-track lines, 90 minutes for double-track lines with common entrances, and 150 minutes for double-track lines.

α_n = reliability coefficient of technical equipment; $\Sigma \tau$ = total time for acceleration and deceleration required to maintain the inter-station interval for a train pair, min.

$$\Sigma \tau = \tau_{nn} + \tau_{ckp} + \tau_{ps} \quad (2)$$

where: τ_{nn} = minimum non-meeting interval for trains travelling in opposite directions; τ_{ckp} = crossing interval; τ_{ps} = time interval for train acceleration and deceleration.

The throughput capacity of a double-track section is determined separately for each track, assuming unidirectional and uninterrupted train movement through intermediate separation points:

— when automatic block signalling and dispatcher centralisation are used on the section:

$$N_{max} = \frac{(1440 - t_{mex}) \cdot \alpha_n}{J_p} \quad (3)$$

where: J_p = calculated inter-train interval in the established direction of movement.

— when semi-automatic interlocking is used on the section:

$$N_{max} = \frac{(1440 - t_{mex}) \cdot \alpha_n}{t_{tp} + \tau_{nc}} \quad (4)$$

where: t_{tp} = travel time of a freight train over the limiting section in the inter-station interval, min; τ_{ps} = inter-station interval for trains travelling in one direction, min.

An analytical examination of throughput capacity formulas (1)–(4) demonstrates that the value of N_{max} is directly dependent on the parameters t_{mex} (time allocated for maintenance), $\Sigma \tau$ (time expenditure for interval maintenance), and α_n (equipment reliability coefficient). The MSAI system employs two identical (duplicated) control blocks located in the relay rooms of adjacent stations, along

with remote technical diagnostics capabilities and automated monitoring functions. These features contribute to a reduction in t_{mex} and $\Sigma \tau$ values, and to an increase in the α_n coefficient, compared to conventional relay-based SAI and ABS systems. According to the analytical expressions above, an improvement in these parameters directly increases N_{max} — i.e., the throughput capacity of the section — without requiring numerical computation, as the directional influence of this systemic difference is unambiguous.

Beyond technical performance indicators, the implementation of the MSAI system offers additional operational advantages. The system's capability to function via radio communication channels on sections lacking wired infrastructure eliminates the need for supplementary cable laying, thereby substantially reducing construction timelines and associated costs. The system's compatibility with standard signalling cabinets or portable modules, its operation on a unified hardware-software platform, and its integration capability with centralised dispatcher management systems distinguish it as a technologically autonomous national solution that reduces dependence on foreign suppliers.

Synthesising the foregoing analysis, the phased deployment of the national digital microprocessor-based SAI system as a replacement for obsolete automatic block signalling, conventional SAI, and telephone-based regulation systems represents the most effective strategic direction. This approach enables improvement in track infrastructure technical condition, enhancement of train traffic safety, and where appropriate conditions are met achievement of operating speeds up to 200 km/h on the respective sections [7-9].

3. Conclusion

The conducted analysis has provided quantitative confirmation of the unsatisfactory technical condition of railway automation and telemechanics systems operating on the network of JSC 'Uzbekistan Railways': 24.7% of the total inter-station section length, equivalent to 1,210.12 km out of 4,892.37 km, has exceeded the established service life. The most critical degree of deterioration was recorded in telephone-based regulation and electric rod signalling systems, while an intermediate level of wear was observed in conventional automatic block signalling (ABS) equipment.

Concurrently, the complete absence of overdue equipment on sections equipped with the microprocessor-based semi-automatic interlocking (MSAI) system — a deterioration rate of 0% — provides empirical validation of the operational stability and reliability of this system. This outcome substantiates the rationale for prioritising microprocessor-based and digital solutions in the modernisation of domestic railway automation and telemechanics systems.

The national digital microprocessor-based semi-automatic interlocking system under development reduces maintenance time expenditure (t_{mex}) and interval time ($\Sigma \tau$) while increasing the equipment reliability coefficient (α_n), owing to its duplicated control blocks at adjacent stations, standardised hardware-software platform, and wireless (radio) channel operation capability. As a result, the throughput capacity of inter-station sections is enhanced, and train operating speeds of up to 200 km/h become



achievable under appropriate conditions. These outcomes are attained through reduced technological dependence on foreign suppliers, lower construction and operational costs, and full integration with centralised dispatcher management systems [10].

Thus, the study findings substantiate that the development of a domestic microprocessor-based semi-automatic interlocking (MSAI) system and its phased deployment — prioritising sections with the highest degree of deterioration, namely those regulated by telephone-based methods and conventional automatic block signalling — constitutes the most viable and economically sound direction for improving the safety, reliability, and efficiency of the transportation process on Uzbekistan's railway network.

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Information about the author

**Eldor
Khujamkulov**

Tashkent State Transport
University, Department of
Automation and
Telemechanics, Assistant
E-mail:
xujamkuloveldor916@gmail.com
Tel.: +998903317209
<https://orcid.org/0009-0004-4556-0746>



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